Title
International Microgrid Assessment: Governance, INcentives, and Experience (IMAGINE)

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International Microgrid Assessment: Governance, INcentives, and Experience (IMAGINE)

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Table of Commonly Used Acronyms

AC – Alternating current
AS – Ancillary services
CEC – California Energy Commission
CERTS – Consortium for Electric Reliability Technology Solutions
CHP – Combined heat and power
CNY – Chinese National Yuan
DC – Direct current
DER – Distributed energy resources
DER-CAM – Distributed Energy Resources Customer Adoption Model
DNO – Distribution network operator
DOD – Department of Defense (U.S.)
DOE – Department of Energy (U.S.)
DR – Demand response
FP – Framework Program (E.U.)
IEEE – Institute of Electrical and Electronics Engineers
IPP – Independent power producer
KERI – Korean Energy Research Institute
LBNL – Lawrence Berkeley National Laboratory
METI – Ministry of Economy, Trade and Industry (Japan)
NEA – National Energy Administration (China)
NEDO – New Energy and Industrial Technology Development Organization (Japan)
NREL – National Renewable Energy Laboratory
NYSERDA – New York State Energy Research and Development Authority
PCC – Point of common coupling
PEV – Plug-in electric vehicle
PQR – Power quality and reliability
PURPA – Public Utility Regulatory Policies Act
PV – Photovoltaic
QF – Qualifying facility
RDSI – Renewable and Distributed Systems Integration
RPS – Renewable portfolio standard
SDG&E – San Diego Gas and Electric
SPIDERS – Smart Power Infrastructure Demonstration for Energy, Reliability, and Security
T&D – Transmission and distribution
UCSD – University of California San Diego

Executive Summary - English

While largely fossil-fuel based grids have supplied an increasing amount of electricity for our world with commendable power quality and reliability (PQR) for more than a century, various concerns are now bringing the familiar universal centralized paradigm into question. One consequence is research, development, and deployment of *microgrids*. Cost, PQR, energy efficiency, harvestable local clean and renewable energy, and climate change mitigation are the most commonly observed microgrid drivers, and various stakeholder groups including customers, technology providers, utilities, and governments are key stakeholders in the successful development of microgrid methods, technology, and policy. Microgrids provide an opportunity for increasing the share of distributed generation in delivered electricity, while control is more dispersed and the quality of service is partially locally tailored to end-use requirements. Definitions of microgrids vary, but two basic requirements commonly cited internationally are: 1) a microgrid must contain both sources and sinks under local control, and 2) a microgrid must be able to function both grid connected and as an island.

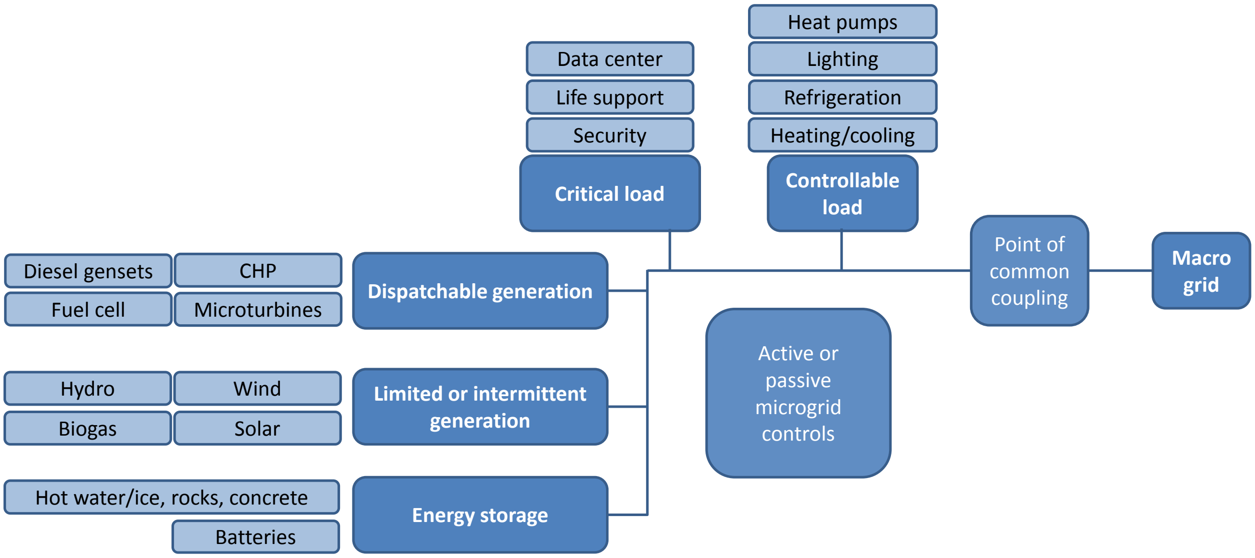

Figure 1: Overview of the main components in a common microgrid, adapted from Siemens 2011

This **I**nternational **M**icrogrid **A**ssessment provides an avenue for understanding the **G**overnance of a macrogrid wherein microgrids receive the **IN**centives needed to capture their benefits, by cataloging international **E**xperience to date. Reading this assessment enables the reader to **IMAGINE** a future for microgrids, as the name of this report indicates. The assessment suggests policy recommendations for a microgrid demonstration program, with specific recommendations for China. This executive summary outlines the drivers for microgrids emphasizing renewable energy, identifies the barriers to microgrid development and suggests potential solutions, and lists policy recommendations.

Drivers for microgrids

Energy customers are increasingly interested in improving their energy efficiency and PQR while lowering costs and environmental footprint. The electricity supply industry is concerned about increasing or simply maintaining PQR while serving a growing load, and meeting clean energy mandates while containing costs. Governments are driving renewable or clean energy adoption in the interests of climate change mitigation, energy security, and other environmental goals. Additionally, technology providers from many diverse sectors, such as information technology and telecommunications, are playing a disruptive role in microgrid development by seeking out innovation opportunities.

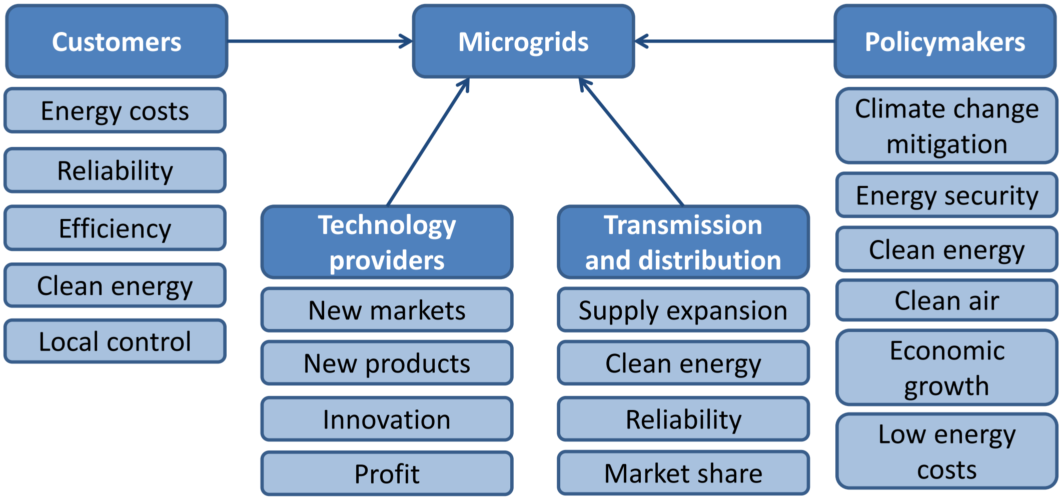

Figure 2: Drivers for microgrids across four stakeholder groups

As seen in Figure 2, the interests of the customer, technology provider, utility, and government stakeholders in a new grid paradigm are profound and have the common threads of cost, reliability, efficiency, clean energy, and climate change mitigation. Many countries and regions around the world have looked to distributed energy systems often as part of *smart grid* initiatives to address these challenges. Governments have enacted policies to increase the share of clean energy and distributed energy resources (DER). However, the interconnection of DER to the conventional network brings technical challenges that threaten PQR or compromise safety. Microgrids are an enabler of increased distributed generation by creating an electrical ecosystem more amenable to small-scale grid unfriendly resources. One of the disruptive forces stimulating microgrid development is the role of technology providers. Companies keen to provide both hardware and services to current utility customers are developing and deploying technologies that increase customer autonomy and enable the transformation of electricity production, delivery, and use.

Microgrids and renewable energy production

Renewable energy production is a common feature of microgrid demonstrations. The two featured case studies in this report, the Santa Rita Jail microgrid in California and the Sendai microgrid in Japan, both feature solar photovoltaic (PV) arrays, as seen in Figure 4 and Figure 3. Because common renewable microgrid resources are intermittent and/or variable, high renewable generation typically requires storage, demand control, and dispatchable generation in tandem. Such a controlled system, however, can buffer the legacy macrogrid and present itself as a source or sink of manageable size and profile comparable to other existing infrastructure on the grid.


Figure 4: Overhead view of the Sendai energy center

Because subsidy support is still prevalent for renewable energy, there is also the question of cost effectiveness in implementing support policies. For instance, utilities are seeking the most efficient way to comply with a renewable portfolio standard (RPS). They also worry about the intermittency of renewables and the challenges they create for effective distribution planning. Microgrids might offer a solution to some of these concerns. Policymakers face barriers to large renewable energy projects that require extensive environmental review (such as offshore wind or large desert solar installations). Here, microgrids can reduce siting issues because the required facilities are smaller. For many commercial and industrial customers in regions with high power prices, solar PV installations are quickly becoming a wise investment decision. Direct current (DC) microgrids also offer interesting applications to incorporate renewable energy production, while reducing losses and offering higher power quality.


Figure 3: Recent photo of Santa Rita jail with ground mounted tracking solar PV in foreground and batteries and fuel cell directly behind

Since microgrids offer an avenue for increased renewable energy production, policymakers should set support policies that are amenable to microgrid penetration and allow microgrids to capture any incentives that are potentially available. For instance, if a renewable portfolio standard is set up with a trading system for renewable energy credits, policymakers could make sure that microgrids would be allowed to get tradable credits for any renewable energy they produce and sell to the utility. Equipment will be needed to ensure that any renewable energy generation can be properly metered for these purposes.

Barriers to microgrid development

The barriers for large scale microgrid deployment can be broken down into two categories: economic and institutional. Economic barriers concern the balance between the benefits microgrids create and the costs they impose. The essential question is whether these benefits and costs can be properly priced to incentivize microgrid development that is simultaneously beneficial to the customer, the utility, and society as a whole. Note that analyzing these benefits and costs will also require contextual considerations such as geographic location of the microgrid on the macrogrid, local gas and electricity rates, local policies, and regional macrogrid power supply mix. Institutional barriers refer to those introduced by the need for unfamiliar practices in the industry. These include interconnection procedures, plus utility, building, environmental, and safety codes.

The benefits that microgrids offer to the customer, utility, and society at large can be broken down into the following categories: economic, PQR, environmental, energy security, and safety. Table 1 provides an overview of some of the main benefits that microgrids can offer and which stakeholders can benefit.

Benefit class	Specific benefit	Customer	Utility	Society
Economic (direct)	Reduced electricity and fuel costs	X		
Economic (direct)	Sale of excess power to grid	X	X	
Economic (direct)	Participation in demand response markets	X	X	
Economic (indirect)	Reduced system congestion costs		X	X
Economic (indirect)	Reduced transmission and distribution losses		X	X
Economic (indirect)	Reduced operating reserves		X	
Power reliability	Reduced power outages on-site	X		
Power reliability	Potential for black-start capabilities		X	X
Power quality	Potential for reactive power/voltage control	X	X	
Environmental	Increased use of renewable energy	X	X	X
Environmental	Reduced SO2, NOx, CO2 emissions			X
Security and safety	Avoided major system outages	X	X	X

Table 1: Microgrid value distribution, adapted from NYSERDA 2010

The direct economic benefits are perhaps the easiest to understand and generally fall into three categories: reduced electricity and fuel costs, sale of excess power to the grid, and participation in ancillary service (AS) and demand response (DR) markets. If a microgrid is able to produce its own power, heating, and cooling services, it will obviously be able to reduce its electricity and fuel costs, ideally in a manner that makes its investment in distributed generation a cost-effective one overall. If there is time of use pricing, then there could be additional energy savings or arbitrage opportunities. There may be instances where microgrid generation exceeds its loads leading to exports. Particularly during peak demand periods, this service could be valuable to the macrogrid. There is a question of whether the microgrid will be compensated for this power, and if so, at what rate: wholesale, retail, or potentially a feed-in tariff (for any renewable, distributed, or other incentivized generation).

Indirect economic benefits derive from postponing periodic investments utilities need to make in their transmission and distribution (T&D) systems. By producing the majority or a significant portion of their own energy microgrids are reducing T&D system congestion and losses. As microgrids are deployed, less will be spent on maintenance and upgrades in the T&D system, and the need for peak generators or operating reserves will be reduced. Microgrids can have a positive impact on macrogrid PQR, partially through the provision of DR and AS. Reliability is a primary concern for many microgrid sites and the ability to produce reliable power on-site and avoid power outages caused by macrogrid disruptions is highly valued by certain customers such as military bases and hospitals. Microgrids may be able to provide services to the distribution grid such as reactive power for voltage control, which could have a positive impact on power quality. Lastly, in the environmental realm, since microgrids can increase energy efficiency and renewable supply, there will be associated emissions reductions for carbon dioxide and criteria pollutants such as sulfur dioxide and nitrogen oxides.

From the "land of penalties" to the "land of payments"

Historically, many utilities have not welcomed development of microgrids and DER, and in certain situations, have actively inhibited their development, placing them in the "land of penalties." They have refused to interconnect the projects or charged prohibitively high connection fees, exit fees, or backup/standby fees. For microgrids to capture the benefits just discussed, policy and technical remedies need to assist microgrids in getting from the "land of penalties" to the "land of payments."

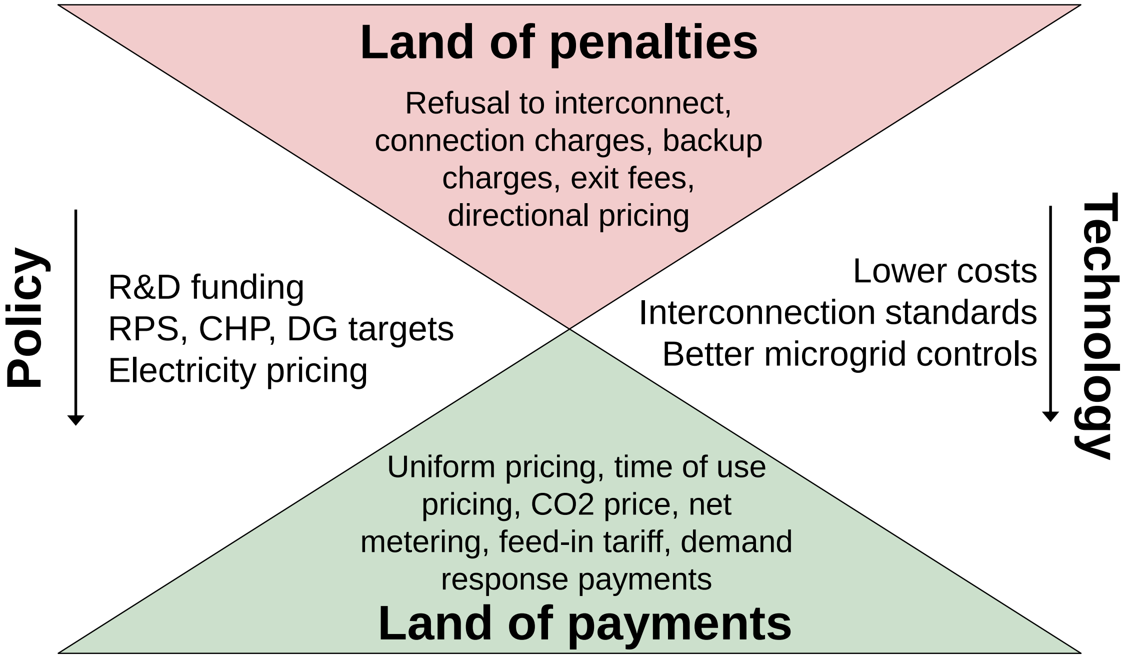

Figure 5: Land of penalties to land of payments using policy and technology remedies

The idea Figure 5 conveys is that microgrids can provide economically valuable services in a cost-effective manner when those services are properly valued with payments or incentives instead of penalties. Technology improvement should consistently lead to improved microgrid functions and services, if properly incentivized. As technology costs come down, interconnection practices become standardized, and microgrid controls (both passive and active) consistently improve, then microgrids will become both increasingly feasible and also of higher quality and robustness. Policy can help incentivize the initial R&D and demonstration phases with funding and targets for microgrid demonstrations (or specific distributed generation and combined heat and power [CHP] targets to be more inclusive). Working on electricity pricing policy will ensure that microgrids can capture a just share of the economic benefits. As seen in Table 2, there are many potential changes on the policy "wish list" relevant to electricity pricing alone. When customers purchase less energy from the utility, the utility has been inclined to request increased service charges or exit fees due to its lost revenue and consequent stranded assets. These charges often eliminate the benefits the customer had initially gained and therefore should not be allowed by regulators unless clearly justified. Note that under dynamic circumstances, such as if local or regional electricity consumption is rising rapidly (as is the case in many developing world regions), then the utility's risk of stranded assets is greatly reduced.

Economic benefit of microgrid	**Regulatory/utility barrier: "Land of penalties"**	**Resolution: "Land of payments"**
Reduce energy costs	Increased service charges or exit fees	Disallow unwarranted increases in charges due to loss of use of service revenue
	No time of use pricing	Create time of use or real-time pricing scheme
Sell excess power to utility	Interconnection charges	Apply a fair and cost-effective interconnection review process
	No compensation provided	Mandate utility purchase of excess power
	Directional pricing used	Consider uniform pricing
	Net-metering not allowed	Mandate net-metering, consider allowing provisions for a mixture of supply technologies
Participate in demand response markets	No compensation provided	Create incentive payments for demand response (interruptible tariffs or contracts)
	Capacity limit set too high	Lower capacity limit so microgrids of all sizes can participate
Increase use of renewable energy	No incentives for renewable energy	Consider RPS or feed-in tariff policies
Reduce CO2 emissions	No CO2 price	Consider carbon pricing policy

Table 2: Valuing the economic benefits of microgrids

Policy recommendations for a microgrid program

Providing the right policy and technology remedies to go from the land of penalties to the land of payments is the last step in a country's microgrid program, as it is the step that leads to widespread deployment. In fact, no country is yet at a deployment stage for microgrids, but many have completed R&D programs and field demonstration projects, steps 1 and 2 in Figure 6. Yet, any country embarking on a microgrid development program should start with this end in mind. Helping to decide the end goal for microgrids in terms of purpose and functionality within a country's grid system can help to determine the initial steps in setting up a demonstration program and commissioning initial demonstration projects. The demonstration program will help to set the long-term goal and an initial foundation for microgrid development. Demonstration projects will help a country identify what functions the microgrid can serve within the specific energy landscape. If it seems that the microgrid can achieve economic benefits for customers, utilities, and society at large, then policies can be implemented to ensure the microgrid owner receives incentives or other support to monetize those benefits.

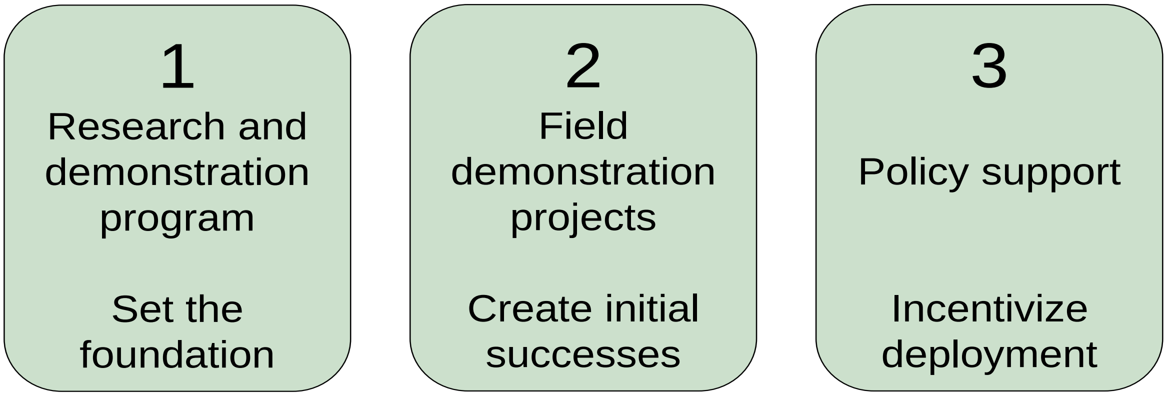

Figure 6: Steps in microgrid program: from demonstration to deployment

The key policy recommendations can be broken down into those for A) the demonstration program as a whole, B) for the individual demonstration projects, and C) for deployment policies.

A. Recommendations for microgrid demonstration program:

1. *Set goals for the demonstration program:* Based on the benefits sought and the stakeholders involved, the program administrator can set overall goals for the microgrid demonstration program in reliability (ability to island, power outages), energy efficiency (both supply and demand side), renewable energy use, energy savings (for both microgrid participants and utilities), or CO2 emissions reduction.
2. *Promote results-oriented demonstrations based on overall goals:* Microgrid development has reached the stage where potential benefits are known and have been demonstrated, but they have been rarely quantified in a rigorous manner. Once overall programmatic goals have been set, quantifiable goals and metrics should be set for the individual demonstration projects. For instance, the U.S. Department of Energy identified a peak load reduction goal of 15% for a series of microgrids it helped to fund. Share of renewable energy production in the microgrid could also be a demonstration goal. Additionally, cost sharing between government and private sector partners is another way to promote results-oriented demonstrations.
3. *Allow for post-demonstration analysis and peer review:* A key component of any demonstration should be analysis following completion of the project. Amassing enough data during a demonstration, and providing budget and opportunity for ex-post analysis can produce valuable results for the project itself, future projects, and overall policy.

B. Recommendations for individual microgrid demonstration projects

1. *Ensure project is close to economic viability:* Various tools have been developed internationally to assess a project's economic viability from the perspective of the microgrid customer who is usually seeking to cut energy costs and/or change PQR, while increasing control over electricity delivery on their site.

2. *Include customer microgrids:* Many of the successful microgrid demonstration projects have been located at customer sites downstream of one meter, where there are fewer regulatory barriers. Maxwell Air Force Base, Illinois Institute of Technology, and Santa Rita green jail projects are all great examples of successful microgrid projects downstream of one meter.
3. *Match technology with end-use requirements:* Demonstrations built around energy supply resources not suitable for the site's energy loads are misguided. Matching PQR of the energy supply to the requirements of end use loads is a defining feature of a successful microgrid, such as the Santa Rita green jail. On the one hand, sensitive loads (military bases, hospitals, data centers, etc.) require very high PQR while on the other hand, some customers' sites may not even need PQR as high as the legacy centralized grid, or *macrogrid*, provides.
4. *Integrate energy functions, such as CHP and CCHP:* Demands for electricity, heating, cooling, and other fuel use, should all be taken into account when designing an optimal microgrid. Even though there is often a policy preference for renewables, some of the best economic and carbon abatement opportunities lie with CHP technologies as well as combined cooling, heating, and power, technologies (CCHP), deployed successfully by the Sendai and University of California San Diego (UCSD) projects, respectively.

C. Recommendations for policies to support microgrid deployment

1. *Develop standards and processes for interconnection of microgrids:* Any policymaker considering a microgrid program should put standards in place (potentially based off of IEEE's 1547 standard) as soon as possible. Additionally, they should develop a process for streamlining interconnection reviews in the short-term but evaluating large scale impacts of distributed generation in the long-term and coming up with a cost-effective response. The amount of distributed generation will rise in most regions of the world, so utilities and policymakers should plan proactively for their impact.
2. *Consider modifications to electricity rate design:* Microgrids must be able to monetize the benefits they create to incentivize their successful widespread deployment. Many of those suggestions have to do with modifications to electricity rate design, including measures for both the purchase and sale of electricity by the microgrid. On the purchase side, time of use pricing and demand charges can be used to incentivize load shifting and energy efficiency. On the sale side, uniform pricing, net-metering, and DR payments can be used to incentivize the sale of energy and services from the microgrid to the macrogrid.
3. *Inventory current incentive policies and analyze barriers and opportunities for widespread microgrid deployment:* Utilities who have to comply with an RPS or cap and trade policies will pursue utility-scale solutions (such as large wind farms or solar thermal generation plants) as opposed to distributed-scale solutions. Eventually, distributed-scale solutions may become cost competitive with utility-scale solutions, but in the interim, mandated policy targets and targeted incentives for CHP or microgrids will help these technology solutions get a foot up as market players gain experience and costs come down.

Specific Recommendations for China's Microgrid Development

China has a wide array of policy drivers for low-carbon growth and clean energy. At the highest level, China has its targets to reduce carbon intensity by 40-45% by 2020 off 2005 levels as well as to increase the percentage of non-fossil fuel energy usage (nuclear, hydropower, renewables) up to 15% by 2020. The National Energy Administration (NEA) plans to build 100 "New Energy City" pilots as well as 30 microgrid pilots. As China develops these demonstration microgrid projects as well as new regulations to promote widespread microgrid development, policymakers should bear in mind the ten recommendations laid forth in the previous section and apply them to China's situation.

There is a possibility that China will approach microgrids solely as a supply side solution (a way to balance out intermittent renewables), but for microgrids to realize the maximum amount of benefit in reliability, energy efficiency, and use of renewable energy, they must integrate supply solutions with demand side efficiency and storage as well, where appropriate. As China develops its microgrid demonstration program and plans for more widespread microgrid deployment, there are a number of policy adjustments that China will need to consider: forming interconnection standards, establishing a central authority on distributed generation and the microgrid demonstration program, and aligning incentives to encourage microgrid deployment.

The NEA has played the most active role to date in promoting microgrids within China's renewable and clean energy development. Recently, NEA drafted the Management Methods for Distributed Energy, but this has yet to become an official piece of legislation. Given that the various functions involving distributed energy are scattered across many different departments, there is a lack of unified management and policy guidance, posing some developmental barriers to distributed energy and microgrids. NEA could take the lead on the microgrid demonstration program and be responsible for its successful implementation, yet work closely with other agencies that are also interested in microgrid deployment, such as the National Development and Reform Commission (NDRC), Ministry of Housing and Urban Rural Development (MOHURD), and Ministry of Finance (MOF). Those three agencies, in conjunction with NEA, released a policy document in 2011 on natural-gas based distributed generation that would be amenable to renewable energy integration. These developments could produce positive momentum for utility-scale microgrid applications. MOHURD has set goals for renewable energy deployment in buildings, but many buildings with renewable energy installations have not been successfully interconnected with the grid. MOHURD is exploring microgrids as a possible avenue to facilitate its policy objective. Finally, MOF will play a key role in establishing the needed funding for microgrid demonstrations.

China's general policy direction provides positive indications for distributed generation and CHP, but concrete incentive policies for these areas are currently lacking. Wider considerations need to be given to electricity pricing policy as a whole to ensure it incentivizes microgrid deployment. Time of use pricing, demand response contracts, uniform pricing, and net-metering policies can all be considered as each would play a positive role in promoting successful microgrids that increase reliability and energy efficiency while lowering carbon emissions.

The lessons and recommendations provided in this report will serve as a useful reference for China's policymakers to develop rigorous policy support for a successful microgrid demonstration program and to create a new avenue for increased deployment of renewable energy technologies. Indeed, taking stock of the international experiences to date will help China to **IMAGINE** a prosperous future for microgrids.

Executive Summary – Chinese – 执行摘要

尽管以化石燃料为主的电网在过去一个多世纪里为我们提供了值得称道的电力质量和可靠性，近年来集中供电模式的局限性却带来越来越多的关注与质疑。这直接推动了微网的研发和推广工作迅速展开。同时，成本、电力质量和可靠性、能源效率、当地清洁和可再生能源利用与减缓气候变化等因素也成为微网的驱动力。此外，用户、技术提供者、公用事业与政府部门等不同利益集团也是影响微网技术和政策成功发展的关键因素。微网提供了一条提高分布式能源电力输送的路径，从而使电力控制更加分散、服务质量更加符合当地用户端的需求。尽管关于微网的定义各有不同，但是通常两个基本点得到国际广泛认同：（1）微网应包括本地控制下的电源和负荷；（2）微网应既能并网也能孤岛运行。

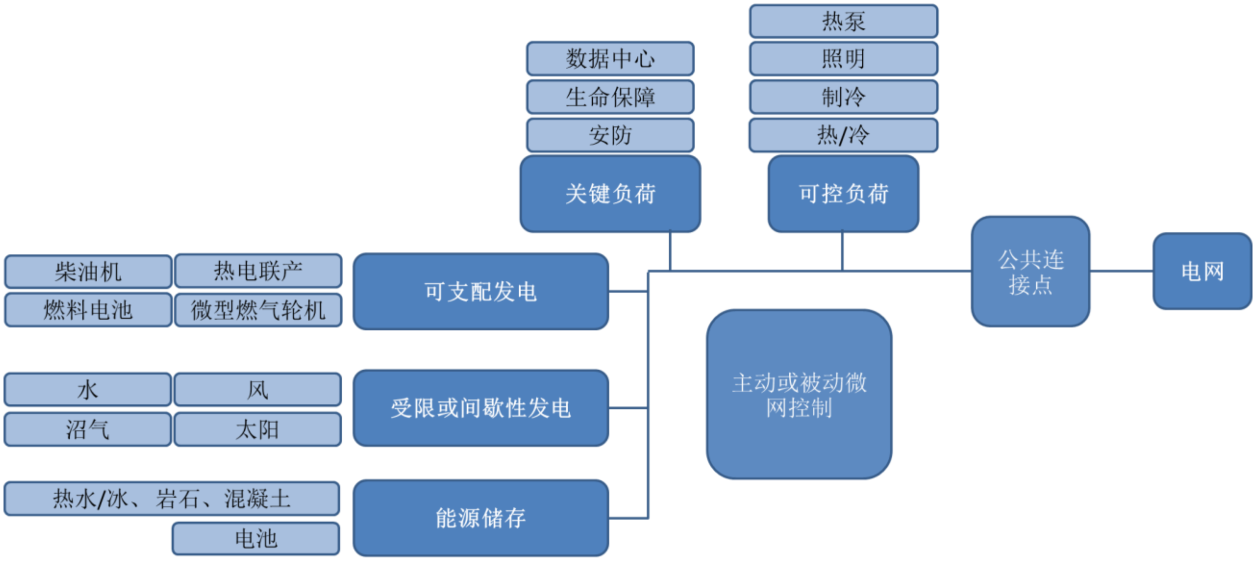

图 1: 微网主要部分一览，改编自： Siemens 2011

本研究对国际微网的评估，通过总结以往的国际经验，探寻微网通过激励达成收益所需的电网管制方法。本评估总结了开展微网示范计划的政策建议，其中包括专门针对中国的具体建议。执行摘要首先概括了微网发展的驱动力，其中特别强调了对可再生能源利用，其次鉴别了发展微网普遍存在的障碍，并提出了可行的解决方案，最后依据以上分析列出具体的政策建议。

微网发展的驱动力

一般而言，微网包括四种主要驱动力，见下图。能源用户为了降低成本和减少环境碳排放对于提高能效与电力质量和可靠性显示出越来越浓厚的兴趣。而电力供给产业一直关注如何在提高和维护电力质量和可靠性以满足不断攀升的负荷的同时如何降低成本并达到清洁能源强制使用标准。同时，政府为了实现减缓气候变化、维护能源安全及其他环境目标正致力于提倡使用清洁能源。此外，来源于许多不同部门的技术提供者，例如信息技术和电信领域，在促进微网发展中扮演着寻求潜在创新机会的重要角色。

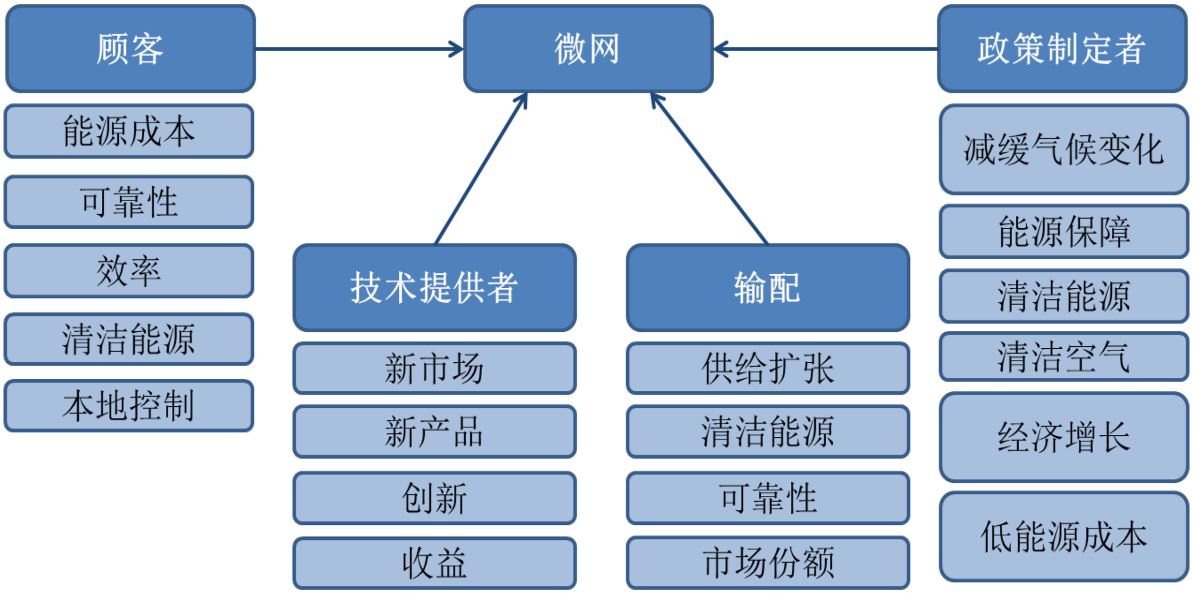

图 2: 微网驱动力：四个主要的利益群体

如图 2 所示，在新电网模式中，顾客、技术提供者、公用事业和政府在成本、可靠性、效率、清洁能源及气候变化等方面拥有着共同的动机。世界上许多国家和地区试图将分布式能源系统作为智能电网创新解决方案的一部分来迎接以上诸问题的挑战。为此，许多政府已经颁布和实施了一系列提高清洁能源和分布式能源资源使用份额的政策措施。然而，分布式能源资源与传统电网并网也带来了诸如影响电力质量和可靠性降低电网安全性等技术挑战。微网通过创造适宜小规模电网资源的电力生态系统为提高分布式能源推广提供了路径。技术提供者是促进微网发展的又一重要力量，为公用事业用户提供硬件技术和服务的公司正积极致力于发展和推广提高顾客自给自足的能源技术，这些技术使电力生产、输送和使用的革新成为可能。

微网与可再生能源发电

可再生能源发电是微网示范项目的普遍特征。在本报告的两个案例研究中——加利福尼亚州圣塔瑞特监狱项目和日本仙台项目，太阳能光伏阵列都是重要的组成部分，见图 3 和图 4。有鉴于可再生微网资源发电的间歇性或易变性，高质量的可再生能源发电需要结合储能设施、需求控制和可支配电源串联使用。这样的一个控制系统，既可以对传统电网起到调节作用并且与现有基础设施相比较它又是一种可管理的电源或负荷。


图 3:俯瞰 仙台能源中心

截至目前，补助政策依然是推进可再生能源利用的主要形式，所以经济性始终是实施支持政策的关键问题。例如，电力公司正寻求最有效的方式以满足可再生能源发电配额制的规定。同时，电力公司也困扰于可再生能源间歇性对于电网的冲击以及开发有效的分布式规划所面临的挑战。正因为如此，微网应运而生，它能够为这些问题提供解决方案。对于大型的可再生能源项目，政策制定者也面临着环境评审障碍，例如，对于海上风电和大型沙漠太阳能设施的安装。而微网的小型化特点可以减少对于安装地点问题的考量。随着太阳能光伏成本降低以及微网技术的推广和应用，太阳能光伏正成为许多承受高电价的商业和工业用户的一个明智的投资选择。 而且，直流微网可以通过可再生能源发电直接应用于负荷从而大大减少电损并提高电力质量和可靠性。


图 4: 圣塔瑞特监狱近照： 地面安装跟踪式太阳能光伏居前、电池和燃料电池居后

鉴于微网是提高可再生能源发电的途径，政策制定者应制定有利于微网普及的政策允许微网借助于任何相关的有效的激励措施得以发展。例如，如果与可再生能源发电配额一起建立可再生能源信用交易体系，那么政策制定者就能确保微网从可再生能源

发电及售电给公用事业中得到交易信用。另外，还应确保用于正确计量可再生能源发电的设备建设。

微网发展的障碍

大规模微网推广的障碍可划分为两类：经济性障碍和制度性障碍。经济性障碍关注微网创造的收益与实施成本之间的均衡。其问题的本质在于是否收益与成本能被合理定价以激励微网发展同时为顾客、公用事业及整个社会带来裨益。当然，收益与成本也需要考虑一些具体背景，例如，微网与电网的相对地理位置、当地的天然气价格和电价、当地政策以及地区电网电力供给结构等。制度性障碍是指产业中引入不熟悉的方式方法而造成的障碍，包括并网程序以及公用事业、建筑、环境和安全等方面的各项法规。

一般而言，微网带给顾客、公用事业和社会的收益可分为以下几方面: 经济、电力质量和可靠性、环境、能源保障及安全等。表 1 概括了微网带给利益相关者的主要收益。

收益层级	具体收益	顾客	公用事业	社会
经济 (直接)	减少电力和燃料成本	X		
经济 (直接)	向电网出售多余电力	X	X	
经济 (直接)	参与电力市场需求响应	X	X	
经济 (直接)	减少高峰期用电成本		X	X
经济 (直接)	减少输配电损失		X	X
经济 (直接)	减少运行储备电站		X	
电力可靠性	减少现场断电	X		
电力可靠性	黑启动（断电启动）潜能		X	X
电力可靠性	无功功率/电压控制	X	X	
环境	提高可再生能源利用	X	X	X
环境	减少 SO2， NOx， CO2 排放			X
保障与安全	避免主要系统断电	X	X	X

表 1: 微网价值分布，改编自：NYSERDA 2010

直接经济收益通常分为三类：减少电力和燃料成本，向电网出售多余电力，以及参与辅助服务和需求响应市场。通过微网自我发电并提供供热和空调制冷服务，显然能够降低电力和燃料成本，在理想状况下分布式发电投资总体上具有经济性。如果电价体系采用分时电价机制就可能获得额外节能或获利机会。例如，微网的发电量超过负荷需求就可以输出多余电力，特别是在峰时此项服务对于电网非常有价值。然而，问题在于微网是否可以为此获得补偿，如果可以，如何定价：批发、零售，或上网电价（对于任何可再生能源、分布式或其他激励的发电形式）。

间接经济收益在于微网可以延滞公用事业对于输配电（T&D）系统的大额度定期投资。首先，通过自我供给所需的大部分能源微网可以减少输配电系统的拥堵状况及损失。随着其推广，只需更少的资金用于维护和升级输配电系统，并能够减少峰时发电机量或运行储备。其次，通过需求响应和辅助服务微网对电网的电力质量和可靠性有着积极影响。可靠性是许多微网项目的首要关注点，它是指通过可靠的现场发电从而避免由于电网中断而造成断电的能力，这种能力对于特定客户如军事基地和医院具有极高的价值。微网能为配电网提供服务从而积极地影响电力质量，如无功功率进行电压控制。最后，对于环境领域，既然微网能够提高能效和可再生能源利用，也必然可以减少二氧化碳及标准污染物的排放量，如二氧化硫和氮氧化物等。

从“抑制”到“回报”

从历史的经验看，许多电力公司并不欢迎微网和分布式能源资源的发展，在某些情况下，还会试图抑制其发展，将其视为处罚对象。他们拒绝微网和分布式能源资源项目并网或者收取过高的连接费、退出费或备用费等。因此，为了使微网能够实现上述收益，就需要政策与技术对策帮助其实现从受抑制到实现回报的跨越。

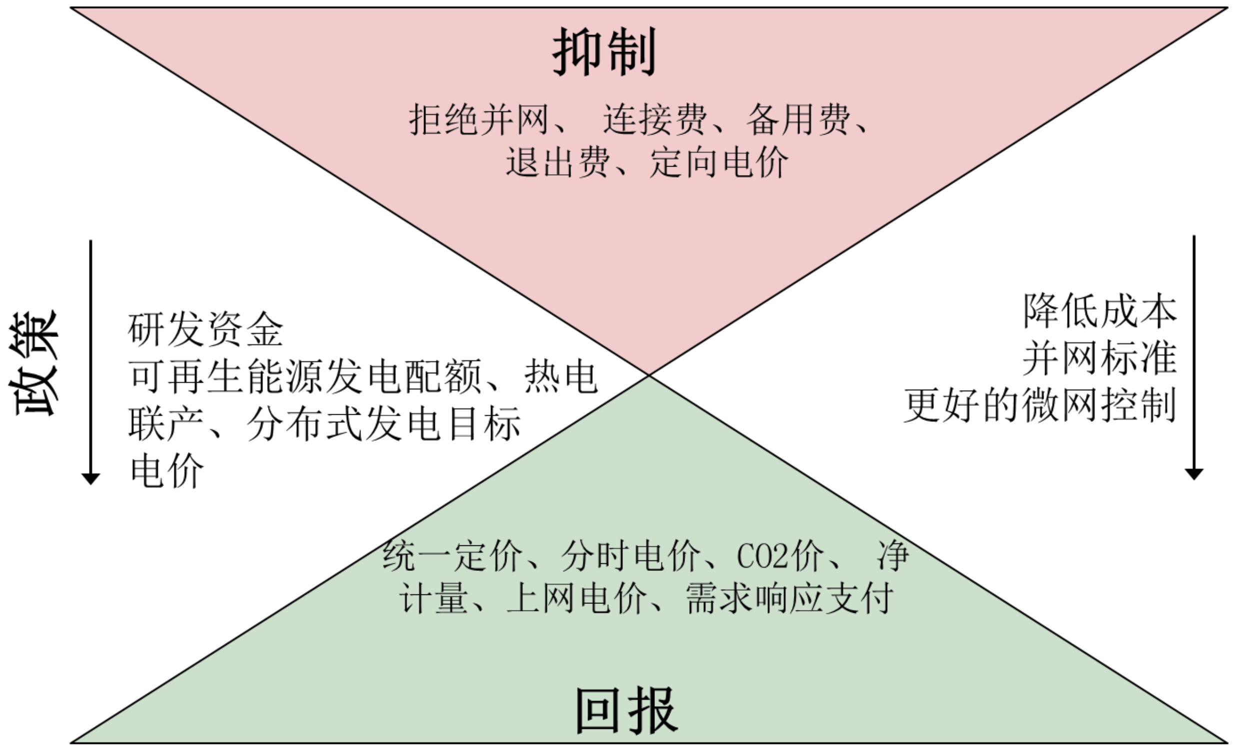

图 5: 通过政策与技术对策从抑制向回报跨越

图 5 概括了微网的经济价值理念，如果微网服务通过报偿或激励的方式（而非处罚的方式）得到合理评估，那么这些服务就能体现出成本效益的价值性。同时，适当激励可以使微网通过技术进步不断地提升其功能和服务。并且，随着技术成本下降、并网标准化和控制（包括主动和被动）能力提高，微网的可行性、质量和坚固性（鲁棒性）也会愈发显著。激励政策不仅能推动微网的研发工作，而且基金资助和目标设立（包括特定分布式发电和热电联产目标）也能促进示范项目实施。此外，电价政策改善将确保微网获取应有的经济收益。如表 2 所示，许多有待于改变的政策都涉及电价问题。当顾客减少从公用事业购买能源就会导致公用事业因为其收入损失和资产闲置而要求提高服务费或退出费。对于这种行为，除非收费合理否则监管机构应不予允许，因为公用事业收取这些费用必然会减少顾客已获得的收益。值得注意的是：在动态情况下，例如随着当地或地区电力消费快速增长（尤其是在许多发展中地区），公用事业资产闲置风险会大大降低。

微网经济收益	管制/公用事业障碍： “抑制”	解决方案： “回报”

减少能源成本	提高服务费或退出费	禁止对于使用减少所造成的收入损失无端增加收费
	无分时电价	设立分时或实时电价机制
向公用事业出售多余电力	并网费	建立公平且具有成本效益的并网审查程序
	无补偿	强制公用事业购买多余电力
	使用定向电价	考虑统一定价
	不允许净计量	强制净计量，考虑许可多样供给技术混合的规定
参与需求响应市场	无补偿	对需求响应设立奖励（中断电价或合同）
	容量限制设置过高	低容量限制，所有规模的微网均可参与
提高使用可再生能源	无可再生能源激励措施	考虑可再生能源电价配额或上网电价政策
减少 CO2 排放	无 CO2 价格	考虑碳价政策

表 2: 微网经济收益评估

实施微网计划的政策建议

正确的政策与技术对策是一个国家支持微网计划从抑制向回报跨越并推进微网推广的最后一步。事实上，尽管目前许多国家已经完成了研发计划和示范项目阶段，但仍没有一个国家处于微网推广阶段，见图 6 步骤 1 和 2。对于任何一国而言，从事一项新的微网发展计划就应该从一开始设想好所有步骤。设立微网在国家电网系统的目的和功能等目标有助于决策示范计划和项目开展的步骤；示范计划则有助于设定微网长期的发展目标并为发展奠定基石；而示范项目可以帮助国家确定微网在特定能源领域所担负的服务功能。总之，微网要实现用户、公用事业及整个社会的综合经济效益，只有通过有效的政策实施确保微网所有者获得激励或财政支持才能实现收益。

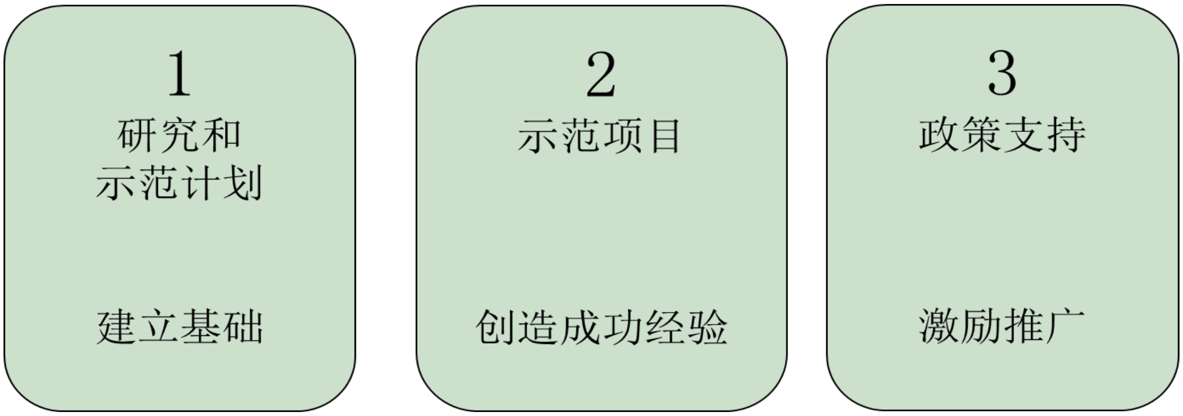

图 6: 微网计划步骤：从示范到推广

主要的政策建议分为三个方面：（A）整体而言的示范计划；（B）具体的示范项目；以及（C）推广的政策。

A. 微网示范计划建议

1. 设置示范计划目标

基于微网收益和利益相关者的目标，计划管理者应该就可靠性（孤岛运行能力和断电情况下）、能源效率（供需端）、可再生能源利用、节能（对于微网参与者和公用事业两方面而言），以及减少二氧化碳排放量等方面设置总体目标。

2. 依据总体目标促进结果导向的示范项目

微网潜在的收益已众所周知并被验证，但是他们很少被严谨地量化。因此，一旦整体目标方案确定，单个项目的量化目标及指标也应相应地设定。例如，美国能源部资助的一系列微网项目致力于减少 15%的尖峰负荷、可再生能源发电比例也是示范项目的实施目标等。另外，政府与私营合作伙伴之间进行成本分担是促进结果导向示范项目的一种方式。

3. 示范后分析考量与同行评议

项目完成后的分析是任何示范项目的关键部分。评估项目实施过程中累积的各项数据、项目预算和事后分析都能为项目本身及未来发展和总体政策提供有价值的信息。

B. 微网示范项目建议

1. 确保项目的经济可行性

国际上，有很多不同工具被研发用于从微网用户端（通过提高当地的电力输送控制寻求减少能源成本、改变电力质量和可靠性）评估项目的经济可行性。

2. 包含用户端项目

许多成功的微网示范项目位于用户端。由于其在计量下游使用一个电表，管制壁垒较少，比较容易实施。麦克斯维尔空军基地、伊利诺斯科技大学和圣塔瑞特绿色监狱等项目等都是成功的范例。

3. 技术与终端用户需求相匹配

不考虑当地能源负荷，只注重能源供给源的示范项目很难成功，为最终用户端匹配相应的电力供给质量和可靠性是一个成功微网内在固有的特征，如圣塔瑞特绿色监狱项目。因为有些用户属于敏感负荷需要非常高的电力质量和可靠性，例如军事基地、医院、数据中心等；而另一些用户所需的电力质量和可靠性可能低于传统电网提供的标准。

4. 整合能源功能：如热电联产和热电冷联产

设计一个最优化的微网应考虑电、热、冷及其它燃料的综合使用。 尽管当前政策偏好于可再生能源，热电联产和热电冷联产仍然是对其进行补充的最好的既经济又减碳的形式，在这一方面，成功的范例包括仙台和加利福尼亚圣迭戈大学等项目。

C. 支持微网推广的政策建议

1. 发展微网并网标准和程序

任何微网方案的决策者应尽快考虑并网标准（可能基于 IEEE1547 标准）问题。同时，还应开发短期简化的并网审查程序和长期评估大规模分布式发电影响程序，以及提出成本收益响应程序。当前，分布式发电量在世界大部分地区呈上升趋势，因此，公用事业和决策者应予以提前规划。

2. 考虑修改电价设计

能够产生经济效益的微网方能促使其成功并被广泛地推广。许多建议都涉及修改电价设计，包括微网购电和售电两方面的措施。在购电方面，分时计价和需求费可以用来激励错峰和能源效率；在售电方面，统一定价、净计量和需求响应支付能够激励微网对主网的能源销售与服务。

3. 总结当前的激励政策并分析推广的差距

由于公用事业受可再生能源发电配额制或总量管制和排放交易政策的制约，所以往往通过寻求公用事业规模的解决方案（如大型风力发电场或太阳能热发电厂）去抵制分布式规模解决方案。尽管最终有可能分布式规模解决方案与公用事业规模解决方案形成成本竞争，然而在过渡期，对于热电联产或微网实施强制的政策目标和有针对的激励措施，将有助于这些技术解决方案通过市场竞争累积经验并且降低成本。

针对中国微网发展的具体建议

首先，中国已经制定和实施了许多政策以驱动低碳增长和清洁能源利用。在国家层次，中国已制定出 2020 年减少 40-45％（2005 年水平）的碳排放强度目标，以及 2020 年将非化石燃料能源使用比例（核电、水电、可再生能源）提高到 15％的目标。 并且，国家能源局计划建立 100 个“新能源城市”示范工程以及 30 个微网示范工程。随着这些微网示范项目及新的激励法规的实施， 决策者可以参考上述十个建议并结合具体国情加以应用。

其次，在中国存在着将微网仅作为供给端解决方案的可能（平衡间歇性可再生能源的方式），然而为了实现可靠性、能源效率和可再生能源利用等诸多收益最大化，应将供给解决方案与需求端的效率和储能等合理因素相整合。 随着微网在中国的发展，一系列政策面临调整，下列问题需要考虑：制定并网标准，建立负责分布式发电和微网示范项目的专门政府机构，以及制定系列政策促进微网推广等。

再者，迄今为止国家能源局在促进可再生能源、新能源和微网发展方面扮演着非常活跃的角色。最近，国家能源局起草了分布式能源管理办法（但尚未正式立法）。鉴于分布式能源的管理职能分散于许多不同部门，而缺乏统一管理和政策指导将导致分布式能源和微网发展面临障碍，国家能源局可以考虑率先领导微网示范计划并负责其成功实施，同时与国家发改委、住建部以及财政部紧密合作共同推进微网建设。在 2011 年，以上部门联合发布了整合可再生能源发展天然气分布式能源的政策文件，这些措施有力地推动了公用事业规模的微网应用。住建部已设立推进建筑领域可再生能源的发展目标。但由于建筑领域的可再生能源设施一直不能并网，可以考虑探索可能的途径提升政策目标。此外，财政部在推进微网建设方面也担负着提供资金资助的重要作用。

最后，虽然在分布式发电和热电联产方面中国的总体政策显示出积极的态度，但是截止目前仍然缺乏具体的激励政策。一方面，整体电价政策需要调整以确保有效地促进微网推广，同时分时计价、需求响应合同、统一定价和净计量等政策也都可以加以考虑，这些措施将在促进微网成功发展、提高可靠性和能源效率以及降低二氧化碳排放量等方面起到积极而重要的作用。

本报告的建议和经验总结将作为中国的决策者制定政策支持微网示范计划及提升可再生能源推广的参考。期望对于国际经验的评估将有助于中国在将来发展并实施成功的微网计划。

1. Introduction

1.1 Purpose of this work

Numerous organizations and research programs have accumulated valuable lessons from their experience with microgrid pilot projects and other aspects of microgrid economic and technical development, as well as with the adoption of standards and other mechanisms to foster expanded microgrid use. Review of international experience can benefit organizations and countries just establishing microgrid research and demonstration programs. In the interest of informing policymakers with illustrations from the collective international experience, this work provides a detailed overview of microgrid definitions, common characteristics, historical development, technology, barriers, and policy prescriptions, as well as descriptions of successful microgrid projects worldwide.

Since the mid 1990's, key developments in microgrid technology and demonstration have taken place in all the major regions: Europe, Asia, and the Americas. The E.U. was an early leader in microgrid development as it was an early leader in climate change mitigation and clean energy policies. In 2003, Japan funded a microgrid R&D program to consider both the reliability and clean energy perspectives. More recently, the U.S. has developed in-depth research and demonstrations through the Smart Power Infrastructure Demonstration for Energy, Reliability, and Security (SPIDERS) program run by the Department of Defense (DOD), which is focused on reliability and energy security, and the prior Renewable and Distributed Systems Integration (RDSI) program run by the Department of Energy (DOE) to focus on peak load reduction, efficiency, and clean energy. Important progress on standards development for interconnection of DER and the islanding operation of microgrids has also been led by the U.S. In the past few years, other Asian countries have become increasingly interested in microgrid development, with demonstration projects starting in China, South Korea, and Singapore. The earthquake and tsunami of March 2011 is also moving Japan's energy policy away from nuclear energy and towards renewables and microgrids.

Microgrids have been demonstrated successfully for a multitude of applications and with numerous technology configurations, operating both grid connected and islanded. For microgrids to reach the next stage of widespread deployment, further reductions in technology cost are needed. Additionally, policy support needs to increase as microgrids are a fundamentally different method of power generation and distribution from the current centralized paradigm. Barriers involving utility tariffs, interconnection, and other issues must be overcome so that microgrids can receive economic benefits (incentives) where they are warranted. In order to realize the benefits of microgrids in the realms of energy efficiency, clean energy, emissions reduction, and energy reliability and security, policymakers must first become familiar with the microgrid barriers and associated technology and policy remedies experienced around the world to date.

1.2 Definitions of a microgrid

The term *microgrid* loosely refers to any localized cluster of facilities whose electrical sources (generation), sinks (loads), and possibly storage (both electrical and thermal) function semi-autonomously from the traditional centralized grid, or macrogrid, i.e. a microgrid is a locally controlled system that can function both grid-tied and islanded. Researchers have created a wide variety of microgrid definitions depending on the context of technology and function, but few formal definitions exist. Following are two efforts:

> *Microgrids are electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded (CIGRÉ C6.22 Working Group).*
>
> *A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode (U.S. DOE Microgrid Exchange Group, 2010).*

The above CIGRÉ and U.S. DOE definitions have two basic requirements: 1) a microgrid must contain both sources and sinks under local control, and 2) a microgrid must be able to function both grid connected and as an island. As noted above, microgrids can be thought of as one of three elements of emerging “smart grid” technology. The other two more widely recognized elements are: 1) improved operation of the traditional macrogrid, e.g. by deployment of phasor measurements, and 2) enhanced interaction between the grid and consumers, e.g. by deployment of advanced metering infrastructure. By contrast to these two well recognized technological changes, microgrids are new entities that have the potential to provide two-way benefits to their participants and the legacy centralized grid, or *macrogrid*. The emergence of microgrid technology represents one aspect of the push towards a more distributed power system.

Some developers using related technologies simply call their project a microgrid based on the use of renewable energy or distribution energy resources. For example, remote islanded networks using renewable energy are often called microgrids but lack connection to the main grid and are therefore not a true microgrid by the two definitions shown. Although they are not strictly microgrids according the definitions given in this study, remote islanded networks often use very similar technology to microgrids and can still produce valuable and relevant lessons for microgrid development. Additionally, executing demonstration is often easier in remote locations where there is no macrogrid to be potentially affected.

Various types of microgrids might not only operate with quite different technologies and objectives but also might fall under different regulatory regimes. Microgrids can be wholly within one traditional utility *customer* site, and in fact most existing demonstrations are of this type, especially in the U.S. Alternatively, a microgrid might involve several sites connected by a fragment of the legacy distribution network. The difference between these two types is critical from the regulatory and policy perspectives. The former is downstream of a single (or very few) meter(s) or point(s) of common coupling (PCCs), which implies a regulatory environment quite distinct from the latter case in which some part of a legacy regulated distribution utility is included.

The key word identifying a microgrid, and particularly differentiating it from traditional distributed generation, is *controlled*. While the macrogrid has traditionally been tightly centrally controlled, local small-scale generation was cast in a slave role, e.g. shutting down immediately in the event of a blackout.

A microgrid must have semiautonomous capability. Note that the CIGRÉ and U.S. DOE definitions say nothing about the technologies involved, their scale, their motive, their fuels, or the quality of power delivered to loads, but both definitions emphasize control. The microgrid's ability to present itself to the macrogrid as a controlled entity has two important implications: 1) it can provide complex services, e.g. buffering variable renewable generation or providing AS to the macrogrid, and 2) it can coordinate with other entities in the network, such as other microgrids or other sites with generation, storage and/or controlled loads. In addition to the self-apparent benefits of potentially providing clean and affordable energy under local control and supplying valuable grid services, microgrids can under some circumstances locally control PQR and tailor it to meet individual load requirements, in contrast to the familiar universal homogeneous PQR service from the macrogrid. For example, this might mean a small local DC system involving solar PV and storage is the best solution even though PQR is poor, whereas in another case it may mean highly reliable and clean power is required, such as for a site whose loads demand it, e.g. a telecom facility. In other words, the PQR of delivered power should be compatible with what is economically available and environmentally desirable, as well as compatible with the PQR requirements of the loads. Note that matching the PQR in this way maximizes the economic benefit.

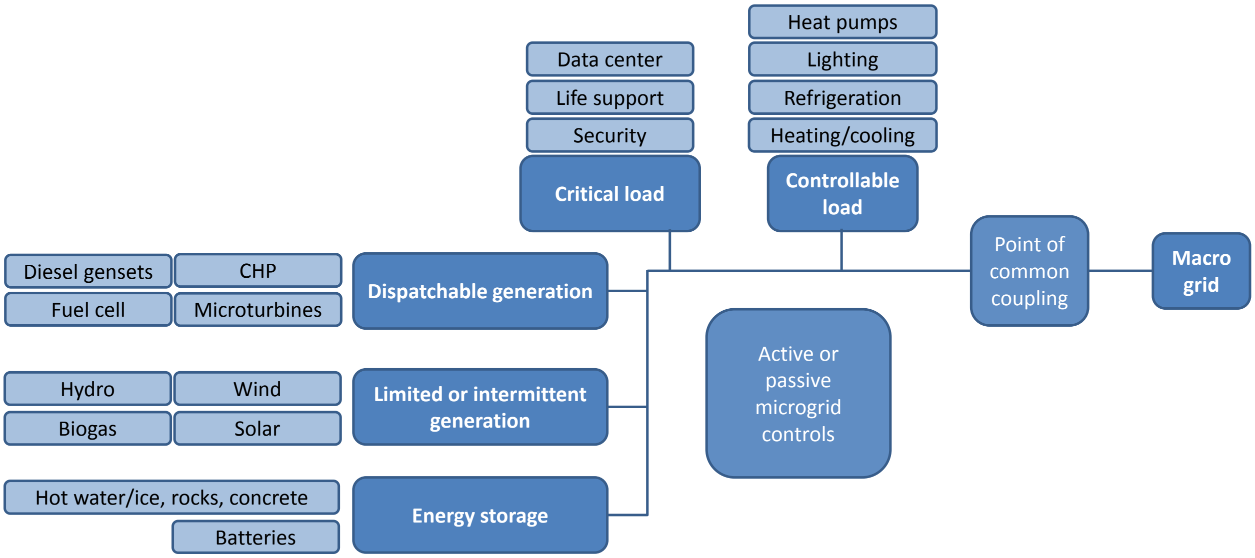

Figure 7: Overview of the main components in a common microgrid, adapted from Siemens 2011

Figure 7 displays the components most readily seen in microgrid demonstrations currently. There are both loads and generation sources. Within loads, there may be critical loads which require high or perfect reliability and cannot lose power, such as a security system at a prison or a life support system at a hospital. There may also be controllable loads which either require lower reliability or whose time of service may be rescheduled without unjustifiably reducing service quality, such as heating, cooling, or refrigeration. Within generation, there are sources which are dispatchable, such fuel cells, or microturbines, possibly in CHP systems. Heat pumps (air, water, or ground source) can often function continuously. Many renewable sources have limited or no dispatchability, such as wind and solar, while others can be dispatchable, such as hydropower or biogas. Energy storage is often incorporated into microgrids as a way to deal with intermittency or to take advantage of pricing structures for grid power.

Thermal storage in hot materials, water, or ice can also capture arbitrage opportunities. Lastly, there are the microgrid controls, which could range widely in sophistication across different applications. In addition to microgrid variability in availability and cost of supply, fluctuation in loads also creates technical challenges. Small power systems generally have greater load variation, a phenomenon that makes control and storage particularly crucial to microgrids.

1.3 Organization of report

Key stakeholder groups and associated microgrid drivers are outlined in section 2. Section 3 (supplemented by the country studies in Appendix A) details the developments to date by region, including the E.U., Asia, and Americas. Section 4 details progress in microgrid technology, with further needed improvements outlined in section 4.2. Section 5 outlines the barriers to widespread microgrid development, while section 6 suggests policy and technical remedies for microgrids to reach the next critical stage in deployment. Recognizing that successful demonstrations must precede a wider deployment program, section 6 also details two of the most successful microgrid demonstration projects to date – the Santa Rita green jail in California and the Sendai project in Japan. Section 7 outlines recommendations for policymakers to successfully prepare a microgrid demonstration program, pilot projects, and deployment policy support. Section 8 refines those recommendations for specific consideration by Chinese policymakers.

2. Microgrid deployment drivers

While largely fossil-fuel based grids have supplied an increasing amount of electricity for our world with a commendable PQR for over a century, various concerns are now bringing the centralized grid paradigm into question. Microgrids are controlled semiautonomous clusters of energy resources and loads that can function either connected to the grid or as islands, offering a new path of development for the electric grid.

2.1 Primary stakeholders

Motivations for promoting distributed generation and microgrids are apparent across at least four distinct stakeholder groups, with many common threads amongst them, as seen in Figure 8. Energy customers are increasingly interested in improving their energy efficiency and reducing their environmental footprint, while the electricity supply industry is consistently worried about increasing or simply maintaining PQR while serving a growing load base and meeting clean energy mandates. Governments, both at the local and national levels, are driving clean energy adoption, in the interests of climate change mitigation, energy security, and other environmental goals. Additionally, technology providers from many diverse sectors, such as information technology and telecommunications, are playing a disruptive role in microgrid development by seeking out potential opportunities to innovate.

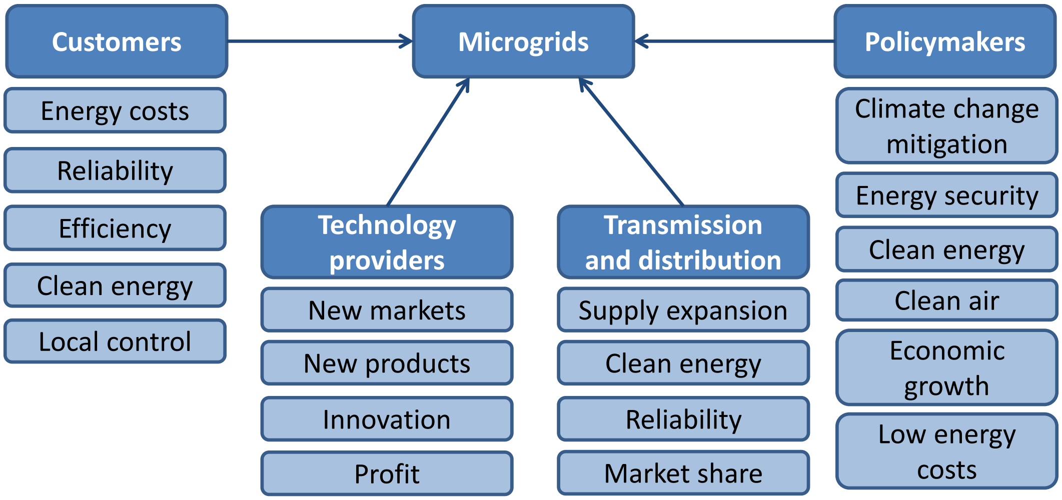

Figure 8: Drivers for microgrids across four stakeholder groups

As seen in Figure 8, the interests of the customer, technology provider, utility, and government stakeholders in a new grid paradigm are profound and have common thread motivations of cost, reliability, efficiency, clean energy, and climate change mitigation. Many countries and regions around the world are looking to distributed energy systems and *smart grid* initiatives to address these challenges. Governments have enacted and implemented a series of policies to increase the share of clean energy and distributed generation; however, the interconnection of distributed generation to the conventional network brings technical challenges such as circuit protection, maintaining PQR, and stability issues. Microgrids could be an enabler of increased distributed generation by creating an electrical ecosystem more amenable to small-scale resources.

There is also the question of cost effectiveness for all of these interested stakeholders. For instance, utilities are constantly seeking the most efficient way to comply with new regulations or mandates, such as an RPS. They worry about the intermittency of renewables and the challenge they create for effective distribution planning. Microgrids might offer a solution to some of these concerns. Policymakers face barriers to large renewable energy projects that require extensive environmental review (such as offshore wind or large desert solar installations); microgrids may reduce siting issues because facilities may be smaller. Finally, reliability poses a concern for many stakeholder groups. Customers certainly value reliability, but how much they are willing to pay for it remains unclear. Note that the cost of universal homogeneous PQR provision in the macrogrid represents a cross-subsidy from customers who value it little towards those who value it highly.

One of the disruptive forces promoting microgrids is the role of unregulated technology providers. Companies keen to provide both hardware and services to current utility customers are developing and deploying technologies that can increase customer autonomy. Several such technologies are enabling the transformation of electricity production, delivery, and use, but a key enabler of microgrids is power electronics devices. These are making control of small-scale systems feasible, economic, reliable, and safe.

2.2 Common microgrid support policies

By now, almost all of the major economies of the world have clean energy support policies, usually in the form of an RPS, cap and trade programs or other climate legislation, feed-in tariffs, and other financial support for clean energy such as tax credits or grants. Yet, renewable energy targets may not be enough to incentivize microgrids specifically, as utilities will seek the lowest cost option to meeting their targets which is likely in utility scale renewables (onshore and offshore wind, solar PV and thermal, biomass, geothermal, etc.) as well as rooftop solar PV, which is becoming increasingly prevalent as solar PV costs reach grid parity. Microgrid development would likely benefit more immediately from specific distributed generation targets beyond rooftop PV as well as targets for CHP. Carbon prices as induced by cap and trade or carbon tax legislation should also provide a price signal in the medium-term for more microgrid development.

The E.U. has the strongest long-term legislative support for clean energy and climate change mitigation, with a 20% RPS for 2020, a 20% mandated increase in energy efficiency, and 20% reduction in greenhouse gas emissions (which may increase to 30%). Additionally, the E.U.'s "Energy and Climate Roadmap 2050," adopted by the European Commission in December 2011, legislated the E.U. to reduce greenhouse gas emissions by 80-95% by 2050. Meanwhile, several feed-in tariff programs in E.U. member states have generated many gigawatts in rooftop solar PV installations. As part of its climate legislation, the E.U. has an emission trading scheme which covers the power, industrial, and aviation sectors. Buildings are not covered, and therefore currently lack a carbon price signal to pursue microgrids.

The U.S. lacks a federal clean energy mandate and climate legislation, although there is notable regional climate change legislation in place, such as California's AB-32 legislation and the Regional Greenhouse Gas Initiative power sector program in the northeast, as well as more than 30 state-level RPS's. The

Obama administration has a notional goal that 80% of electricity will be produced from clean sources (including natural gas, nuclear, and carbon capture and sequestration in addition to renewable energy) by 2035, but this has yet to be legislated. Of the 30 state-level RPS's, only a handful have specific goals for distributed generation.

In Asia, Japan's Basic Energy Plan, which was revised in June 2010, called for an RPS of 20%, and nuclear power increasing up to 50%. This plan is now in question because of the earthquake and Fukushima meltdown. China has legislated a goal of achieving 15% of primary energy consumption from non-fossil fuel energy sources (nuclear, hydro, and renewables) by 2020. The country's NEA has announced plans for 100 "New Energy City" pilots and 30 microgrid pilot projects.

2.3 Macrogrid limits

At the same time as strong drivers and innovative technology are enabling more dispersed control of electricity delivery, the conventional centralized power delivery system (macrogrid) paradigm is showing its limitations. Expanding supply to meet expected growing demand represents a major financial drag, especially for emerging economies facing the huge upfront investment costs. Additionally, it is increasingly a priority (or mandate) for utilities to increase clean energy supply while fostering competitive wholesale electricity markets and maintaining or improving on PQR enjoyed today. These contradictions have led some to question the traditional paradigm. One challenge to the macrogrid is that clean energy generation, at least in the case of wind and solar, is variable and relatively unpredictable compared to traditional fossil fuel based generation. Another problem is that much of it is expected to come from relatively small installations, e.g. residential rooftop solar PV systems, and some may even be mobile, e.g. plug-in electric vehicles (PEV). Controlling numerous, possibly millions, of new small supply sources has led analysts to consider alternatives, such as microgrids, that could manage these smaller scale and problematic assets locally. In other words, if small sources can be aggregated by microgrids, the legacy macrogrid could continue to be managed centrally and organize similar numbers and sizes of participants as are successfully handled today.

While some modern central station technologies can achieve excellent efficiencies as measured by historic standards, the overall systemic efficiency of generation delivers barely a third of the initial fossil energy to ultimate devices. This is mostly due to heat to electricity conversion losses in power generation with additional, smaller losses of 5-10% occurring during T&D. One partial solution to this problem is smaller-scale generation closer to loads, which increases the potential for CHP improving overall efficiency significantly. While the power generation efficiency of CHP may not be as high as at a large-scale power plant, the ability to use waste heat directly results in a systemic efficiency. In many warm climates, using the waste heat to cool buildings can be particularly attractive because doing so further reduces expensive on-peak electricity use and downsizes needed generating capacity.

Customer desire and government objectives to reduce energy costs and increase energy efficiency may be the most powerful drivers of microgrids. With the declining costs of clean energy and energy storage and attractive propositions of on-site efficiency and CHP, a growing amount of customers have an economic interest in producing their own power and purchasing less from the macrogrid. Moreover, many customer sites have reliability in mind, whether from the perspective of cost, energy security, or infrastructure interdependency. In fact, sites with exceptionally high PQR requirements are likely early microgrid adopters.

Infrastructure interdependency has become a growing concern for governments, utilities, and customers alike, since our current power delivery system is highly vulnerable to both natural and malicious threats. The consequences of blackouts are serious in large measure because so many other critical infrastructures, such as communications, transportation, water treatment, etc., depend upon it. To some extent, independent and local power generation for key customer functions can reduce the severity of this problem.

Reliability is costly even though customers do not see it as a line in their electricity bills. Maintaining high levels of reliability incurs two significant types of costs. First, equipment investments to improve PQR, such as underground versus overhead lines, impose direct costs on utility operations. Second, the paramount concern with maintaining high PQR leads to conservative grid operations, for example, potentially economic exchanges of energy are foregone because approved transmission capacities are limited by reliability concerns. It may be that sustaining high PQR across the board no longer makes economic sense. If we are now able to provide PQR locally and more closely matched to the requirements of the customers, then the standards of the centralized grid can be rethought. In other words, the levels of PQR currently thought necessary in the macrogrid might be relaxed. While hard to quantify, the most benefit from microgrids may derive from this lowering of macrogrid costs.

Some have suggested that electricity delivery should move from its current highly hierarchical centralized paradigm to one that is more dispersed. One way to imagine an alternative is moving the control from the center to the periphery. Systems that have their sensitive capabilities out on the edge tend to be more robust, e.g. the internet’s intelligence is in the laptops and data centers that it interconnects, rather than in the routers and other devices that move the packets around. Microgrids are one manifestation of a more dispersed grid control paradigm with peripheral intelligence. Some analysts consider this one of three legs of the smart grid. The first is better operation of the tradition meshed high voltage grid, e.g. through operator visualization technology; the second is improved supply-demand interaction, e.g. through advanced metering infrastructure; and the third is decentralized control.

3. Microgrid programs to date – International review

This section summarizes: the policies driving renewable energy, distributed energy and microgrids; the main microgrid research programs implemented to date; the agencies involved; and the key projects in each of the regions, Asia, EU, and the Americas. Table 3 summarizes this information. While this section will provide a summary, more detailed country reviews can be found in Appendix A.

In general, the EU was the earliest developer of microgrid research programs, followed by NEDO's program in Japan, and the RDSI and SPIDERS programs in the U.S. Most recently, countries in Asia (China, South Korea, and Singapore) have a growing interest in microgrids. Japan may also have renewed interest given its difficulties with nuclear power. A timeline of these developments is provided in Figure 9. While there has been significant progress in microgrid technology and interconnection standards, microgrid policy support remains somewhat insufficient for widespread microgrid deployment outside of specific government sponsored programs.

3.1 Europe

The E.U. was the earliest leader in microgrid development, with comprehensive R&D efforts dating back to 1998. Under the 5th, 6th, and 7th Framework Programs (FP), comprehensive research and demonstrations have been carried out in the area of microgrids. The FP 5 had a theme of large-scale integration of micro-generation onto low voltage grids while FP 6, also known as "More Microgrids," focused on microgrid control and operations. These programs have launched many microgrid projects over the years, most notably the Kythnos Island Microgrid, the National Technical University of Athens Power Systems Laboratory, the MVV utility microgrids in Stuttensee and Mannheim Wallstad, the Bornholm Island Multi Microgrid, and the Eigg Island remote system. For more information on the E.U.'s efforts in the area of microgrids, see Appendix A.

Region	Country	Renewable energy/ microgrid policies	Other policies, drivers, and interests	Agencies involved	Demonstrations and research facilities
Asia	Japan	RPS (2002), feed in tariff (2012) Interconnection guidelines (1995); electric law amendments allowing IPPs and partial liberalization (1995, 1999, 2003); New Energy Basic Plan (2010)	Highly dependent on fossil fuel imports, partially liberalized electricity market, nuclear phase out (Fukushima), 25% reduction in greenhouse gas emissions by 2020	NEDO; METI	Hachinohe, Sendai, Aichi, Kyotango, Yokohama (Tokyo Gas), Tokyo (Shimizu) lab/demonstration, Aperture Project (U.S.)
	China	15% non-fossil target (2009) Renewable energy law (2006) 100 New Energy cities, 30 microgrid pilots (2011) Draft management methods for distributed energy (2011)	50 GW CHP target, natural gas targets, feed in tariffs for renewable energy, 40-45% carbon intensity reduction target for 2020 (below 2005 levels)	NEA; Chinese Academy of Sciences: Inst. of Electrical Engineering	Hangzhou Dianzi Univ., Hefei Univ. of Technology, Xiamen Univ.
	South Korea	RPS – 2% by 2012, 4% by 2015, 10% by 2022	Focus on smart grid, Green Growth law, 30% below BAU greenhouse gas target for 2020	KERI	KERI microgrid; Jeju Island Smart Grid test bed
	Singapore	Singapore Initiative in New Energy Technology (SINERGY) (2007)	Nearly entirely dependent on fossil fuel imports, 16% below BAU greenhouse gas target for 2020	Energy Market Authority, A*STAR Inst. of Chemical and Engineering Sciences	Pulau Ubin, Experimental Power Grid Center (EPGC) Laboratory
Europe	E.U.	20% renewable energy by 2020; Framework plans 5 (large scale integration of micro-generation), 6 (More Microgrids), and 7 (smart grid), EU Emissions Trading Scheme	20% reduction in greenhouse gas emissions by 2020, feed in tariff programs in Spain, Germany, Italy, etc., unbundling of distribution system operators	European Commission, Director General for Energy and Transport	Kythnos, National Tech. Univ. of Athens, Mannheim Wallstadt, Bornholm Island, Eigg Island, Fraunhofer Inst.
Americas	U.S.	30 states with RPS, 44 states with interconnection policy, 44 states with a net metering policy	Development of CERTS technology, DER-CAM and µGrid software, IEEE 1547 standard development, proposed 80% clean energy goal by 2035, 17% reduction in greenhouse gas emissions by 2020	DOE, CEC, DOD, NREL	SPIDERS (Hickham AFB, Fort Carson, Camp Smith); RDSI grants (Santa Rita Jail, Borrego Springs, Univ of Hawaii, Univ of Nevada Las Vegas, ATK Space Systems, City of Fort

					Collins, Illinois Institute of Tech, Allegheny Power, ConEd NY); UCSD); CERTS (Univ of Wisconsin, AEP)
	Canada	Green Energy and Green Economy Act of Ontario, Ontario feed in tariff, British Columbia clean energy act (2010), Renewable Energy Standard Offer Program (2006)	Western Climate Initiative, 17% reduction in greenhouse gas emissions by 2020; notional clean energy standard – 90% from hydro, nuclear, wind, solar, or CCS by 2020	Natural Resources Canada, NSERC Smart Microgrid Network	Hartley Bay, BCIT microgrid, Boston Bar
	Chile	RPS of 20% by 2020	Strong renewable resources (solar, geothermal, wind), 20% below BAU greenhouse gas target for 2020		Huatacondo

Table 3: International review of policy drivers and microgrid projects

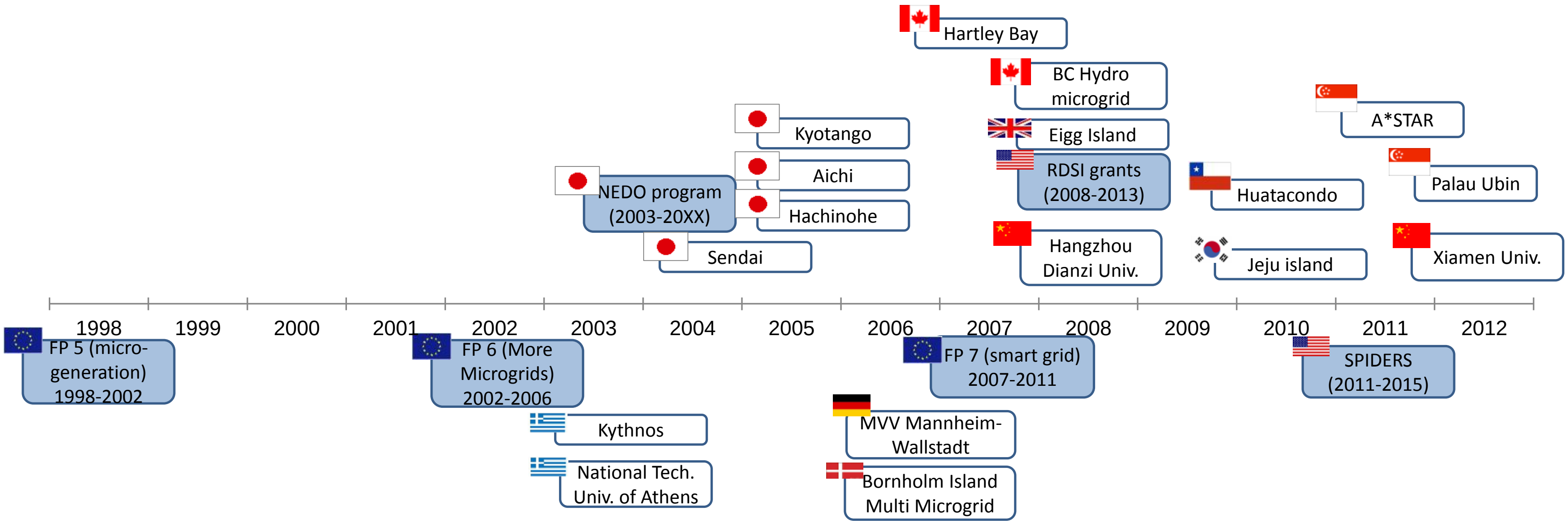

Figure 9: Timeline of microgrid programs (blue) and select projects (white) to date

While the E.U. has strong support for renewable energy (RPS in the EU and feed-in tariff programs in many member states), there is not a strong enough policy signal for widespread deployment of microgrids. For instance, the E.U. has a very strong long-term climate and energy package with an ambitious greenhouse gas target of 80% off 1990 levels by 2020. Yet, the E.U. Emissions Trading Scheme covers utilities but not buildings, so there is not yet a strong price signal for building owners to consider carbon abatement options such as microgrids.

3.2 Asia

Japan was an early leader in microgrid research, with the New Energy and Industrial Technology Development Organization (NEDO) funding a number of successful demonstration projects starting in 2003. An increasing number of private sector entities are getting engaged in microgrid development, as the recent earthquake has caused a resurgence of interest in distributed and renewable energy amidst the downturn of nuclear power. Additionally, one microgrid demonstration project in Sendai successfully operated as an island for two days, providing power and heat to a local hospital and other campus buildings. Japanese companies such as Shimizu and NT Facilities are also actively seeking microgrid project development opportunities abroad as well, such as in the U.S. and China. Given Japan's dependence on fossil fuel imports and its ambitious clean energy and climate targets, microgrids should prove to be an increasingly promising energy option.

In addition to Japan, other Asian countries have been developing microgrid demonstration programs in recent years, such as China, South Korea, and Singapore. Since 2008, a handful of microgrid demonstration projects have been developed in China, mostly at universities around the country. Now, China's NEA is planning a larger scale role for microgrids as it plans its 100 New Energy Cities, of which 30 are set to be powered by microgrids. China has an overall non-fossil energy target of 15% by 2020, as well as CHP target of 50 GW. It is looking at natural gas to provide more opportunities for distributed generation and integration of renewable energy, having recently drafted Management Methods for Distributed Energy. As of yet, however, no single agency has jurisdiction over distributed energy policy.

Singapore and South Korea each have one microgrid demonstration project under development, with South Korea showing particular interest in developing more smart grid or microgrid demonstrations similar to its Jeju Island smart grid test bed. Additionally, Singapore's official launch in late 2011 of its Experimental Power Grid Center (EPGC) at the A*STAR Institute of Chemical and Engineering Sciences signals increasing interest and research capability in Asia in the area of microgrids. More information on Japan, China, Singapore, and South Korea can be found in the country reviews in Appendix A.

3.3 Americas

In recent years, the U.S. has become a leader in microgrid demonstration and technology development, under two flagship microgrid grant programs run by the DOD (SPIDERS) and DOE (RDSI grants). DOD is running a $38.5 million grant program for three different military base microgrid demonstrations, with reliability and energy security as its main goals. DOE gave out over $50 million in grants to nine projects (over $100 million with participant cost share) that all have to demonstrate a 15% peak load reduction in the local distribution feeder (or substation) using DR and DER.

Additionally, other efforts in standards (IEEE 1547), technology (CERTS), and software (DER-CAM) have filled in certain developmental gaps in the microgrid sector. Various U.S. stakeholders were instrumental in driving the authoring and publication of standards for interconnection of DER to the grid as well as islanding standards for microgrids. CERTS microgrid control technology has enabled spotlight projects at the Santa Rita Jail, the Sacramento Municipal Utility District headquarters, and Maxwell Air Force Base. Finally, the Distributed Energy Resources Customer Adoption Model (DER-CAM) developed by Lawrence Berkeley National Laboratory (LBNL) has been instrumental in helping various microgrid projects to optimize the operation of demand and supply side energy technologies for maximum cost and CO2 reduction.

In the absence of a federal clean energy policy, the majority of states in the U.S. have been pursuing clean energy legislation, with some positive developments for microgrids as well. Net metering laws and interconnection standards exist in 44 states, and RPS's exist in 30 states. A handful of states have specific carve-outs for distributed energy including Illinois, New Mexico, and Arizona. Lastly, California's cap and trade program may provide a promising environment for more development of CHP, distributed generation, and microgrids.

Other geographies throughout the Americas also have developments in the microgrid sector. Canada and Chile both have microgrid projects serving remote communities, increasingly reliability and lowering dependence on costly fossil fuel imports by barge or truck. Canada also has an R&D program called the NSERC Smart Microgrid Network, with a total funding of $4.6 million over five years and a flagship project at the British Columbia Institute of Technology. In 2009 Canada already produced 77% of its electricity from carbon-free sources, largely hydro, nuclear, biomass, and wind, and has a notional goal of increasing that proportion to 90% by 2020. More information on microgrid development in the U.S., Canada, and Chile can be found in Appendix A.

4. Overview of Microgrid Technology Development and Status

This section will provide an overview of the most common microgrid technologies used, typical microgrid applications and sites, and the most notable technological progress in recent years as well as further improvements needed.

4.1 Common microgrid technologies and applications

The suite of technologies chosen in a microgrid depends on its energy services requirements. The most common customer applications for microgrids to date have been groups of commercial buildings, such as school campuses, hotels, shopping malls, office buildings, hospitals, and government buildings. Military applications are becoming increasingly common, while few industrial applications have been seen to date. Finally, small residential communities that are either remote or on an island have also been the site for many projects incorporating microgrid technology. Different applications will have very different energy demand profiles; the needs of a hotel or school will be quite different from a military base or hospital. The most common demands for electricity include: lighting, office equipment, refrigeration, and cooling by electricity powered compression. Besides electricity demands, there are space heating, cooling, and hot water demands which can be met with a combination of thermal fuels such as waste heat, solar heat, and natural gas-fired equipment.

In commercial buildings in the U.S., space and water heating, air-conditioning, and refrigeration account for 58% of energy consumption on average, while lighting and office equipment account for another 24% on average. Given this breakdown, microgrids can function most efficiently when taking into account all opportunities for savings in heating and cooling, particularly in the use of any waste heat generated from on-site power generation. While clean energy technologies such as solar PV and wind are seen as the leaders of the clean energy revolution, CHP by fuel cells, reciprocating engine gensets, or microturbines with heat exchangers can often realize much impressive energy savings and CO2 emissions reductions.

Technology category	Examples
Supply technologies – Dispatchable	CHP, fuel cells, microturbines or gas turbines, reciprocating engine gensets, macrogrid energy purchases
Supply technologies – Intermittent/limited	Wind, solar (PV and thermal), biogas/biomass, hydropower, heat pumps (air/ground)
Demand side technologies	Absorption chillers, absorption refrigeration, natural gas chillers and boilers, lighting and office equipment, other HVAC equipment
Storage technologies	Batteries, thermal (hot and cool), flywheels, super-capacitors, precooling/ preheating
Control technologies	DR, load control, islanding switches, smart meter, CERTS

Table 4: Overview of supply, demand, storage, and control technologies available for microgrids

Table 4 outlines the supply, demand, storage, and control technologies most commonly seen in microgrid applications. Supply technologies should be broken out into those that are either dispatchable or nearly 100% reliable, assuming a constant fuel supply (since most run on natural gas or diesel), and those that are either intermittent (wind and solar) or limited in reliability (hydropower and biomass may vary seasonally for instance).

Within dispatchable supply technologies, CHP should be emphasized as being a very high efficiency option given that waste heat (normally lost at conventional power plants) can be used on site for heating, cooling, or refrigeration. Building CHP technology can typically reach energy conversion rates of 75% and potentially as high as 90%, while the capacity of CHP technology can range from as small as 1 kW to as large as 10 MW. Absorption technologies on the demand-side can be installed to utilize waste heat meeting cooling or refrigeration loads. While inefficient relative to standard electrical cooling, these technologies are becoming increasingly common, especially in warm or hot climate zones.

Microturbines are small high rotational speed turbines ranging from 20 kW to 500 kW that can run on many fossil fuels, such as natural gas, but also on low quality biogas. Microturbines have several advantages such as small size, light weight, and low maintenance costs. Nonetheless, they do release combustion product emissions, and high first cost in part because of their complex power electronics remains another drawback to their use.

Electricity storage is a common element in microgrids for reasons of load following, energy cost reduction, and PQR. Storage solutions include batteries, flywheels, and even more expensive super capacitors. Storage can: 1) help ensure power balance despite fluctuations in demand and supply; 2) can be used for tariff arbitrage by purchasing electricity when it is cheapest and storing it for use during expensive periods; 3) electricity stored up in batteries or flywheels can be used to ease the transition between grid-connected and islanding modes and can likewise mitigate other transients. Thermal storage is also becomingly increasingly common for reasons of energy cost reduction and installed generating capacity reduction. For example, electricity is purchased during off-peak hours at night to produce ice that can then be used to cool the building during the following day's peak period. Thermal storage that lowers peak electrical load in this way is particularly valuable because it displaces expensive electricity and the related generating capacity, whether in the microgrid or the macrogrid.

Lastly, there are control technologies which ensure the reliable and cost effective operation of the microgrid and smooth interaction between the microgrid's supply, demand, and storage components. These control technologies include DR, generator and load management, Supervisory Control and Data Acquisition (SCADA), smart meters, and switching required for microgrids to successfully island without unacceptable disturbance to loads or generators.

4.2 Technological progress in microgrids

Two key indicators of the technological progress for microgrids are cost and control. Cost reduction and increased economic viability will lead to an increased number of microgrid applications and installations. Improved control function will ensure that microgrids can deliver the benefits they are seeking to offer, such as decreased energy costs, increased reliability, and increased penetration of renewable energy. Beyond decreased cost and increased control function, there is still room for new technological innovations. Table 5 summarizes where key technological achievements have been made in recent years and where further improvement is needed.

	Achievements	**Needs**
Reduced cost	Solar PV, wind, power electronics	Electrical storage (batteries, PEVs), solid

		state switching, heat pumps, controls
Increased control	CERTS, heterogeneous PQR (DC/AC)	Load control/DR, PEV interaction, system design and integration tools

Table 5: Achievements and needs in microgrids across cost, control, and innovation

Cost reductions

According to Bloomberg New Energy Finance, the cost of crystalline silicon solar modules has fallen by 24% on average for every doubling in installed capacity, while the cost of thin films modules has fallen by 12% for every doubling (Figure 10). This has brought thin film modules below the $1/W price mark and more efficient crystalline silicon modules very close to that mark.

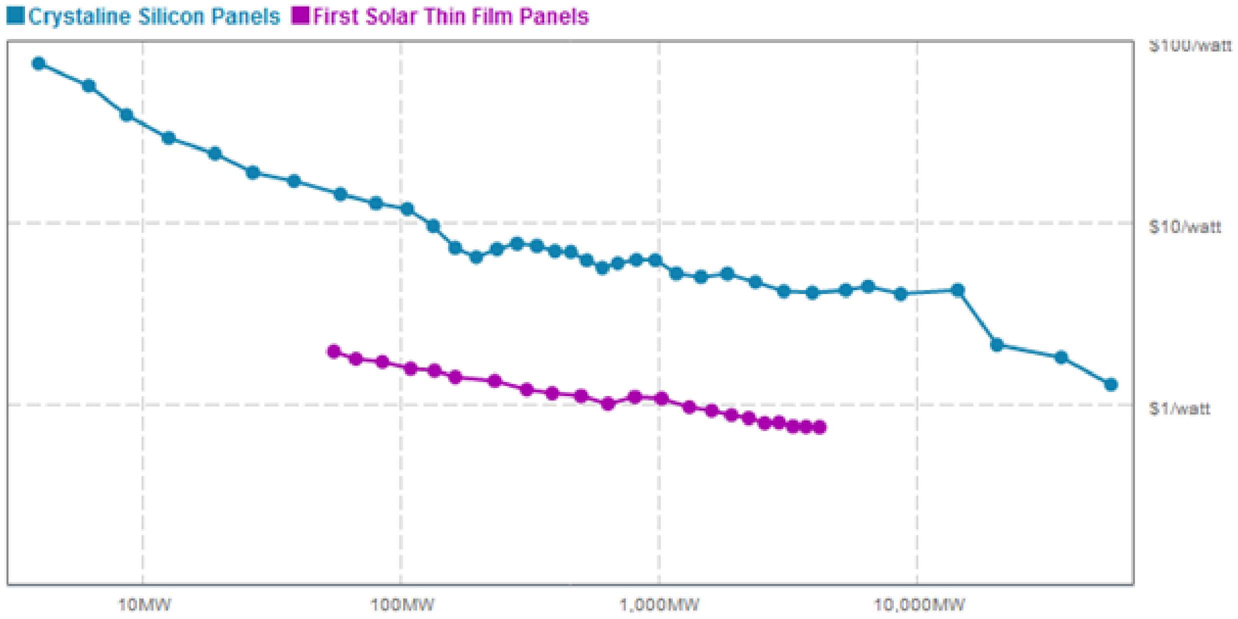

Figure 10: Cost reductions vs. installed capacity in solar PV modules; Source: Bloomberg New Energy Finance

The levelized cost of wind energy (LCOE) has also fallen steadily over time. A recent LBNL study found that the wind LCOE for US wind projects will fall by 24-39% to $33-65 per megawatt hour over the next year or two from their previous low in 2002. Of course, most commercial buildings do not have room to put up large wind generators, so the use of large scale wind generators will be limited to remote or island residential communities or military bases that have adequate land. Smaller commercial building sites have installed small wind generators, but the reliability of these generators still needs to increase.

Further cost reductions and increased lifetime and cycles in battery technologies are needed before widespread applications can occur. Another Bloomberg New Energy Finance study noted that grid-scale lithium-ion battery projects today cost more than $1,000/kWh, but given manufacturing oversupply in the short term, costs are expected to drop over the next three years to $600/kWh by 2015. Batteries in electric vehicle may also be opportunities for microgrids in the future, and as sales pickup further price drops are expected there as well. Current costs stand around $800-1000/kWh and battery costs are expected to hit $350/kWh by 2020, according to Bloomberg's study. While Li-ion batteries are the expected battery of choice for electric vehicles, many other storage options are used at the building and grid level, including lead-acid, nickel-cadmium, sodium-sulfur, sodium-nickel-chloride, vanadium redox, and zinc-bromine batteries; double layered capacitors and super-capacitors; and flywheels. The associated costs of these options are outlined below in Table 6.

Energy storage option	$/kWh	$/kW
Lead acid	50-400	175-600
Nickel-cadmium	400-2400	175-1500
Lithium ion	500-2500	175-4000
Sodium sulfur	250-500	150-3000
Sodium-nickel-chloride	100-800	150-300
Vanadium redox	150-1000	175-5000
Zinc bromide	500-1000	175-2500
Super-capacitors	300-20000	100-350
Flywheel	300-5000	250-350

Table 6: Cost of energy storage options, Source: IEA 2011

Certain parts of the microgrid control technology could also benefit from further cost reductions. The Santa Rita green jail project reported having paid $800,000 for its one islanding switch, which disconnects the microgrid during a grid disturbance within milliseconds. This is certainly an incredibly high cost for one piece of equipment, although it is critical for a high PQR microgrid's successful operation and safety. Switch costs are lower, however, depending on the time of response and disconnection; relays that would island the microgrid within a few seconds as opposed to milliseconds would be significantly less costly and be perfectly adequate for many applications.

Increased control

Microgrids need to be able perform the following key control functions in order to maintain successful and safe operations:

- Present itself to the grid as a single self-controlled entity
- Avoid power flow patterns exceeding line ratings
- Regulate the voltage and frequency within acceptable bounds during islanding
- Dispatch resources to maintain energy balance
- Island smoothly and safely reconnect and resynchronize to the macrogrid

These functional requirements can be achieved using many technologies at various levels of technical sophistication. High PQR microgrids might use costly solid state switches, high granulation data acquisition, and complex control schemes. The attraction of microgrids however rests in part on their ability to match service quality to the requirements of the loads. Consequently, various microgrids will apply different technologies as is appropriate to the microgrid's objectives.

5. Economic and institutional barriers in microgrid development

Effective incentives to stimulate deployment of microgrids are not readily apparent. Identifying, quantifying, and capturing the benefits of microgrids, and likewise establishing efficient markets for their services will require new initiatives and pose some significant policy challenges. The policy and regulatory environment will have a profound effect on the adoption of microgrids, their composition, and their likelihood of success and sustained operation.

From an interconnection standpoint, it is important to describe the technical, regulatory, and economic barriers that microgrids commonly face, and identify possible solutions. A policy environment supportive to microgrids that minimizes such barriers will require that the following questions have a "yes" answer.

- **Do policies or codes allow independent power producers (IPPs), such as microgrids?** In Europe, the U.S., and Japan, a series of electricity market liberalization measures has supported the development of distributed energy and microgrids, including the unbundling of generation, transmission, and distribution services as well as provisions for IPPs to compete in wholesale electricity markets and potentially retail markets as well.
- **Does local distribution grid utility/operator allow DER to interconnect to the macrogrid (in both grid parallel and islanding modes)?** In developed countries, various interconnection regulations have been enacted to encourage the penetration of renewables and distributed generations. Although these regulations exist, vested interest groups (including utilities) will still resist the wide deployment of distributed generation to meet renewable energy targets, instead favoring utility-scale renewable energy generation.
- **Are there incentives for microgrids to decrease demand or sell excess power into the macrogrid, particularly during peak periods (time of use pricing, net metering, feed-in tariffs, etc.)?** Time of use pricing and net metering policies can allow microgrids to save on energy costs or potentially earn a profit by scheduling their loads and generation resources. Especially during peak periods, these services can be potentially valuable to the local utility.

These are the basic requirements for a policy environment that is supportive of, or at the very least not hostile to, microgrid development. The barriers for large scale microgrid deployment can be broken down into two categories: economic and institutional. This section will go in to more detail on these barriers.

Economic barriers refer to the benefits that microgrids are creating and costs that microgrids may be imposing on utility distribution systems. The essential question is whether these benefits and costs can be properly priced such as to incentivize microgrid development that is beneficial to the customer, the utility, and society as a whole. Note that analyzing these benefits and costs will also require contextual considerations such as geographic location of the microgrid on the macrogrid, local gas and electricity rates, local policies, and regional macrogrid power supply mix.

Institutional barriers refer to those barriers introduced by new practices that may be unfamiliar to various stakeholders, based on current practice in the energy industry. These include interconnection, utility, building, environmental, and safety codes that may need to be modified or simply paid attention to when developing a microgrid project.

5.1 Economic barriers

Benefits that microgrids offer

The benefits that microgrids offer to the customer, utility, and society at large can be broken down into the following categories: economic, PQR, environmental, energy security, and safety. Table 7 provides an overview of some of the main benefits that microgrids can offer and from which stakeholders can benefit. The economic benefits include those that are direct, where the customer or utility may realize direct savings or payments, and those that are indirect, where benefits may be benefiting the utility's bottom line either indirectly or gradually over time.

Benefit class	Specific benefit	Customer	Utility	Society
Economic (direct)	Reduced electricity and fuel costs	X		
Economic (direct)	Sale of excess power to grid	X	X	
Economic (direct)	Participation in DR markets	X	X	
Economic (indirect)	Reduced system congestion costs		X	X
Economic (indirect)	Reduced T&D losses		X	X
Economic (indirect)	Reduced operating reserves		X	
Power reliability	Reduced power outages on-site	X		
Power reliability	Potential for black-start capabilities		X	X
Power quality	Potential for reactive power/voltage control	X	X	
Environmental	Increased use of renewable energy	X	X	X
Environmental	Reduced SO2, NOx, CO2 emissions			X
Security and safety	Avoided major system outages	X	X	X

Table 7: Microgrid value distribution, adapted from NYSERDA 2010

The direct economic benefits are perhaps the easiest to understand and generally fall into three categories: reduced electricity and fuel costs, sale of excess power to the grid, and participation in AS and DR markets. If a microgrid is able to produce its own power, heating, and cooling services, it will obviously be able to reduce its electricity and fuel costs, ideally in a manner that makes its investment in distributed generation a cost-effective one. If there is time of use pricing, then there could be additional energy savings or cost arbitrage opportunities.

There may be instances as well where the microgrid's generation is exceeding its loads and the microgrid can sell excess power to the grid. Particularly during peak demand periods, this service could be valuable to the local utility. There is a question of whether the microgrid will be paid for the power it exports to the macrogrid, and if it is paid, then what rate it is paid at: wholesale, retail, or potentially a feed-in tariff (for any renewable, distributed, or other incentivized generation). Finally, the microgrid may be able to participate in AS and DR markets, which are usually structured around interruptible service, but can also involve direct response to grid instructions. Under California's default large customer critical peak pricing tariff, they effectively agree to have high costs imposed for an agreed number of times and durations in exchange for lower prices at other times. Other forms of DR programs typically involve a capacity payment given in exchange for called load reductions. Direct participation in grid AS markets is also possible. For example, California's regulation market requires a 4-second response to direct instructions to adjust output. There must be some form of payment, however, otherwise the microgrid customer will not be interested in performing this service.

Indirect economic benefits have largely to do with the larger periodic investments that utilities need to make in T&D systems. Theoretically, microgrids in producing the majority or a significant portion of their own energy are reducing T&D system congestion as well as T&D losses. As more and more microgrids are deployed, this would eventually lead to less money spent on maintenance and upgrades in the T&D system as well as reduced need for peak generators or operating reserves. All of these indirect economic benefits are characterized by the fact that microgrids are a form of distributed energy production and local control as opposed to centralized energy production and long distance transmission.

Microgrids can have a positive impact on PQR, partially through the provision of AS. Reliability is a primary concern for many microgrid sites and the ability to produce reliable power on-site and avoid power outages caused by macrogrid disruptions is highly valued by certain customers such as military bases and hospitals. Microgrids may be able to provide services to the distribution grid such as reactive power and voltage control, which could have a positive impact on power quality. Finally, black-start capabilities could be offered by microgrids when the macrogrid faces widespread power outages and needs some small amount of power to get large centralized power plants up and running again. Since the microgrid's generation capacity is relatively small, it will most certainly have to be located close to the power plants that need to be started up again.

Where microgrids can lead to increased amounts of energy efficiency, CHP, and renewable energy, there will be associated emissions reductions for carbon dioxide as well as criteria pollutants such as sulfur dioxide and nitrogen oxides. Attention should be paid to any local power production that is fossil fuel based, however, ensuring that it has the proper pollution controls. Microgrids should enable greater use of renewable energy in a number of fashions. Not only is this an environmental benefit, but it could enable an economic benefit via more cost-effective handling of intermittent renewables and compliance with clean energy related mandates. By reducing load on the grid, utilities will have an easier time meeting targets in RPS's, since the requirements for renewables purchasing are a function of total power supplied. Potentially, excess wind generation that a utility's transmission or distribution grid is not able to handle could be absorbed by microgrid storage or loads.

Finally, there is the benefit of overall energy security and safety of the macrogrid. If microgrids can help to ensure power reliability locally, this will aid the macrogrid in ensuring the overall reliability of the grid and reduce the number of macrogrid power outages.

Costs that microgrids impose

A number of studies to date have evaluated the barriers that microgrids face, and the most commonly cited barriers are related to extra costs that utilities impose on microgrids. The costs imposed are either related to a microgrid's impact on the utility's reliability or its revenues. Often, utilities charge stand-by rates for DER and microgrids, contending that either the microgrid will impact the macrogrid's overall reliability or the microgrid will not always be able to produce the generation they plan to, due to system maintenance or failures; therefore, the utility will need to provide extra stand-by generation. Another common occurrence is that utilities adjust a customer's rates or impose high exit or interconnection fees if they install microgrid or other distributed generation capabilities, citing the fact that the utility will lose revenue from this customer, i.e. sunk cost assets will be "stranded."

The impact of any single microgrid of up to a few megawatts in capacity on T&D system stability and reliability or utility revenue streams is very minimal. The penalties that single microgrid installations face allow a fair amount of discretion and are likely being imposed in a manner that truly overestimates the costs imposed by microgrids and their impact on the larger system. It could also be argued that effective planning of microgrids and their interconnection could maximize their contribution to the overall power grid performance, just as unchecked penetration of distributed generation and microgrids at weak grid points could create more costs than benefits (although microgrids are usually designed to satisfy their local loads and not export a large portion of energy).

A new utility model?

It is more likely the case that the utilities are worried about the case were microgrids proliferate on the system, and are therefore inclined to discourage their deployment from the beginning. If a utility's existing capital costs are spread over a declining base of customers, this can also raise significant equity issues for the remaining customers who might see their rates rise. Any large financial losses might be borne by the utility shareholders or customers, depending on the regulatory status and legal form of the utility.

Indeed, widespread deployment of microgrids does require consideration of revenue erosion and stranded assets for traditional utilities. Others might argue that market forces and technological developments are already at work to deconstruct the traditional business model, such as energy efficiency, DR, distributed generation, and smart grid. It just so happens that a well-designed microgrid will take advantage of many of these market forces and technological developments. In the end, deregulation that allows market forces and competition will create new utility models. The transition from current models to those new ones and the infrastructural, social, and economic problems that transition creates are the primary questions that need to be addressed. Some forward looking utilities have started exploring new strategies, such as services that would target electric vehicles or provided differentiated energy services to customers, such as varying levels of PQR.

Ironically, and as discussed above, microgrids may provide at least a partial solution for utilities trying to develop new revenue streams that offset losses to their traditional base by providing a portfolio of services and products that utilities can offer customers. These may include providing services targeting electric vehicles, products monetizing various environmental attributes, or utility owned or directed microgrids that provide differentiated energy services to customers, i.e., varying levels of PQR. Many forward-looking utilities have already begun exploring strategies to pursue these emerging market opportunities as new sources of revenue. The structural and technical similarities of microgrids to today's electricity grid may provide utilities with a significant competitive advantage in developing and deploying microgrids. Still, moving toward a distributed services business model will require a significant shift in the thinking at most utilities, where the paradigm of the centralized grid has become entrenched over the past one-hundred years.

5.2 Institutional barriers

Interconnection codes

Low and medium voltage lines and distribution grids were designed under the centralized paradigm where customer loads are passive and power flows only from distribution substations to the customer and not in the opposite direction. Microgrids operate differently from this paradigm, and that is why microgrids (and DER at large) require special interconnection codes. The costs of microgrid deployment can be significantly influenced by the details of these codes and especially by any delays in application processing, so their establishment has to be based on an open standards setting process, and their enforcement has to be evenhanded. In the U.S. considerable effort has ultimately led to passage of standards that are accepted by most states (IEEE 1547). California had already adopted its own rule, which was later changed to comply with IEEE 1547. One of the areas of particular sensitivity concerns the effect of connecting generation on the local distribution network and its customers. The costs of conducting analyses of these effects alone can be significant, and utilities often contend that investments to mitigate any impacts can be substantial (although in practice, they often are not). California rules specify time limits on processing of documents and conducting of analysis. The ground rules under which these studies are done and how any consequent remediation measures are paid for requires particular clarity. Also note that the effects of any one interconnect are not isolated from others. The sequence in which access to the network is granted to exporters carries consequences, so the process needs to not only be fast but also transparent and fair to interconnection applicants.

As for the technical procedures for connecting DER to the grid, special codes are needed to ensure safety and reliability of the grid. The Institute of Electrical and Electronics Engineers (IEEE) has developed a specific standard, IEEE1547: Interconnecting Distributed Resources with Electric Power Systems, which has very important implications for DER and microgrids. While IEEE 1547 for distributed resources at large was first established as a standard in 2003, a specific standard for microgrids was not set until June 2011. It is called IEEE 1547.4: Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems. Now, there are standards for systems operating in both grid parallel and islanding modes.

The EU has also developed extensive codes on interconnection of DER, although some minor revisions and adjustments are still needed to accommodate the full deployment of microgrids, such as with codes for intentional islanding. Japan revised its interconnection standards under the 1995 Electric Utility Industry Law amendment, which permitted owners with DER to sell excess power to the utilities and required the utilities to provide standby electricity for them. Japan also established technical standards for proper interconnection equipment to ensure safety and PQR in the local distribution feeder, such as relays, switches for protection, and communication systems. But, it is unclear in these rules what the cost share for this equipment should be between the customer microgrid and the utility responsible for the local distribution feeder.

In the U.S., while interconnection standards outline the technical procedure for DER operating in parallel with the grid (usually referencing IEEE 1547), these standards do not establish the level or quality of power that the grid can expect from that resource. These power quality requirements are usually found in tariff documents of the area investor-owned utility (IOU) or regulatory agency. The fundamental requirement is that when a distributed energy resource is operating grid parallel, the PQ of that grid's local operating area should not be diminished. Interconnection standards describe the process by which a customer can connect an electricity generation unit to the grid, including the technical and contractual terms that system owners and utilities must abide by. Since most generation units are small in size, they are usually connecting at distribution voltages, in which case it is the region's public utilities commission which establishes the standard and procedure.

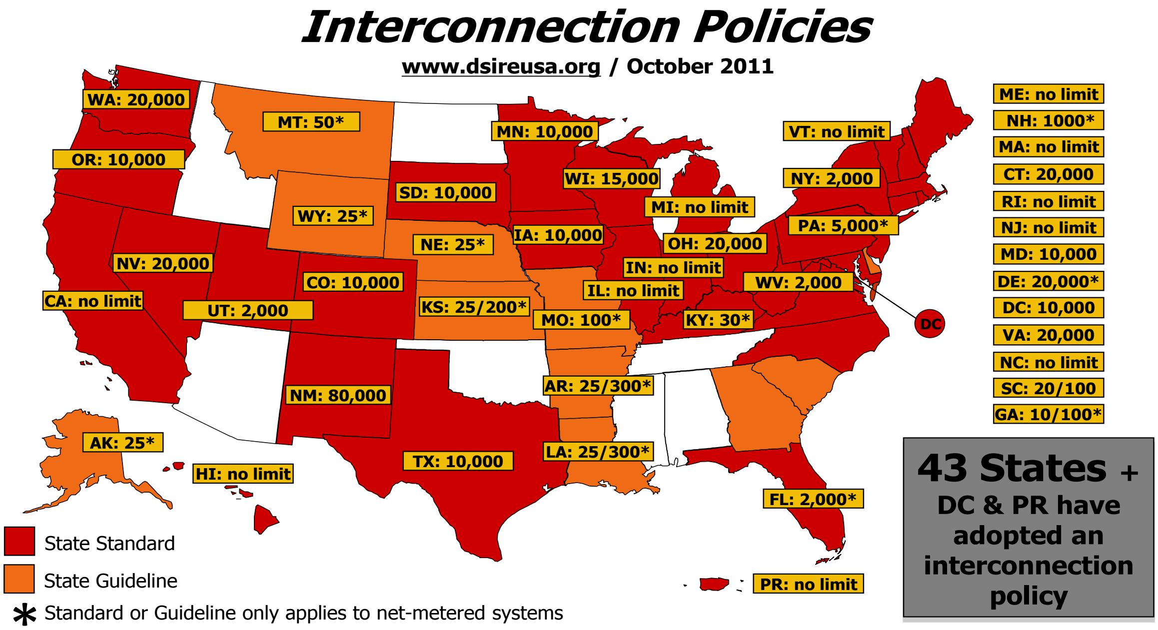

Figure 11: U.S. interconnection policies by state; Note: Numbers indicate system capacity limit in kW. Some state limits vary by customer type (e.g., residential/non-residential). "No limit" means that there is no stated maximum size for individual systems. Generally, state interconnection standards apply only to IOUs. Source: Database of State Incentives for Renewables and Efficiency

In the U.S., 43 states plus the District of Columbia and Puerto Rico have adopted interconnection policies as shown in Figure 11. Some states have set an upper limit of 10-80 MW for electricity generation units connecting to the grid, while other states have no upper limit. Some states have much more modest limits of 10-100 kW, which often only apply to net-metered systems. Still, many of these interconnection policies only apply to systems that operate in grid-parallel or under net-metering. Microgrids have the added functionality that they can run in an islanded mode. Since microgrids are still relatively uncommon, states do not yet generally have specific policies or standards for the interconnection of microgrids. In many cases, the local utility will treat the microgrid as a standalone distributed generation system and will follow those interconnection procedures.

Many states have standard application and review procedures for interconnection. New York, for instance, has a standard application procedure for distributed generation systems up to 2 MW in size. After filing an application to interconnect, the utility will develop a cost estimate for the "Coordinated Electric System Interconnection Review," consisting of a review of the impacts that the interconnection will have on the utility system and a review of the system's compliance with interconnection criteria, including: (1) Design Requirements; (2) Operating Requirements; (3) Dedicated Transformer; (4) Disconnect Switch; (5) Power Quality; (6) Power Factors; (7) Islanding; (8) Equipment Certification; (9) Verification Testing; and (10) Interconnection Inventory. The utility will estimate the costs and provide a statement of cost responsibility for the interconnection equipment, modification to utility system, administration, metering, and on-site verification testing. In a study done by the New York State Energy Research and Development Authority (NYSERDA) in which state regulatory officials were interviewed, it was found that most officials did not perceive the interconnection of microgrids to the distribution grid as posing any greater of a problem from a technical or regulatory perspective than the interconnection of distributed generation projects. Some interviewees noted, however, that the interconnection process would likely become more stringent as the generation capacity of the proposed microgrid increased.

Utility and legal codes

In some cases, microgrids might be considered public utilities. The rules under which microgrids become utilities and the rules under which they must operate need to be carefully examined. As with many aspects of microgrids, small such considerations can have major implications for economic and regulatory feasibility. In the experience of microgrids internationally to date, the most commonplace concerns for microgrid designs that may trigger legal implications are 1) whether the microgrid involves multiple PCCs with the macrogrid and 2) whether the microgrid crosses a public road for delivery of electricity or heat to a customer. Either of these cases might cause the microgrid owner to apply for regulatory permission as a utility as the design either involves use of and potential impact on the distribution grid or other public infrastructures. For the latter case, the easiest solution is to avoid delivery of electricity or heat across public right-of-way, if possible, although the Sendai project in Japan was able to avoid this problem courtesy of participation by the municipal government when such a design was needed for their planned microgrid to serve local government facilities. After the initial demonstration period, service across the public road was suspended.

For the former case, the easiest solution is to design all of the microgrid components (generation and loads) downstream of one PCC with the grid. Microgrids with a single PCC with the macrogrid will appear as a single customer unit from the perspective of the utility no matter how many buildings the microgrid is actually serving. Being downstream of a single PCC in this way is no guarantee of escaping regulatory oversight, but it will likely make deployment easier.

In the U.S., microgrids might have even greater regulatory ease if they are deemed a "qualifying facility" (QF), as defined by the Public Utilities Regulatory Policies Act (PURPA) of 1978. The requirements to become a QF (usually cogeneration or small power production facilities) include limitations on generating capacity, fuel-use criteria, and efficiency standards; the QF's must also not be majority-owned by a utility. Once classified as a QF, these facilities are entitled to receive special regulatory treatment, including the requirement that utilities sell or purchase electricity to and from QF's, although the rate at which utilities purchase electricity is usually determined by state authorities and terms vary widely.

In the U.S., local distribution utilities have legal obligations to provide electric service to any customer who requests it and is willing to pay for it on approved tariffs. Most customer-based microgrids would likely like to avoid having such obligations although applications for utility-owned microgrids are being introduced, which could involve microgrid islanding of an entire distribution feeder or a part of one. The San Diego Gas and Electric (SDG&E) Company's Borrego Springs microgrid project has received funding from the California Energy Commission (CEC) and the DOE totaling $15 million. Although SDG&E is already a legally operating utility, the project features both utility and customer-owned distributed generation and storage assets, and thus will likely present its own unique legal questions. As the project develops, these questions should begin to reveal themselves and offer important experience and lessons for the future development of utility-owned microgrids, as opposed to customer-owned microgrids.

Other codes (building, safety, environmental)

Besides interconnection and utility codes, microgrids will also have to consider building, safety, and environmental codes and regulations during design and implementation. When installing distributed generation involving fossil fuel combustion (such as CHP or microturbines), proper codes need to be consulted for such considerations as fuel storage and piping, fire safety, and environmental permitting. For example, microgrids that produce heat or power through combustion of fossil fuels, biomass, or other materials (such as municipal solid waste) will be subject to local and national laws governing air emissions, which often require specific permitting and operating procedures. Also, electrical systems that deliver power will need to comply with codes for electrical safety. In the U.S., these are governed by the National Electric Safety Code (NESC) and National Electric Code (NEC), where the NESC covers the safeguarding of personnel involved in installations, operations, and maintenance of electrical supply and communications lines and equipment at the utility level while the NEC addressed those installations and operations at the commercial, residential, and industrial level.

6. Policy and technical remedies

The above mentioned NYSERDA report states that some U.S. state regulatory officials expressed the opinion that microgrids should be unnecessary if the local distribution utility were effective at its job. That is, if the utility could provide high reliability, accommodate increasing amounts of distributed energy generation, and allow for DR functionality. Yet, with an increasing focus around the world on building a smart grid and investing more in distribution systems that can accommodate more renewables and distributed generation, utilities may be stretched to complete the task. Microgrids will likely play a pivotal role, and at least in the interim, they provide a valuable opportunity for utilities and governments to test many smart grid functionalities without costly and risky installations over a widespread service territory. Utilities should therefore become increasingly accepting of working with microgrids, and governments should create economic incentives to promote an increasing amount of demonstration projects. Meanwhile, technology improvements can continue to push the state of the art and allow microgrids to become economically feasible without incentives, leading to widespread deployment. Missing from this picture is islanding capability. In the developed world, continued reliance on a reliable legacy macrogrid makes for a compelling vision for the future, but nonetheless the quality of macrogrid service will be increasingly under from high renewables penetration, volatile wholesale markets, and constraints on supply and delivery infrastructure. In emerging economies, the provision of such infrastructure is so costly that the macrogrid may develop along different lines that are not so focused on high PQR.

6.1 From the land of penalties to the land of payments

Historically, many utilities have not welcomed development of microgrids and DER, and in certain situations, have actively inhibited their development, placing them in the “land of penalties.” They have refused to interconnect the projects or charged prohibitively high connection fees, exit fees, or backup/standby fees. For microgrids to capture the direct economic benefits they are due as discussed in section 5.1, policy and technical remedies need to assist microgrids in getting from the “land of penalties” to the “land of payments.” Figure 12 shows the main policy and technical remedies that will assist in this transition, and Table 8 outlines how penalties can become payments for the main economic benefits that microgrids provide.

The idea Figure 12 conveys is that microgrids can provide economically valuable services in a cost-effective manner when those services are properly valued with payments or incentives instead of penalties. Technology improvement should consistently lead to improved microgrid functions and services, if properly incentivized. As technology costs come down, interconnection practices become standardized, and microgrid controls (both passive and active) consistently improve, then microgrids will become both increasingly feasible and also of higher quality and robustness. Policy can help incentivize the initial R&D and demonstration phases with funding and targets for microgrid demonstrations (or specific distributed generation and CHP targets to be more inclusive). Working on electricity pricing policy will ensure that microgrids can capture as many of the economic benefits as possible. As seen in Table 8, there are many changes on the policy “wish list” relevant to electricity pricing alone. When customers purchase less energy from the utility, it has been inclined to request increased service charges or exit fees due to its lost revenue and consequent stranded assets. These charges often eliminate the benefits the customer had initially gained and therefore should not be allowed by regulators unless clearly justified. Note that under dynamic circumstances, such as if local or regional electricity consumption is rising rapidly (as is the case in many developing world regions), then the utility's risk of stranded assets is greatly reduced.

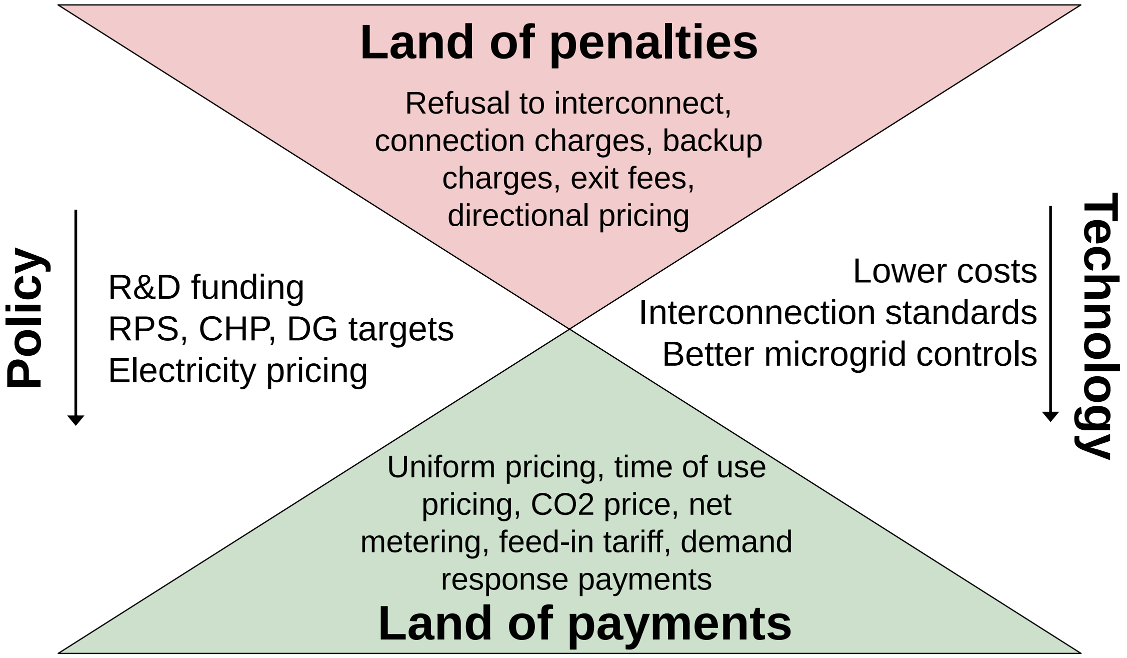

Figure 12: Land of penalties to land of payments using policy and technology remedies

Economic benefit of microgrid	**Regulatory/utility barrier: "Land of penalties"**	**Resolution: "Land of payments"**
Reduce energy costs	Increased service charges or exit fees	Disallow unwarranted increases in charges due to loss of UoS revenue
	No time of use pricing	Create time of use or real-time pricing scheme
Sell excess power to utility	Interconnection charges	Apply a fair and cost-effective interconnection review process
	No compensation provided	Mandate utility purchase of excess power
	Directional pricing used	Consider uniform pricing (see Figure 13)
	Net-metering not allowed	Mandate net-metering, consider allowing provisions for a mixture of supply technologies
Participate in DR markets	No compensation provided	Create incentive payments for DR (interruptible tariffs or contracts)
	Capacity limit set too high	Lower capacity limit so microgrids of all sizes can participate
Increase use of	No incentives for renewable	Consider RPS or feed-in tariff policies

renewable energy	energy	
Reduce CO2 emissions	No CO2 price	Consider carbon pricing policy

Table 8: Valuing the economic benefits of microgrids

For selling any excess power to the local utility, there is a gradient of policies from hostile to friendly. While it cannot be expected that interconnection of microgrids will not impose any costs on the macrogrid, a cost-effective interconnection review process should be applied to ensure a fair outcome. In some cases, no compensation is provided for power provided to the macrogrid. In other cases, only the wholesale power price is provided, also known as directional pricing as seen in Figure 13. Uniform pricing should be considered, as this pricing policy values the economic benefit of local customer microgrids whereby they are not imposing any burden on the transmission system and should therefore not be charged for it. Time of use pricing can also incentivize microgrids to shift loads, which can help in peak load shaving for the utility. Real time pricing is also becoming increasingly common. In this case, electricity consumers are charged prices that vary over short time intervals, typically hourly, and are quoted one day or less in advance to reflect marginal supply costs of generators and utilities. Participation in DR markets should be incentivized with interruptible tariffs or contacts. Some markets have lower capacity limits for participation which are too high (>5-10 MW) for many potential microgrids to participate, so lower limits can be considered.

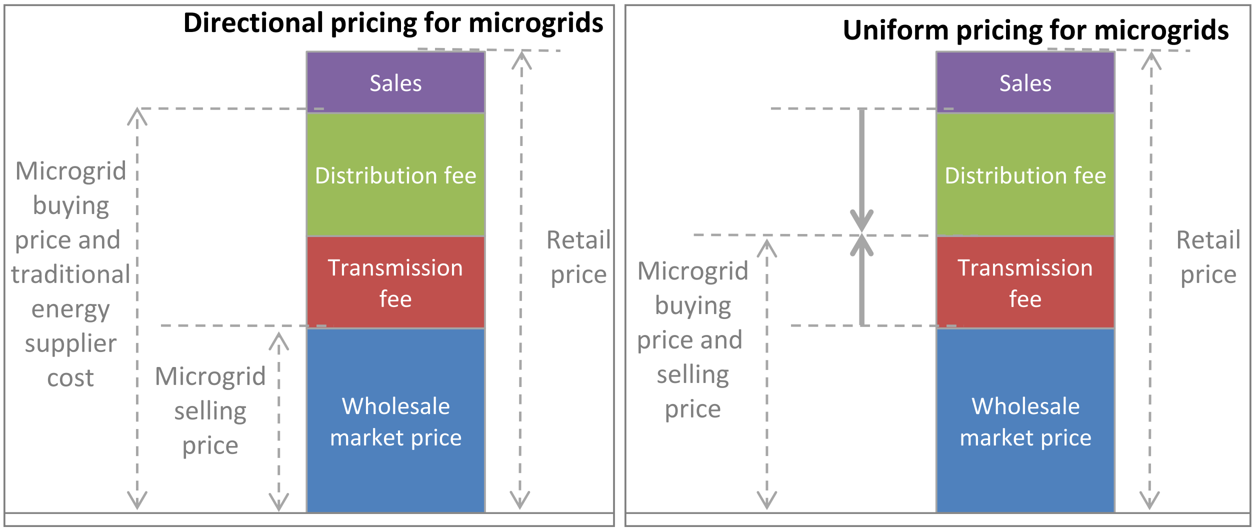

Figure 13: Directional versus uniform pricing in microgrids, adapted from Schwaegerl 2009

Net-metering can be used to incentivize the microgrid to sell electricity to the utility while also simplifying the payments between utilities and microgrids. Net metering stipulates that when the amount of electricity a customer is generating exceeds that customer’s use, that electricity will be sold back to the grid, offsetting electricity used at different times during that billing cycle. Net metering is often limited to systems that produce renewable energy, with specific energy source limitations and system capacity limits varying significantly from state to state. In California, the system capacity limit is 1 MW normally, and up to 5 MW for systems owned by local governments or universities. In some states, the buy and sell prices are asymmetric, e.g. Hawaii. The definitions for net-metering would ideally be altered to allow for hybrid systems that incorporate multiple supply technologies as microgrids do. In this case, individual generators may need to be metered as different tariffs or pricing may apply to different technologies (e.g. solar vs. CHP).

Incentives for renewable energy (through an RPS or feed-in tariff) or pricing of carbon emissions can help promote microgrid development. California is home to a specific feed-in tariff policy for distributed renewable energy generation systems up to 3 MW. The system owner is allowed to enter into a 10-, 15-, or 20-year contract with its local IOU and be paid based on the time-differentiated market price referent table, set by the California Public Utilities Commission. This is in contrast to feed-in tariffs in Germany or Spain, whereby there is an additional premium tariff on top of the market price with a "sunset" feature such that the premium will decline over time as the cost of clean energy equipment falls. Feed-in tariffs are very commonly used in many EU member states, and Japan's new feed-in tariff policy (to be funded by a public interest surcharge) was passed in August 2011 and will be implemented beginning in July 2012.

6.2 Structuring a program – From demonstration to deployment

Providing the right policy and technology remedies to go from the land of penalties to the land of payments is the last step in a country's microgrid program, as is the step that leads to widespread deployment. In fact, no country is yet at a deployment stage for microgrids, but many have completed R&D programs and field demonstration projects, steps 1 and 2.

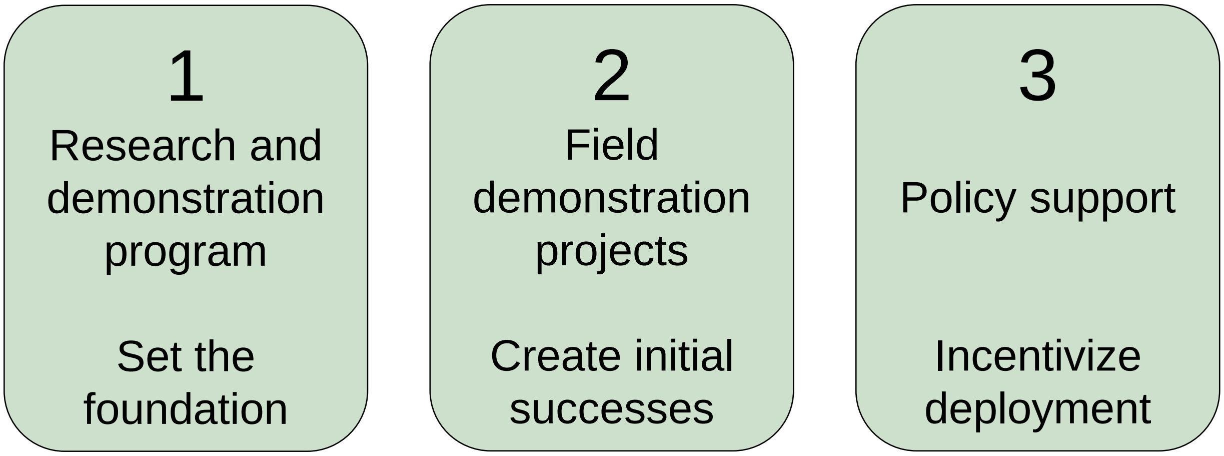

Figure 14: Steps in microgrid program: from demonstration to deployment

Yet, any country embarking on a new microgrid program should start with the end in mind. Helping to decide the end goal for microgrids in terms of purpose and functionality within a country's grid system can help to determine the initial steps in setting up a demonstration program and commissioning initial demonstration projects. The demonstration program will help to set the long-term goal and an initial foundation for microgrid development. Demonstration projects will help a country identify what functions the microgrid can serve within the specific energy landscape. If it seems that the microgrid can achieve economic benefits for customers, utilities, and society at large, then policies can be implemented to ensure the microgrid owner receives incentives or other support to monetize those benefits.

The following case studies on the Santa Rita green jail in California and the Sendai microgrid in Japan will illustrate how demonstration projects have helped identify and validate key microgrid functions and benefits, such as decreased energy costs and increased reliability.

6.3 Demonstration microgrid case study 1: Santa Rita Jail

History and goals

Santa Rita Jail is the third-largest jail[1] in California and the fifth largest in the United States. The Jail houses up to 4,500 inmates and is located in Dublin, California, about 75 km east of San Francisco. Due to a series of installed DER and efficiency measures at the jail, it is also often referred to as the "Green Jail." The goal of the microgrid project there is to demonstrate the first implementation of the CERTS microgrid technology combined with large-scale energy storage, new and legacy renewable energy sources, and a fuel cell. The goals as outlined by Alameda Country (the local county government in charge of the jail) are as follows:

- Reduce peak electrical load and monthly demand charges
- Store renewable and fuel cell energy overproduction
- Shift electrical loads to off-peak electrical hours
- Improve grid reliability and reduce electrical voltage surges and spikes
- Enable the jail to be a net-zero electrical facility during the most expensive summer peak electrical hours
- Expand the jail's onsite generation capacity to include three renewable energy sources: solar PV, wind turbines, and solar water heaters

Over the past decade, the project has implemented various energy efficiency measures and installed a wide array of distributed energy technologies, which have slowly accumulated into a full microgrid. In the spring of 2002, the jail installed a 1.2 MW rated rooftop PV array, followed in 2006 by a 1 MW molten carbonate fuel cell (MCFC) with CHP capability. Most recently, with the aid of DOE and CEC grant money, as well as funding and participation from industry partners Chevron Energy Solutions, Satcon Power Systems, and Pacific Gas and Electric, the jail has gained full microgrid capabilities with the installation of a large 2 MW – 4 MWh lithium iron phosphate battery, an islanding switch, and associated power electronic upgrades. Table 9 summarizes the main characteristics of the Santa Rita Jail microgrid.

Criterion	Description
Technologies used (supply)	1.2 MW rooftop solar PV, 240 kW ground mounted tracking solar PV, 1 MW multi-carbonate fuel cell, two 1.2 MW emergency diesel generators, four 2 kW wind turbines, 2 MW – 4 MWh battery, static disconnect switch

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[1] While the definitions are blurred, in general in the U.S., jails house prisoners awaiting trial or otherwise involved in the justice system, while prisons house convicted criminals.

Load sources (demand)	HVAC, lighting, computers and servers, security systems, cooking, refrigeration, hot water
Electrical storage	2 MW – 4 MWh lithium iron phosphate battery
Thermal storage	Solar water heating
Total supply	Solar PV and fuel cell only: 604 kW (average), 1474 kW (peak)
Total demand	3 MW (peak)
Heating/cooling equipment	Fuel cell has waste heat that can be utilized
Investment	$14 million (does not include solar PV or energy efficiency measures which are described in Figure 15)
Local electricity price	see Table 10
Grants received	DOE, CEC, DOD, and PG&E
Dates of operation	2002-present
General energy conversion efficiency	Electrical efficiency 35%, Thermal efficiency 17%

Table 9: Main characteristics of Santa Rita Jail microgrid

In addition to generation equipment, the jail has also implemented a series of building equipment retrofits to improve efficiency and reduce peak electricity demand. A T-8 lighting ballast retrofit completed in 2009 was estimated to save 225 kW from the peak power demand and 1.34 GWh of electricity annually. Second, the 2010 installation of induction lighting in day rooms will save 217 kW peak power and 1.55 GWh annually. These two measures represent a 15% savings in peak power at the jail. In addition to these, a number of other efficiency improvements were implemented in the middle of the 1990s targeting HVAC systems, lighting, refrigeration, and other end-uses which altogether decreased peak demand by 912 kW. Among them, an upgraded chiller shaved an estimated 423 kW off of peak power demand. The jail also plans to install a roof-mounted solar-thermal system which, when operational, will provide 40% of its hot water needs.

LBNL has also been an active partner with the jail, using its DER-CAM model a number of times throughout the development of the microgrid, to analyze electricity and heat requirements and develop plans for the jail to meet its needs at minimum cost. Additionally, battery chemistries were compared, operating schedules that minimized risk were developed, and opportunities for participation in DR and AS markets are now being analyzed.

Funding and savings

This microgrid is sponsored by federal (DOE), state (CEC), and industrial funds together with four major partners: Chevron Energy Solutions, Alameda County, Satcon Power Systems, and Pacific Gas & Electric Company. The funding for the microgrid (battery, islanding switch, and power electronics upgrades) breaks down as follows:

- DOE Grant: $6,900,000
- CEC Grant: $2,000,000
- PG&E Incentive: $2,000,000
- PG&E Incentive CSI Solar Thermal $500,000
- 3rd Party Funding: $200,000
- Alameda County Energy Funding $100,000

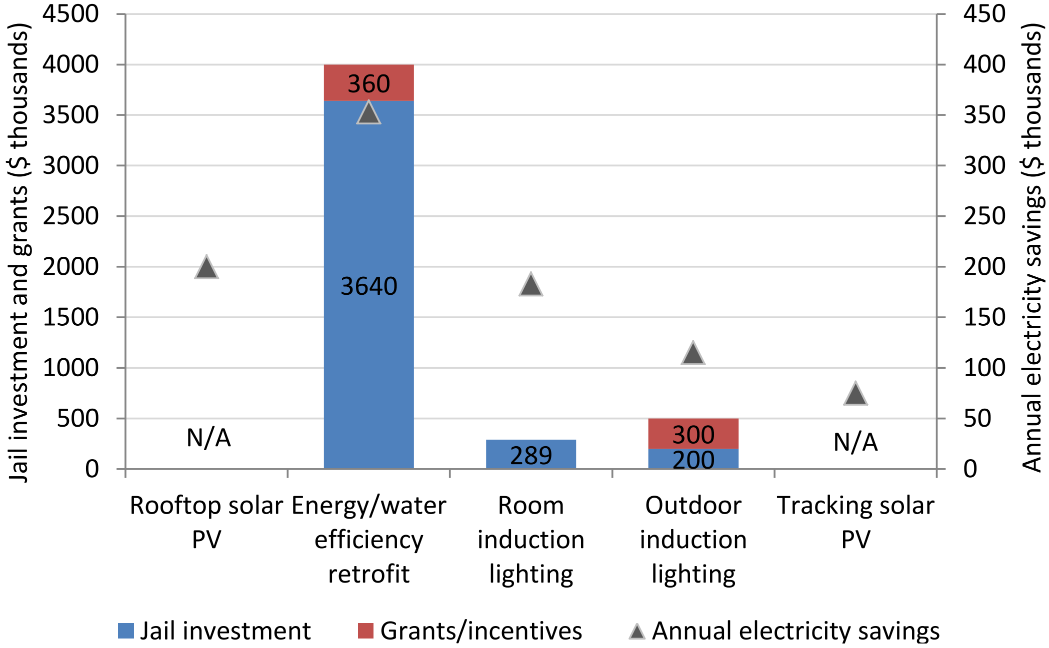

Figure 15: Investment and annual electricity savings for Santa Rita Jail solar PV and energy efficiency projects

Alameda County has related funding and savings information on their various energy efficiency upgrades and solar PV projects, as shown in Figure 15. The lighting retrofit measures had payback periods of 1-2 years, while the larger integrated energy and water efficiency retrofit had a payback period closer to ten years. Investment costs for the solar projects were not available, although each project was estimated to shave about 5% off their electricity bill at the time of implementation. When considering all energy efficiency and water saving measures implemented at the jail since 1993, Alameda County estimates a total $1.9 million of electricity bill savings (70% reduction), $285,000 in natural gas cost savings (40% reduction), and $540,000 in water/sewage cost savings (50% reduction). The demand and energy charges for the jail are shown in Table 10 for peak and off-peak, summer and winter months.

Period		Demand [$/kW]	Energy [$/kWh]	Duration
Summer May-Oct	on-peak	11.04	0.14040	12:00-18:00, M-F
	mid-peak	2.59	0.09807	8:30-12:00, 18:00-21:30, M-F
	off-peak	0.00	0.07992	21:30-8:30, M-F; Weekends
	monthly max	7.45	-	
Winter Nov-Apr	mid-peak	0.82	0.08585	8:30-21:30, M-F
	off-peak	0.00	0.07664	21:30-8:30, M-F; Weekends
	monthly max	7.45	-	

Table 10: PG&E E-20 Industrial Rate (2012)

Technologies used

The jail's array of generation, storage, and demand side efficiency technologies consist of:

- Distributed energy resources:

    - 1.2 MW rated rooftop solar PV system which has an actual peak generation of about 700 kW
    - 1 MW molten carbonate fuel cell with CHP which can supply pre-heating for domestic hot water (15% of hot water needs) in addition to base load electricity
    - Two backup 1.2 MW emergency diesel generators
    - Five 2.3 kW wind turbines
    - 275 kW rated tracking ground-mounted solar PV system
- Energy storage:
    - 2 MW – 4 MWh lithium iron phosphate battery for demand offset and time-of-use pricing
- Power electronics:
    - Fast static disconnect switch for islanding and plug and play control
    - CERTS capable battery electronics and islanding back-up generator controls
- Energy efficiency retrofits
    - 1990's: Energy efficient lighting and fan motor retrofits
    - 2001: Cool roof application and chilled water plant retrofit
    - 2008: Water efficiency retrofit: replaced and retrofitted toilets, urinals, showerheads and valves
    - 2009: Integrated energy and water efficiency project
    - 2010: Day room induction lighting retrofit: 822 fixtures
    - 2011: Outdoor induction light retrofit: 600 fixtures

Current operating status

On March 22, 2012, the microgrid system was formally commissioned by the government and industry partners. During the period of operation since 2002, some issues with the technology have emerged. The solar PV system has recently had a peak output of 700 kW on a 1.2 MW rated system because of system degradation and module soiling. Yet, the rooftop solar PV system still provides a valuable service which is able to mitigate both energy and demand charges with estimated savings topping $20,000 a month during the summer. The new ground-mounted tracking solar PV system should add significantly to these savings. The fuel cell installed in 2006 has been plagued by outages, and recently output has been limited to about 80% of capacity. Sometimes, these outages are due to mechanical problems or voltage disturbances, but the fuel cell has also been turned off to avoid exporting power in a number of cases. Currently, the jail has a fairly predictable load and an electricity peak demand of about 3.0 MW. The combination of generation and storage technologies allows the jail to significantly reduce its daily purchases from the macrogrid and to operate as an island in the event of a power supply disruption. A switch detects any macrogrid anomaly and immediately disconnects the jail from the grid.

Simultaneously, microgrid controls and software allow the jail's suite of backup supply and storage technologies to provide uninterrupted power. Because the battery is used to balance load and supply during islanding, if the back-up generators are needed, they can operate at full power while charging the battery. This results in more efficient operation than direct genset load following. Under the terms of the U.S. DOE grant, the jail must endeavor to reduce the peak load on the local feeder by 15%. The performance target towards this goal has not yet been verified, although it is believed that the jail can reduce peak load by up to 20% with the latest installment of the battery.

Figure 16: Overhead view of the Santa Rita Jail showing the rooftop PV array

Figure 17: Recent photo of Santa Rita jail with ground mounted tracking solar PV in foreground and batteries and fuel cell directly behind

Secrets of success and lessons learned

A major element to the Santa Rita Jail microgrid's success was the central role of a local government entity, Alameda County. The facilities of local governments often make good host sites for microgrid projects. Federal and state governments are keen to support a progressive local authority whose resources are fewer and budgets are smaller. The County was seeking to be innovative from the start, being a first mover for demand side energy efficiency measures and on-site generation with solar PV and fuel cells. At the time of installation in 2002, that rooftop solar PV project was the largest on any government entity in the U.S.

A second element of the microgrid's success was the diversity of partners involved. Local, state, and federal government entities were all involved plus partnership with the local utility (PG&E), technology providers (Satcon and S&C Electric), an engineering services company focused on renewable energy and CHP (Chevron Energy Solutions), and multiple laboratories (University of Wisconsin, LBNL, and NREL). Many of the partners had a large financial stake in the project while others were seeking pilot projects for microgrid technology that had only been demonstrated in the laboratory. The University of Wisconsin, with its involvement in the development of CERTS microgrid technology, had tested its approach at a utility-owned laboratory, American Electric Power's Dolan Laboratory. Satcon, S&C Electric, and Chevron were very capable technology and engineering companies who were able to execute the implementation properly. With the combination of the static switch, droop control in the battery inverter, and new controls in the diesel generators, the CERTS microgrid functioned properly in the field. The jail's involvement of LBNL as a partner helped them to optimize the economics and risk involved in the project, which is another key element of any successful demonstration. Data collection was key, as proper analysis cannot be performed without a sufficient amount of historic data.

The major lesson learned is that the costs of the battery were very high and only made possible through federal and state government grants. Storage costs still need to fall before its widespread adoption can take place. The jail has very high requirements for reliability and now can operate without worry about the consequences of future grid outages since it can island and provide its own electricity. Large electrical storage applications will only make economic sense where ultra-high reliability requirements are in place. Smaller, more affordable size battery installations can be used for sites with lower reliability requirements and still potentially have a net positive economic impact given the price arbitrage opportunities of purchasing lower cost electricity during off-peak periods.

6.4 Demonstration microgrid case study 2: Sendai microgrid

History and goals

The Sendai project is a microgrid located in Sendai, Japan that can supply multiple levels of PQR. The project was supported by Japan's NEDO under the Ministry of Economy, Trade, and Industry (METI) from 2004 to 2008. The main collaborators on the project were Nippon Telegraph and Telephone Corporation (NTT), the NTT Facilities Research Institute, Tohoku Fukushi University, and the city of Sendai. The goal of the project was to build a microgrid system that could supply multiple PQ levels of AC power as well as DC power to various consumer loads at the same time. Ideally, the cost, equipment space, and electrical power losses of the system would be less than those of pre-existing PQ countermeasures which used an uninterruptible power supplies (UPS). The microgrid was completed in October 2006 and operated until 2008. After completion of the NEDO demonstration phase, some changes were made to the microgrid, and it continued to operate today as a university-owned installation. The campus belongs to a small private university specialized in medical training.

Figure 18: Overhead view of the Sendai energy center

The loads served during the NEDO phase are those on either side of a city street. On one side are municipal facilities, a water plant, and a high school. The University is on the other side and includes a hospital with communication apparatus, medical instruments, nursing care facilities, computers, etc. as well as university buildings with computers, servers, lighting, ventilation, and fans. This project includes its own solar PV array, fuel cell, and gas-powered generators to provide electricity to these customer loads. Figure 19 provides a map of the Sendai microgrid and Table 11 details the main characteristics of the microgrid.

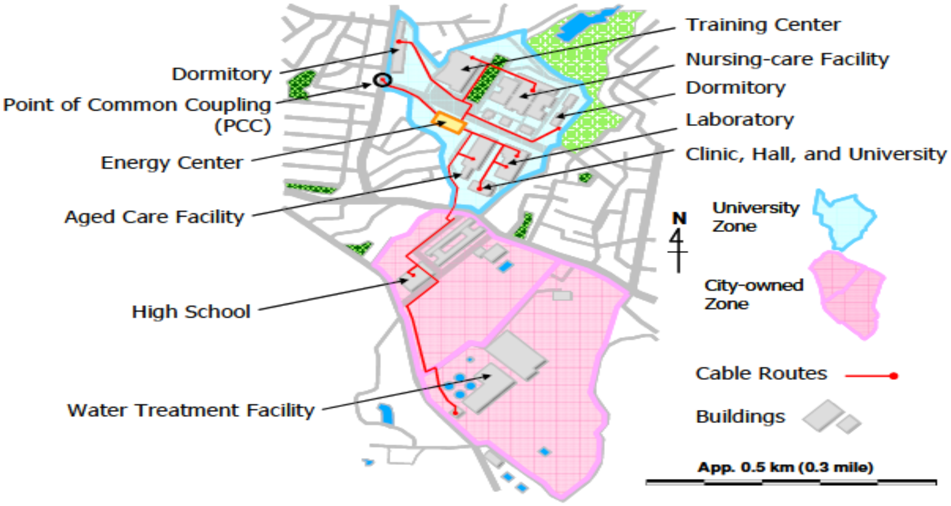

Figure 19: Map of Sendai microgrid elements and customers

Criterion	Description
Technologies used (supply)	Two 350 kW gas gensets, 250 kW molten carbonate fuel cell, 50 kW rooftop solar PV
Load sources (demand)	City buildings (water plant, high school), hospital (communication apparatus, medical instruments, nursing care facilities, computers) university buildings (computers, servers, lighting, ventilation)
Electrical storage	Lead-acid battery: 600 Ah
Total demand	University: 1170 kW (peak), 260 kW (minimum) City: 420 kW (peak), 80 kW (minimum) [Data from 2005-2007]
Investment	$25 million (estimate)
Local electricity price	12 ¥/kWh
Local gas price	60 ¥/ nominal m^3
Grants received	NEDO
Dates of operation	2007-2008 (city + university), 2009-present (university only)
Heat recovery efficiency	Gas gensets: 34.5%; fuel cell: 18%
General energy conversion efficiency	Gas gensets: 75%; fuel cell: 65%

Table 11: Main characteristics of Sendai microgrid

Funding

The project was estimated to cost $25 million from 2004-2008 and was almost entirely funded by NEDO. Further improvements after the demonstration phase ended were made using Tohuku Fukushi University funds.

Technologies used

The microgrid's array of generation, storage and supply technologies include the following:

- Distributed energy resources (rated at a total of 1 MW)
  - 50 kW solar PV array
  - Two 350 kW gas gensets
  - 250 kW molten carbonate fuel cell
- Energy storage
  - 600 Ah lead acid battery
- Power electronics
  - Monitoring system to take measurement for voltage, frequency, and current at 22 locations and record waveform data in 18 locations
  - Integrated power system (IPS) with static switch inverters, DC-DC converters
  - Two dynamic voltage restorers (DVRs)

When islanding, the battery can offer 30 minutes of backup power and restrain voltage and frequency fluctuations resulting from loads changes and PV output. A control system with active and reactive power outputs and a bidirectional power converter can control the voltage and frequency fluctuation of the AC bus. In addition, the microgrid also includes a "back-to-back" system to ensure that any voltage dips are of small depth and short duration. Most voltage dips last less than 100 milliseconds during normal system operation.

Through 2008, the microgrid system directly served some DC loads and provided four different qualities of AC service to customer loads within the university and city zones as seen in Figure 20. After 2008 when NEDO support ended, the microgrid added a heat supply system, which can supply heat produced by the gas gensets and fuel cell to the Tohoku Fukushi University hospital, training center, and nursing facility. The microgrid no longer supplies power to any of the city-side loads, instead only serving university loads.

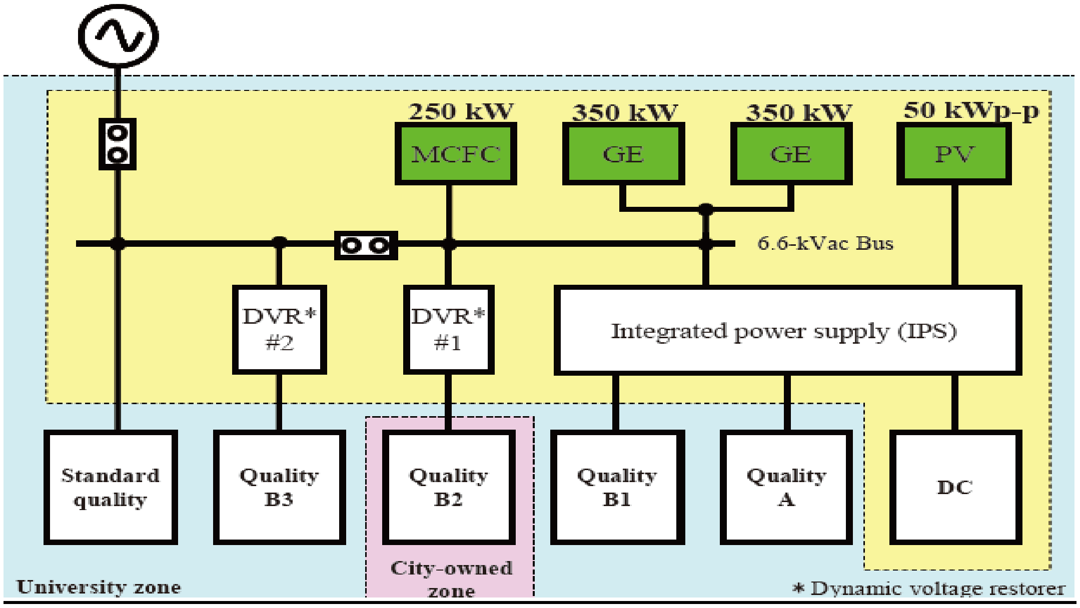

Figure 20: Technology configuration for Sendai microgrid

Operating status

In 2004, power demand and PQ at the project site were monitored in order to inform microgrid design. From 2005 to 2006, project hardware, including the natural gas gensets and the fuel cell, two sets of dynamic voltage restorers, and an integrated power system were developed and installed at the site. From 2007 to March 2008, after various validation tests using dummy loads for the system, electrical power was supplied to facilities in the city and university zones. During this period, many tests were conducted to verify microgrid performance, including power outages, voltage dips, and other types of tests.

Results throughout eight months of testing showed that the system met its evaluation criteria and was able to provide stable electrical power to loads. Meanwhile, the cost, space, power loss, and CO2 emissions were compared with a baseline of 15 years of cost and performance data. It was found that the system could reduce energy costs by 14-30%, reduce equipment space by 23-42%, cut CO2 emission by 12%, and have equivalent or slightly decreased electrical loss compared to the pre-existing system.

The microgrid continues to function today, but only supplies power to the university zone. Its reliability was dramatically tested by the March 2011 Japan earthquake and tsunami. The microgrid functioned successfully as an island for the duration of a two-day blackout that followed the disaster, providing uninterrupted DC power and heat to the sensitive loads in the hospital as well as AC power to other loads. It successfully reconnected to the grid and continued to function until natural gas supply was disrupted two weeks later. The Sendai area has a reinforced high pressure natural gas distribution network.

Secrets of success and lessons learned

Similar to the Santa Rita Jail microgrid, the Sendai microgrid also benefited from having a supportive local government host. The supply of power to both city and university zones involved crossing a public road. Normally, this would invoke utility codes making the microgrid subject to public utility regulation. Fortunately, the city was able to sidestep the regulation and create an exception for the microgrid.

The Sendai microgrid benefited from the oversight and consistent involvement of NTT Facilities. Other NEDO microgrid demonstrations, i.e. Hachinohe, Aichi, and Kyotango, had multiple partners involved but not fully motivated. NTT Facilities sought to make their project a success and sees great potential for widespread microgrid deployment in the future in Japan and other regions.

The project also benefited from very generous funding from NEDO, without which, much of the demonstration would not have been possible. Given the generosity of funding, Sendai lost some focus regarding economics of the project, although it did meet all of its designed goals as described in the previous section. Additionally, NEDO was somewhat constrained in its vision for their series of demonstration projects. NEDO wanted each microgrid to demonstrate one aspect of microgrid functionality. Hachinohe was the all-renewables microgrid, for instance, while Sendai's focus was solely on delivering multiple levels of PQR. However, microgrids are designed to have multiple technologies providing a number of functionalities. Because Sendai was constrained by NEDO in its scope, it did not consider the additional benefit of CHP. When the NEDO demonstration phase ended in 2008, NTT Facilities reduced the microgrid's scope to only the university zone. It also added CHP capacity to take advantage of the gas genset and fuel cell waste heat to heat university and hospital buildings. This experience offers a vital lesson. Microgrid demonstrations should be planned to be either as economic as possible, or to represent anticipated economic operation. Designing and executing demonstrations based solely on technical goals are likely to prove highly uneconomic, and this outcome can overshadow any technical achievement and impede future deployment.

7. Recommendations for establishing a microgrid program

Based on this international review of microgrid programs and technologies as well as common barriers and remedies, we have formed the following ten recommendations for implementing successful microgrid programs. This section lays out these recommendations based on preceding observations with relevant background and context from existing developments around the world. Recommendations are broken down into three categories: overall demonstration program recommendations, pilot project recommendations, and policy support recommendations.

A. Demonstration program recommendations – set the foundation
    1. Set goals for the demonstration program based on the microgrid benefits and functions sought and considering the interests of all stakeholders involved
    2. Promote results-oriented demonstrations based on overall goals
    3. Allow for post-demonstration analysis and peer review
B. Pilot project recommendations – create initial successes
    1. Ensure project is close to economic viability
    2. Include customer microgrids
    3. Match technology with end-use requirements
    4. Integrate energy functions, such as CHP and CCHP with solar thermal support
C. Policy support recommendations – incentivize deployment
    1. Develop standards and processes for interconnection of microgrids
    2. Consider modifications to electricity rate design with time of use, demand charges, distribution charges, etc. to ensure cost-based incentives
    3. Inventory relevant incentive policies and analyze barriers and opportunities for widespread microgrid deployment

While a country must begin with the end in mind by envisioning a future policy support framework for widespread microgrid deployment, these recommendations are not meant to be entirely chronological. Although demonstration projects will precede deployment, the microgrid program administrator should consider policy support from the beginning. For instance, considerations of incentives and electricity rates and interconnection policies figures into designing successful demonstration projects just as for widespread deployment. Additionally, it will be hard to set a goal for the demonstration program without understanding the current policy framework. Finally, recommendations for single demonstration projects will also be helpful in designing a framework support policy for microgrids, especially with the focus on economic viability and integrated energy functions.

Recommendation A1: Set goals for the demonstration program

The first recommendation is to set goals for the demonstration program, based on the microgrid's expected benefits and functions sought and considering the interests of all stakeholders involved.

Demonstration projects will help the research program identify what functions the microgrid can serve within that country's specific energy landscape for specific benefits, such as reduced energy costs, increased reliability, increased energy efficiency, increased use of clean energy, and reduced CO2 emissions. Analyzing these potential benefits and functions requires contextual consideration such as geography, locally available renewable energy resources, fossil fuel supply conditions, local fuel and electricity rates, and regional macrogrid power supply mix.

Microgrids can be a disruptive technology in some cases because they introduce functionality that did not exist before and that current institutions are not accustomed to; therefore, many of the barriers for implementing successful microgrid projects are institutional. There are two possible conclusions. The first argues that a microgrid must merely do no more harm than the current worst actor in the system. Clearly, this position mostly applies to customer microgrids downstream of a single PCC. The second conclusion would argue that while the first conclusion is true for widespread deployment, proper design of any single microgrid as well as a framework microgrid policy requires consideration of the interests of all stakeholders involved, including:

- Microgrid loads: residential, commercial, or industrial loads within the microgrid
- Grid customers: loads outside the microgrid but potentially affected by its existence
- Independent power producers (IPP): owner of distributed generation in the microgrid
- Utility or distribution network operator (DNO): the entity responsible for correct operation of the grid
- Technology providers: equipment manufacturers, microgrid solution providers, and research organizations
- Society: everyone who might be affected by microgrid externalities
- Local and central governments: policy-maker and often responsible for providing financial or legal support (such as in regulation or codes)

In an ideal setting, a properly functioning microgrid would provide energy for the needs of its customers while also providing energy or services to the larger macrogrid which the utility or DNO would find valuable. The local government and utility regulator would set codes whereby a microgrid could interconnect to the macrogrid and get paid for any energy, DR, or AS it sold to the macrogrid. This distinction between the microgrid being merely as harmless as the current worst actor in the distribution network versus being a net benefit is sometimes referred to as the microgrid being a *good* or *model* citizen of the grid.

Based on the benefits sought and the stakeholders involved, the program administrator can set overall goals for the microgrid demonstration program in terms of reliability, i.e. ability to island and survive power outages, energy efficiency, renewable energy use, energy savings, and CO2 emissions.

Recommendation A2: Promote a results-oriented demonstration program

Once overall goals have been defined for the program as a whole, desired results can be identified for early demonstration projects. Microgrid development has reached the stage where potential benefits are known and have been demonstrated, but they have rarely been quantified in a rigorous manner. And while clear quantifiable results are desirable, the economics of each demonstration project should not be unduly compromised (Recommendation B1). Each demonstration should make maximum economic sense, given local costs, benefits, and other circumstances. This may require setting different desired results and objectives for different projects, rather than the same objective for every project in the program. Yet if demonstration projects can meet the required objectives, it will show industry players (utilities, in particular) that microgrids are feasible not only on paper, but also in pilot projects, and there are potential economic benefits involved for multiple players if microgrids are promoted in a pragmatic fashion.

The Renewable and Distributed Systems Integration (RSDI) program started by DOE in 2008 is a targeted research effort (with nine projects receiving federal funds) with the goal that each microgrid should demonstrate that it can reduce the local distribution network's peak load by 15%. While this goal is admirable, project circumstances were widely different across the nine projects, and for many, the goal was impractical or not reachable.

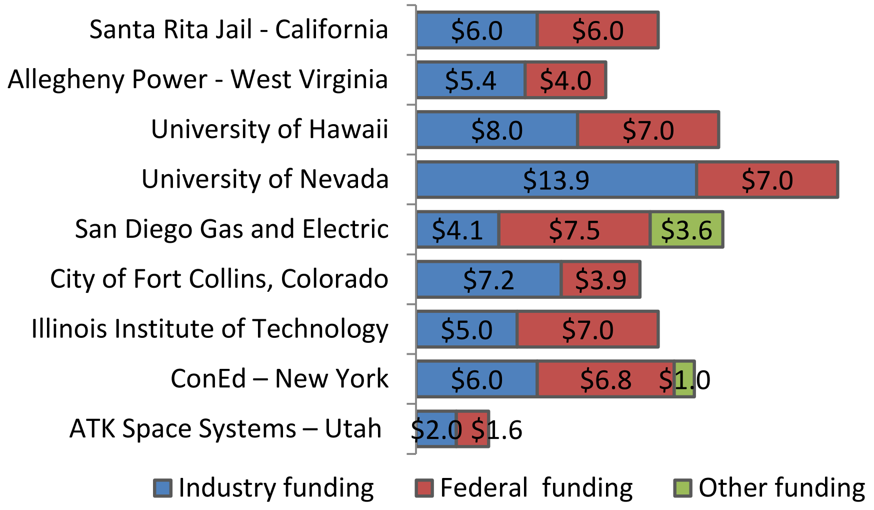

Figure 21: Cost sharing of DOE Renewable and Distributed Systems Integration (RDSI) microgrid projects

Another way to promote a results-oriented demonstration program is to encourage or mandate cost sharing between government and private sector partners. Cost-sharing between industry and government players is critical to ensure that private sector parties, such as utilities and technology companies, have a vested interest in the successful implementation of the project. The RDSI projects run by DOE are a good example of this, as shown in Figure 21. All projects have an industry cost shares in the range of 50% with a high of 67%, for the University of Nevada, and a low of 42%, for Illinois Institute of Technology. Some projects also had funding from local government players, since there are often local government interests and benefits at stake in microgrid projects. Inclusion of industry players is critical as they drive cost effective technological innovation. Across many regions, private sector players are increasingly entering microgrid demonstration projects seeking future market opportunities.

Recommendation A3: Allow for post-demonstration analysis and peer review

A key component of any demonstration should be analysis following completion of the demonstration. Whether the project met its prescribed objectives and whether the program offers useful broadly applicable lessons are the key questions any demonstration should answer. Many decisions and choices made during planning and execution of a demonstration have a significant effect on the outcome.

Amassing enough data during a demonstration, and providing budget and opportunity for ex-post analysis can produce priceless results. Particularly, it is important to answer "what if" questions. How the project's economics may have changed with different equipment sizes or different tariff structures or regulatory regime would be particularly valuable results for policy makers.

The quality of analysis on microgrid demonstration projects to date has varied widely. The use of a third-party contractor to perform post-demonstration analysis may be advisable in situations where the main microgrid developer might provide a biased or incomplete opinion. Many microgrid project developers may be inclined to paint their project in an entirely positive light, without due assessment of the project's design flaws, shortcomings, or difficulties. They may also be unfit to perform an assessment from all angles, including technical, regulatory, and economic perspectives. If the project developer was a technology provider, then the post-demonstration analysis may only have information related to the technical performance of the project, without due evaluation of policy and economic issues. If the developer cannot provide an unbiased and complete assessment, then a third party organization should be contracted to perform the assessment. Appropriate funds should be set aside ahead of time in either case, and the process by which the assessment will be conducted should be evident at the outset of the demonstration.

Recommendation B1: Ensure project is close to economic viability

A microgrid project's economic viability must be considered from the outset. Absent the likelihood of eventual full economic viability, projects should not be considered successes and are not moving development forward. In addition to pure economic analysis, evaluation should take a broader stakeholder perspective. Although demonstrations of new technologies should not be expected to be fully economically viable, projects that are unduly expensive are perceived as failures and impede rather than foster deployment. Consequently, while full financial viability certainly is not required, the economics of projects should nonetheless be seriously evaluated during project selection.

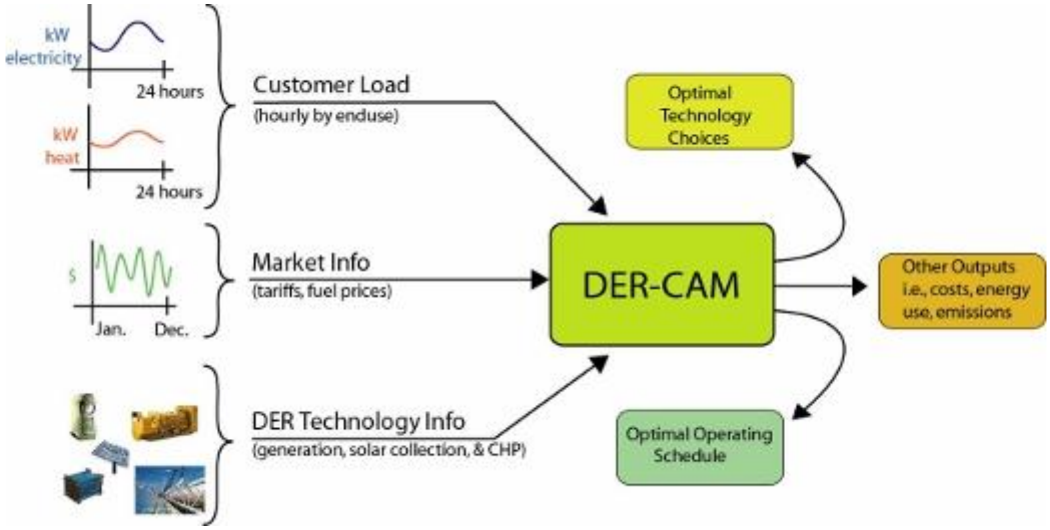

Figure 22: DER-CAM functionality

First and foremost, the project's technical feasibility and economic viability should be addressed from the eyes of the microgrid participants. Researchers at LBNL have developed an analytic tool from the customer's perspective, DER-CAM, which optimizes the equipment capacity and minimizes the cost or carbon footprint of operating distributed generation and CHP for individual customer sites or microgrids. Based on specific site load and price information, the model makes economic choices for the mix of technologies the site should adopt and how that technology should be operated. A schematic for DER-CAM can be seen in Figure 22. The model has been used internationally for about 10 years.

Other simpler screening tools are readily available. The NREL developed the HOMER computer model which evaluates the economic and technical feasibility of design options for both off-grid and grid-connected power systems for remote, stand-alone, and distributed generation applications. RETScreen, developed by Natural Resources Canada, is another similar tool, assessing economic feasibility of potential renewable energy, energy efficiency, and cogeneration projects at a particular site.

The optimal least-cost solution to the supply of a site's energy services requirements is a combination of equipment purchase and dispatch of the chosen system, as well as potential load shifting or DR and AS market participation. Optimality requires minimizing a complicated cost function dependent on often complex tariffs, fuel prices, and equipment characteristics. Optimality can also be sought along other dimensions, e.g. carbon footprint minimization.

One of the main parameters of interest for microgrid customers is a reduction in their energy bills, and revenue from power or services sales may also be important to that bottom line. For the local DNO, the main parameters of interest include reduced peak load, increased distribution reliability, reduced congestion, and deferred capacity upgrades. On the cost side, for a utility to accommodate interconnecting generation might require network upgrades, or conversely loss of load might result in stranded assets whose cost must necessarily be recovered over lower energy sales as discussed in the barriers section. Any costs for interconnection should be estimated when considering a project's economic feasibility. Yet, the macrogrid must be amenable to microgrid participation. Valuation at both the project and policy level of the benefits a microgrid provides to the utility is needed in order to help promote and facilitate microgrid development.

As an example of a microgrid project for which economics was a primary consideration, consider the Santa Rita microgrid project, which was intended to achieve a 15% reduction in the peak load of the local distribution feeder. Based on the 2 MW – 4 MWh battery that the jail installed, about a 6% reduction in peak load is possible. However, the jail has previously installed a number of other measures of distributed generation and energy efficiency upgrades that in total allowed an approximately 16% reduction in peak load. These investments include a rated 1.2 MW rooftop solar PV array, a 1 MW molten carbonate fuel cell, a chiller plant upgrade (423 kW peak saving), T-8 lighting retrofit (225 kW peak saving), induction lighting retrofit (217 kW peak saving), and a freezer evaporator retrofit (71 kW peak saving). Most of these were innovative technologies and not economic on their own merits, but some funding was required from Alameda County, the Jail's owner, thereby ensuring the project was at least reasonably close to being economic, especially when considering the high value the Jail places on power reliability.

Recommendation B2: Include *customer* microgrids

Many of the successful microgrid demonstration projects have used customer sites downstream of one meter, or PCC, such as a military base, campus, or jail. There may be multiple buildings and diverse loads on that customer site, but there is one point of connection to the larger macrogrid and one billed customer. Maxwell Air Force Base (see page 98), Illinois Institute of Technology (see page 97), and Santa Rita Green Jail (see page 57) projects are all good examples of successful microgrid projects downstream of one meter. The primary motivation for including single customer demonstrations in any microgrid program is that regulatory barriers are much less daunting downstream of the meter. Projects that involve legacy regulated public utility assets naturally face much tougher regulatory challenges.

If a microgrid project tries to incorporate elements (generation or load) beyond the meter, in most jurisdictions it will then be treated as a utility, which brings a number of regulatory burdens that the microgrid (given its size and capabilities) may not be able to bear. Once the customer is playing in the realm of the distribution network (in between the microgrid's meter and the local substation, as seen in Figure 23), an area that the utility controls and is responsible for guaranteeing PQR and safety, then many new technical and legal issues come into play.

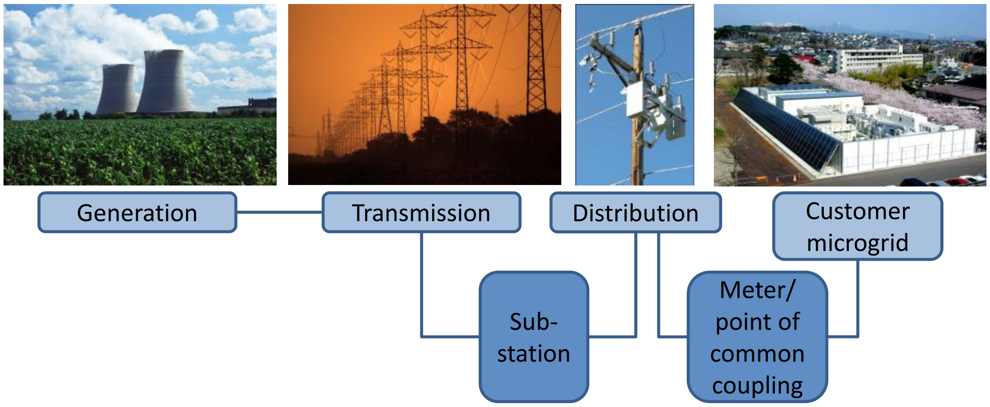

Figure 23: Power grid, from generation to customer microgrid

Recommendation B3: Match technology to end-use requirements

A key feature of microgrids is that the technologies applied are appropriate to requirements of its loads. This recommendation reflects a central feature of microgrids, namely that service quality matches the highly heterogeneous requirements of loads. To determine what mixture of supply technologies a site needs requires knowing the end-use demand requirements and then matching those with a supply mixture of the appropriate size and reliability. Additional considerations beyond demand requirements, especially in the case of military installations, include the security of fuel and energy supply and remoteness leading to poor PQR. Consequently, military bases are becoming increasingly common microgrid hosts.

Matching PQR delivered to the requirements of end use loads can also potentially save money; that is, the cost of matching PQR of supply to specific end user needs is less than the cost of universal PQR, or 100% reliability for all end users. This is part of a vision for a dispersed grid. Recently, a rise in sensitive loads (military bases, hospitals, data centers, etc.) has led to rise in the use of uninterruptible power supplies and backup generators in the case of macrogrid failure. Over 90% of macrogrid faults in the U.S. happen because of faults on the distribution network (due to its exposure to extreme weather and accidents), while faults on the generation and transmission side are rare. Sensitive loads can best be addressed in two ways: first, improvements in distribution system and second, use of supply closer to sensitive end-uses to protect them at the levels they demand. Microgrids provide a solution that meets both of these requirements, so long as the PQR of supply is matched with end-user requirements.

The use of multiple technologies, both on the supply and demand sides, is certainly more interesting from a technical standpoint, but should only be justified when end-user requirements truly warrant it. As solar PV costs continue to fall, many microgrid customer sites will opt to install rooftop solar panels. Additionally, local or federal law may provide incentives for PV. The installation of solar however, will require backup generation or storage to serve sensitive loads. In the case of the Santa Rita Jail, a legacy 1.2 MW solar PV system and a recently installed tracking PV system were paired with a molten carbonate fuel cell with CHP capability, a 2 MW – 4 MWh Li-ion battery, and two 1.2 MW emergency diesel generators. The jail needs power with as complete a guarantee of supply as possible to ensure the safety of its facility and staff, thus the need to back up solar PV with traditional generation from diesel generators and fuel cells, in addition to normal macrogrid service.

The Hachinohe Project (see page 96) was one of the initial projects funded by NEDO. With highly reliable grid power available as back-up, this project focused on a maximum renewable fuel mix. The system includes two 50 kW and three 10 kW PVs, small wind turbines, a 100 kW lead acid battery bank and three 170 kW gas engines fed by sewage and wood waste biogas. At the sewage plant, a 1.0 t/h wood-waste steam boiler was installed to supply heat to safeguard the bacteria and exhaust heat from the gas engines was reused by the gas fermentation process. The electricity was transmitted to schools, the local city hall, and an office building by a private distribution line 5.4 km, 6 kV feeder.

Some microgrids only use a single supply technology where the demand for PQR is low or a high load factor is not needed. For instance, consider a hypothetical sewage treatment plant which has a biogas digester and generator that produces the facility's power. Typically, biogas generators are not reliable and the ultimate quality of power depends on the quality of waste gas. In this case, it may be possible to achieve adequate PQR using the waste gas. Note that a connection to the local distribution grid with 99.9% reliability is enough to secure the assurance needed, but other facilities require higher reliability above macrogrid levels.

Recommendation B4: Integrate energy functions: CHP and CCHP

Many microgrid projects focus on delivering power while other forms of energy needs, such as heat, are neglected. Demands for electricity, heating, cooling, and other fuel use, e.g. cooking, should all be taken into account when designing an optimal microgrid. Even though there is often a strong policy preference for renewables, some of the best economic and carbon abatement opportunities lie with CHP as well as CCHP. CHP equipment is designed to produce power from fossil or biofuels into electricity and use the waste heat from the conversion process either directly or to produce more power through turbines. Facilities with high heating loads will typically prove to be the most appropriate for CHP installation from a purely economic standpoint, but warmer regions with high cooling loads can also contain good sites for CCHP. Analysis has shown that, surprisingly, medium-size commercial buildings (with peak electric loads ranging from 100 kW to 5 MW) are often good sites for distributed generation with CHP. Yet, optimal systems for such buildings can nonetheless be complex, involving solar thermal assistance to CHP waste heat use, or thermal storage.

The UCSD microgrid (see page 99) is an excellent example of a CCHP system that consists of two 13.5 MW gas turbines, one 3 MW steam turbine, a 1.2 MW solar PV installation, a 14.4 million liter cold water storage tower, a 2.8 MW methane powered fuel cell, and PEVs, together supplying 85% of the campus's electricity needs, 95% of its heating needs, and 95% of its cooling needs. When demand is lower at night, excess power generation is used to chill water and store it to be used for the next day's air conditioning. The turbines produce 75% fewer emissions of criteria pollutants than a conventional gas power plant. By the use of an existing campus steam distribution system, UCSD uses waste steam from the turbines for facilities' heating and hot water needs.

The Sendai Project (see page 96) in its post NEDO phase also includes CHP. The system has two 350 kW gas gensets, a 250 kW MCFC, a 50 kW PV array, and a 50 kW battery bank. The microgrid directly serves some DC loads and additionally supplies four different qualities of AC service to a university campus, a high school, and a sewage plant. The integrated system consists of a two-way mode power module, DC-AC inverter, and a battery bank. The project provides power and heating simultaneously to improve energy efficiency and is still in operation in large part due to its near economic viability.

Recommendation C1: Develop standards and processes for interconnection of microgrids

As distributed generation and microgrid projects increase in number, standards and processes for interconnection need to be put in place so as to decrease costs, increase safety, and streamline successful operations. In fact, interconnection standards for microgrids are a top priority for policymakers, since most microgrids are designed to operate either connected to the macrogrid or disconnected as an island. The development of IEEE standard 1547 for distributed generation and substandard 1547.4 for islanding operations have provided a common standard for microgrid operators and utilities to practice safe interconnection. It is common for most grids to shut down all distributed generation that is connected to the grid during a macrogrid power outage or disruption, in order to guarantee the safety of workers. This is why the substandard was created, such that microgrids with distributed generation that wanted to continue operating during a power outage, could disconnect from the grid and continue safe operation within their own confines.

Utilities should also work to streamline the process of review for interconnection. While it is important to assess how a microgrid's generation assets and operation might impact the local distribution network, many distributed generation projects in the U.S. have come up against very high review costs creating a financial barrier for implementation. A few, small DER installations or microgrid projects connecting to the macrogrid should not have a large impact. In the beginning of implementation for a new policy supporting microgrids, review processes should not be costly and could potentially be streamlined. As the number of DER and microgrid projects grows, utility operations have a greater chance of being affected, but smart grid technology and proper planning can help ensure that reliable and safe operations can be maintained.

Any policymaker considering a microgrid program should attempt to put standards in place, potentially based on IEEE's 1547, as soon as possible. Additionally, they should develop a process for streamlining interconnection reviews in the short-term but evaluating large scale impacts in the long-term and coming up with a cost-effective response. The amount of distributed generation will rise in most regions, so utilities and policymakers should plan proactively for their impact.

Finally, it may be helpful to enact a statutory definition of a microgrid to formalize its elements and obligations as well as the obligations of utilities in dealing with microgrids. In the U.S., many public utility commissions are dealing with microgrids on a case by case basis which is burdensome. A legal definition could be based on the definitions used by CIGRE or DOE, which highlight that microgrids can operate grid-connected or as an island, and that they have both generation sources and loads. The definition could potentially also address restrictions on total capacity/size, number of customers, percentage of a utility's total load that may be served by microgrids, and form of ownership, among other items. It could outline a microgrid's obligations to shut down or island in the event of macrogrid outage, as well as the obligations of the utility to interconnect microgrids and purchases their energy and services at market rates.

Recommendation C2: Consider modifications to electricity rate design

As previously noted, microgrids must be able to monetize the benefits they create to properly incentivize their successful widespread deployment. The main economic benefits were outlined in Table 8 along with possible suggestions as to how to capture those benefits. Many of those suggestions have to do with modifications to electricity rate design, including measures for both the purchase and sale of electricity by the microgrid, as outlined here:

- Purchase: time of use pricing, demand charges
- Sale: mandate purchase, uniform pricing, net-metering, DR payments

Time of use pricing and demand charges will help incentivize the microgrid to shift its loads to off-peak hours, which should theoretically lead to savings for both the customer and utility, which will not have to run as much costly, marginal peaking capacity. Additionally, there could be contracts for the customer to provide DR and shed load when the macrogrid needs those services. Any payments there can further incentivize energy efficiency and load control/DR capabilities for the microgrid. Finally, some microgrids will have the ability to export excess generation to the utility. A first step would be to mandate that the utility purchase this energy at fair market prices, which should reflect all the benefits they deliver, including congestion relief, upgrade deferral, and energy savings. A uniform pricing scheme (as described in Figure 13 on page 55) would provide an even greater incentive for the microgrid and properly price out its cost to the transmission system. Net-metering policies can help simplify payments between microgrids and utilities, by stipulating that when the amount of electricity a customer is generating exceeds that customer's use, then that electricity will be sold back to the grid, offsetting electricity used at different times during that billing cycle. The microgrid operator would simply receive a balance of net-use or net-generation at the end of each billing period and payments would be made accordingly.

Recommendation C3: Inventory relevant incentive policies and analyze barriers and opportunities for widespread microgrid deployment

Beyond modification to electricity rate structure that policymakers can help mandate, considerations should also be given for other direct or indirect incentive policies. Direct incentives would include subsidies for CHP, distributed generation, or microgrids themselves. Additionally, special pricing premiums (such as a feed-in tariff) could be offered for any renewable energy generation in the microgrid. Indirect incentives would include RPS's and carbon pricing policy (carbon tax or cap and trade). RPS or cap and trade policies, by design, create a demand for either renewable energy generation or carbon abatement. As supply for these items is constrained, a price for renewable energy credits or carbon emission allowances is created. Given CHP's high efficiency, a carbon price will make it a competitive source of distributed generation to single cycle fossil fuel-based grid power. Often utilities that have to comply with RPS or cap and trade policies will pursue utility-scale solutions, such as large wind farms or solar thermal generation plants, as opposed to distributed-scale solutions. Eventually, distributed-scale solutions may become cost competitive with utility-scale solutions, but in the interim, mandated policy targets and targeted incentives for CHP or microgrids will help these technologies get a foot up as market players gain experience and costs come down.

8. Recommendations applied to China

China has a wide array of policy drivers for low-carbon growth and clean energy. At the highest level, China has a target of reducing carbon intensity by 40-45% by 2020 from 2005 levels as well as increasing the percentage of non-fossil fuel energy usage up to 15% by 2020. NEA plans to build 100 "New Energy City" pilots as well as 30 microgrid pilots. As China develops these demonstration microgrid projects as well as new regulations to promote widespread microgrid development, policymakers should bear in mind the ten recommendations laid forth in the previous section and apply them to China's situation.

8.1 Demonstration project goals

First, China must decide on the overall goals of its microgrid demonstration program. Since microgrids have great potential to increase reliability, energy efficiency, and use of renewable energy, all of these should be relevant goals for China's program. There is a possibility that China will focus on microgrids solely as a supply side solution, i.e. as a way to balance out intermittent renewables, but for microgrids to realize the maximum amount of benefit, they must integrate supply solutions with demand side efficiency and load control solutions plus storage, where appropriate.

An RD&D fund should be set up for distributed generation and microgrid demonstration projects, and both universities and research institutes should be encouraged to research these fields and apply for funding. To encourage positive results from funded projects, cost-sharing between the RD&D fund and the funding applicant should be required. Additionally, performance requirements should be set for funded demonstration projects, such demonstration of interconnection and islanding abilities, reduction of peak demand of the local distribution feeder, customer efficiency benchmarks, or on-site storage capabilities.

As for project specific recommendations, each demonstration project should be close to independent economic viability. Additionally, a diversity of project sites can be chosen initially, to provide for different test beds for microgrid technology and policy. For instance, university campuses, a small group of municipal buildings, or military bases are ideal locations downstream of one meter that will each have a diverse set of energy demands in terms of heating, cooling, electricity, PQR, and storage. China may also wish to consider larger district or city projects with multiple meters, such as the recently approved Xinjiang Turpan microgrid project, remaining aware of the regulatory difficulties that may arise when siting projects within the distribution realm of the grid. The types of supply technologies used should match end-user requirements, and CHP technologies should be considered at sites where there is high space cooling or heating demand, or a need for other process heat.

8.2 Policies to support microgrid deployment

As China develops its microgrid demonstration program and plans for more widespread microgrid deployment, there are a number of policy adjustments that China will need to consider. These adjustments include forming interconnection standards, establishing a central authority on distributed generation and the microgrid demonstration program, and aligning incentives to encourage microgrid deployment.

The first consideration is on interconnection standards. Many distributed generation projects, such as rooftop solar PV projects funded through the Golden Sun subsidy program, have had trouble getting an interconnection to the grid. Microgrids by definition must be able to function grid-tied and as an island. If microgrids are not interconnected to the grid, then they lose much of their functionality and many of the benefits they are able to create may be lost. Yet, microgrids must be able to function safely when they are grid-tied, and thus the need for interconnection standards. California has a growing amount of distributed generation and a handful of microgrid projects. It developed interconnection standards before IEEE 1547 emerged, but subsequently adjust to comply with it. China would be wise to consult the IEEE standards, which are becoming increasingly prevalent in many regions around the world, as distributed generation and microgrids emerge.

The NEA has played the most active role to date in promoting microgrids within China's renewable and clean energy development. NEA could take the lead on the microgrid demonstration program and be responsible for its successful implementation, similar to NEDO's role in Japan and CEC's role in California. Yet, support from other agencies such as the National Development and Reform Commission (NDRC), Ministry of Housing and Urban Rural Development (MOHURD), and Ministry of Finance (MOF) will also be crucial for microgrid demonstration and deployment. Those three agencies, in conjunction with NEA, released a policy document in October 2011 called "Guidance on natural-gas based distributed generation" where applications involving CHP and renewable energy integration were both discusses. These developments could produce positive momentum for utility-scale microgrid applications. MOHURD has set goals for renewable energy deployment in buildings, including a goal to have 250 million square meters of building space powered by renewable energy applications such as rooftop solar PV, building integrated PV, geothermal heat pumps, and biogas digesters. These applications should add up to a total energy savings equivalent to 30 million tons of coal equivalent. However, many buildings with renewable energy installations have not been successfully interconnected with the grid, so MOHURD is exploring microgrids as a possible avenue to facilitate its policy objective. Finally, MOF will play a key role in establishing the needed funding and incentives for microgrid demonstrations and deployment.

Recently, NEA drafted the Management Methods for Distributed Energy, but this has yet to become an official piece of legislation. Given that the various functions involving distributed energy are scattered across many different departments (see Figure 24), there is a lack of unified management and policy guidance, posing some developmental barriers to distributed energy and microgrids. Currently, disputes between State Grid Corporation and the various ministries implementing policies on renewable energy or distributed energy must be settled by the Legal Affairs Office of the State Council or the National People's Congress, who often refer to the Electricity Law of 1997 for their main legal guidance.

Closer interpretation of the Electricity Law is needed to ensure that it does not hold any barriers for successful development of distributed generation and microgrids. Article 25 states that there should only be one utility (electric power retailer) for a given area, which is responsible for electricity sales. Article 10 states that that electricity produced by generation companies or IPPs must only be sold by the utility. Since customer microgrids do not assume utility functionality, then neither of these articles should pose a conflict for microgrid development. However, if China develops utility microgrids, then further legal consideration is needed.

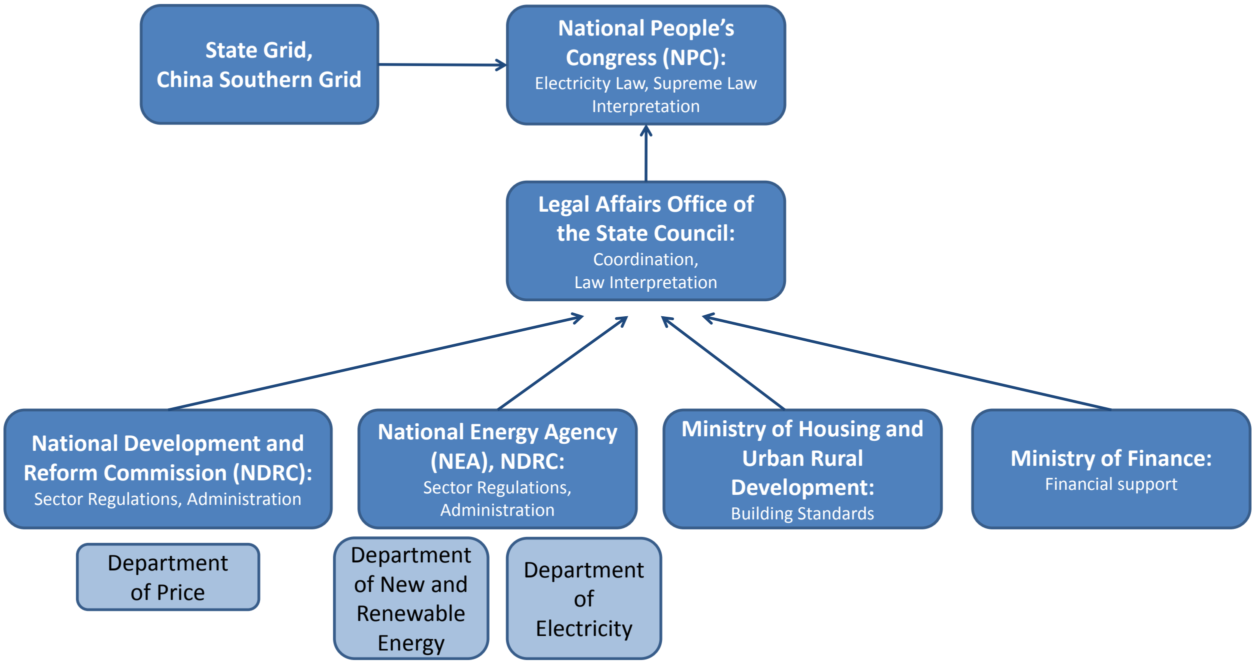

Figure 24: Policy-making bodies for renewable energy and distributed generation in China

After looking at interconnection standards and the policy making bodies surrounding distributed generation and microgrids, China will need to form a more comprehensive suite of incentive policies to encourage deployment. China's general policy direction provides positive indications for distributed generation and CHP. There is a target of 50 GW for natural gas-based distributed generation (including CHP) by 2020, but concrete incentive policies for these areas are currently lacking. Programs like the Golden Sun should continue to be promoted but only after safe and enforceable interconnection standards have been set for smaller, distributed installations. Additional considerations can be given for other on-site generation, including wind, biomass, CHP, fuel cell, etc., and what mixture of tariff should properly support those technologies and any electricity, DR, or AS they might provide to the larger grid should be given careful consideration. Wider considerations need to be given to electricity pricing policy as whole, to ensure it incentivizes microgrid deployment. Time of use pricing, DR contracts, uniform pricing, and net-metering policies should all be considered as each will play a positive role in promoting successful microgrids that increase reliability and energy efficiency while lowering carbon emissions.

Some experts contend that China's current electricity system lacks the flexibility to integrate dispersed renewable energy on a large scale with acceptable cost and reliability. For instance, wind energy development in China has faced a number of barriers regarding interconnection and curtailment, given the geographic mismatch between the wind resource and demand centers as well as the relatively small amount of dispatchable generation in China's grid. Additionally, China's growth in peak demand will increase the need for daytime DR and possibly solar PV generation. China has had a relatively flat load curve in the past due to high demand from industry. Microgrids, if properly deployed, can aid China in meeting its renewable energy and carbon intensity goals in a cost effective manner while continuing to supply enough energy for its growing end-use demand.

9. Conclusions

Microgrids can provide an avenue for increasing the amount of distributed generation and delivery of electricity, where control is more dispersed and quality of service is locally tailored to end-use requirements. Much of this functionality is very different from the predominant utility model to date of centralized power production which is then transmitted and distributed across long distances with a uniform quality of service. This different functionality holds much promise for positive change, in terms of increasing reliability, energy efficiency, and renewable energy while decreasing and carbon emissions. All of these functions should provide direct cost savings for customers and utilities as well as positive externalities for society. As we have seen from the international experience, allowing microgrids to function in parallel with the grid requires some changes in electricity governance and incentives to capture cost savings and actively price in positive externalities. If China can manage to implement these governance changes and create those incentive policies, it will go beyond the establishment of a successful microgrid demonstration program and become an international leader in microgrid deployment.

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Appendix 1: Microgrid programs – country reviews

Europe

Item	Description
Government agencies involved	European Commission, Director-General for Energy and Transport
Main demonstration projects	Kythnos; National Tech. Univ. of Athens; MVV utility microgrid; Bornholm Island Multi Microgrid; Eigg Island
Supportive policies	FP 5 (large scale integration of micro-generation), FP 6 (More Microgrids), and FP 7 (smart grid); RPS for EU: 20% by 2020; feed-in tariff programs in Spain, Germany, Italy, etc.; long-term climate and energy package with 80% greenhouse gas reduction target for 2050; EU Emissions Trading Scheme

Table 12: Summary of Europe's activities and policies surrounding microgrids

The E.U. was the earliest leader in microgrids, with comprehensive R&D efforts dating back to 1998. Under the 5th, 6th, and 7th FP's, comprehensive research and demonstration has been carried out in the area of microgrids. In clean energy policy, many countries already experience a high penetration of renewables, such as Denmark, Ireland, and Spain. The E.U. as a whole has a 20% goal for renewable energy by 2020.

R&D programs and demonstration projects

The goal of FP 5 was to integrate renewable energy and distributed generation into Europe's electricity grid. Within FP 5 (1998-2002), the "Microgrids: large scale integration of micro-generation to low voltage grids" activity was funded at €4.5 million, with the involvement of 14 partners from seven E.U. countries. The research objectives focused on operation and control of microgrids, especially islanded operation. FP 6 from 2002 to 2006 extended the microgrids research under the name "More Microgrids" (Advanced Architectures and Control Concepts for More Microgrids) with funding of €8.5 million for 11 projects with 22 partners. Its goals were to increase the penetration of micro-generation in electrical networks by deepening and extending the definition of microgrids, seek new control strategies and design solutions for microgrids, and develop suitable tools for microgrid operations.

From 2007 to 2011, the FP 7 took "Smart Grid" as the core research field and divides the core theme into seven topics including smart grid, high efficient DER generation technologies, demand side management and DR, new energy services, improved T&D technologies, viable new technologies, and energy storage. Beyond the FP 7, 22 member states have also been addressing smart grid initiatives through the European Electricity Grid Initiative (EEGI) funded by the European Commission and member states. The four focuses for this initiative are smart customers, smart metering, DER integration, and smart distribution, with a goal to perform gap analysis on existing technological issues, form common standards and regulatory framework, and accelerate the implementation of demonstrations and pilot projects.

Throughout the implementation of these three FP's, many demonstration projects have been completed, including the Kythnos Island Microgrid (more information in Appendix B), the National Technical University of Athens (NTUA) Power Systems Laboratory, MVV utility microgrid (more information in

Appendix B), Bornholm Island Multi Microgrid, Eigg Island microgrid, and several other projects (LABEIN, Continuon MV/LV facility, and EDP microgrid).

NTUA's systems include two solar PV generators, one wind turbine, battery energy storage, controllable loads, and a controlled interconnection to the local low voltage grid. The battery unit, PV generators, and wind turbine are connected to the AC grid via fast-acting DC/AC power converters. The battery converter in particular is suitably controlled to permit the operation of the system either interconnected to the low voltage network or in islanded mode, with a seamless transfer from one mode to the other.

Bornholm Island Multi-Microgrid system has a 55 MW peak load, 16 60/10 V transformers, 39 MW diesel generator (oil-fired), 39 MW steam generator (oil-fired), 37 MW steam generator (coal/oil-fired) a CHP system, 30 MW of wind, four district heating systems, and six heat generators. It can supply electricity for 28,000 customers. The project's main research objectives are to describe system's ability to balance active/reactive power and to achieve blackstart operation and reconnection to main grid.

Eigg Island Project consists of a 110 kW hydroelectric generator, four small wind generators for a total of 24 kW, and a 10 kW array of PV panels, for a total generating capacity of 144 kW. About 11 km of cable was laid for the grid, most of it on the surface. There are 96 4V batteries at the control building, where the system is regulated to ensure a continuous supply of electricity to the island. Limited capacity, especially in the summer months when there is little wind or rain, is the biggest limitation.

Policy support

Although there has not been a common legal framework on distributed generation in Europe, the related provisions of European energy law have provided some fundamental guidance on distributed generation. The Directive 2003/54/EC offered the essential elements such as unbundling and third party access to a deregulated and liberalized electric market. Some member states in Europe have already introduced the legal unbundling of distribution system operators (DSOs) as well as national policies to promote distributed generation. For interconnection policies, anti-islanding provisions exist in all European codes, forcing immediate disconnection during blackout to prevent potential safety threats to other networks users and utility field operators, as well as avoid operation and protection complexities. Intentional islanding to improve PQR at any individual customer site is allowed, however.

Feed-in tariff policies have been especially effective in promoting renewable energy and distributed energy in a number of E.U. member states. With programs that started in 1991, 1992, and 1998, respectively, Germany, Denmark, and Spain have achieved high proportions of distributed generation at 20.5%, 53%, and 7.8%. The E.U. as a whole has a 20% renewable energy target for 2020 as well as a long-term climate and energy package to reduce greenhouse gas emissions by 80% by 2050, both of which are providing a strong long-term policy signal for distributed generation and renewable energy.

Japan

Item	Description

Government agencies involved	NEDO, METI
Main demonstration projects	Aichi, Kyotango, Hachinohe, Sendai, Yokohama (Tokyo Gas), Tokyo (Shimizu)
Supportive policies	Electric law amendments allowing IPPs and partial liberalization (1995, 1999, 2003); RPS (2002); New Energy Basic Plan (2010), Feed-in tariff for renewable energy (2011); interconnection guidelines and requirements in 1995 electric law amendment

Table 13: Summary of Japan's activities and policies surrounding microgrids

Japan was an early leader in microgrid research, with NEDO funding a number of successful demonstration projects starting in 2003. A number of stakeholders remain engaged in microgrid development, as the recent earthquake has caused a resurgence of interest in distributed and renewable energy amidst the downturn of nuclear power.

R&D programs and demonstration projects

NEDO is in charge of government research funding and management for projects involving distributed and renewable energy. From 1974 to 2002, NEDO directed $1,740 million, $77 million, and $655 million, for solar (Sunshine), wind (Moonlight), and geothermal (New Sunshine) programs, respectively. Starting in 2003, they funded microgrid demonstration projects at Aichi, Kyoto, Hachinohe, and Sendai. More information on Hachinohe and Sendai projects can be found in Appendix B. The goals of the projects were to utilize dispatchable power sources to compensate for variable demand and increase uptake of local small-scale intermittent renewables. The Hachinohe project focused itself as an all-renewables microgrid, with biogas as its dispatchable power source and solar PV and wind as its intermittent renewable sources. The project had some initial successes, but once government funding ran out, the project stopped since it was not economically viable to continue. The Sendai project focused on providing multiple types of power delivery (AC/AC, DC/DC, DC/AC) with high reliability to the various customers on its microgrid (city buildings and a hospital). The project successfully operated as an island for two days after main power supply was cut off during the March 2011 earthquake.

Since June 2009, METI has agreed to finance two-thirds of a JPY 9 billion to perform ten remote island microgrid demonstrations, which are being implemented by two selected companies, Kyushu Electric Power Co., Inc. and Okinawa Electric Power Co., Inc. In addition to the government-sponsored projects, the private sector is also becoming increasingly involved in microgrid projects. Tokyo Gas and the University of Tokyo developed an integrated DER control system based on simulation studies and experiments at its test facilities in Yokohama. Shimizu Corporation has also developed a microgrid control system at its Tokyo test facility. With the earthquake and newly supportive policies for renewable energy, increasing interest and investment in microgrid projects are expected. Japanese companies such as Shimizu and NT Facilities are also actively seeking microgrid project development opportunities abroad as well, such as in the U.S. and China.

Policy support

Of particular relevance to microgrids are a number of amendments to the Electric Utility Industry Law of Japan. Amendments in 1995, 1999, and 2003 to the Electric Utility Industry Law of Japan allowed IPPs and permitted a partial liberalization of the retail market. In 1994, MITI (the predecessor of METI) established technical recommendations for distributed generation's access to the grid (EGA970-1993). These requirements were revised in the 1995 law amendment, permitting owners of distributed energy sources to sell excess power to electric utilities and requiring the utilities to provide standby electricity for them. The requirements included provisions for relays, protection switches, islanding prevention, and communication systems, but did not include provisions on which parties will bear the costs for this equipment.

Of relevance to the larger low-carbon power sector, an RPS was implemented in 2002, requiring utilities to acquire 1.3% of electricity from renewable energy sources. A new feed-in tariff law which has been passed and will come into force in July 2012 will provide favorable tariffs to solar PV and wind energy producers. Finally, the New Basic Energy Plan was passed in 2010, calling for a doubling of Japan's energy independence ratio, a doubling of the percentage of renewable energy power generation, and a 30% reduction of energy related CO2 emissions by 2030. The status of this plan is now in limbo, as the plan would have put huge requirements on nuclear power, and in the wake of the Fukushima disaster, the government is still determining the fate of nuclear power in the country.

China

Item	Description
Government agencies involved	Chinese Academy of Sciences – Institute of Electrical Engineering, NEA
Main demonstration projects	Hefei University of Technology, Hangzhou Dianzi University, Xiamen University, Foshan Power Bureau?
Supportive policies	15% non-fossil energy for 2020; feed-in tariffs for renewables; draft management methods for distributed energy; CHP target of 50GW by 2020; support for natural gas-based distributed energy

Table 14: Summary of China's activities and policies surrounding microgrids

Since 2008, various microgrid demonstration projects have been developed in China, mostly at universities around the country. Now, the NEA is planning a larger scale role for microgrids as it plans its 100 New Energy Cities, of which 30 are set to be powered by microgrids.

R&D programs and demonstration projects

A number of projects have been built at universities in China, funded jointly by private parties and the national or other foundations. One microgrid demonstration at the Hefei University of Technology in Anhui province was funded by a central government grant. It has 10 kW of solar PV, two 30 kW wind generation simulators, 5 kW fuel cell, 300 Ah battery bank, ultra-capacitor bank, two 15 kW conventional generators, and various loads (resistors, capacitor, inductors, AC and DC motors, and other electronic loads). Another project in Zhejiang province at Hangzhou Dianzi University, which is supported by a collaborative China-Japan technology program, has piloted a microgrid project called "Advanced and steady solar PV access to grid system". It was jointly developed by Chinese and Japanese parties to supply electric power for two teaching buildings. The project began in October 2008 and includes 120 kW solar PV, 120 kW diesel generators, 50 kW/h lead-acid battery bank, 100 kW super capacitor, and a compensator system for voltage fluctuations. In the daytime with sufficient sunshine, the power supply for two buildings is basically met by PV, but grid power is used to compensate on overcast days or at night. The storage system can help maintain a steady power flow at the PCC. During islanding operation, the diesel generators and storage can supply power to meet loads.

A new project recently developed at Xiamen University (in Fujian province) involves a number of foreign companies including Nextek, People Power, Intel, LBNL, and Canadian Solar. The all DC micro-grid project will utilize solar PV directly (no conversion to AC) to power the building's lighting, air conditioning, and charging system for electric vehicles.

Policy support

China has a number of policies in place likely to push microgrid deployment. First, it has a goal of achieving 15% non-fossil energy as a proportion of total primary energy consumption by 2020. Second, in 2011, China's NEA drafted the Management Methods for Distributed Energy, an attempt to promote the microgrid concept and to facilitate the expansion of renewable energy and other DER. Also, the Technical Standard for Distribution Energy Resources Access to Grid (Q/GDW480-2010) was promulgated and put into force on 2 August 2010. Lastly, in the 12th Five-Year Plan (2011-2015), NEA is directed to use microgrids as the basis for 100 New Energy City pilots, and 30 microgrid pilot projects have also been proposed. A full list of China's policies in the area of renewable and distributed energy can be found in Table 15.

Year	Policy
1995	Outline on New and Renewable Energy Development in China, State Planning Commission (SPC), State Science and Technology Commission (SSTC), State Economic and Trade Commission (SETC)
1995	Electric Power Law Article 25: Power generation companies are approved to supply power to a permitted area. There is only one utility or power retailer permitted in any given area. Article 10 of Electricity Supply and Use Regulations: The electricity produced by electric power producers must be sold by utilities.
1995	New and Renewable Energy Development Projects in Priority (1996-2010) China, by SSTC, State Power Corporation, and SETC
1996	Ninth Five-Year Plan and 2010 Plan of Energy Conservation and New Energy Development by the State Power Corporation
1996	Ninth Five-Year Plan of industrialization of New and Renewable Energy by SETC
1997	Energy Conservation Law
1998	Incentives Policies for Renewable Energy technology Localization by State Development and Planning Commission (SDPC) and Ministry Of Science & Technology (MOST)
1999	Circular of MOST and SDPC on Further Supporting the Development of Renewable Energy
2003	Renewable Energy Promotion Law
2006	Renewable Energy Law was implemented
2007	Medium and Long Term Renewable Energy Development Plan was implemented
2007	Management Methods for Power Grid Enterprises' Purchasing of Renewable Energy Electricity was implemented
2008	The 11th Five-Year Renewable Energy Development Plan was implemented
2009-2011	Various feed-in tariffs for wind, biomass, and solar PV revised or introduced

2009	Golden Sun solar subsidy program
2010	Technical Standard for Distribution Energy Resources Access to Grid (Q/GDW480-2010)
2011	Draft of Management Methods for Distributed Energy

Table 15: Detailed table of Chinese policies on renewable and distributed energy

China has a number of feed-in tariff policies that encourage the development of renewable energy resources, such as small hydro, wind, biomass, and solar PV. The feed-tariffs for application of these technologies, in comparison to the wholesale price for coal-fired power, are shown in Figure 25. There is usually a gap between the feed-in tariffs for renewable energy and the tariffs paid to coal-fired power generators, and this gap is in part subsidized by a public interest surcharge of CNY 0.008/kWh.

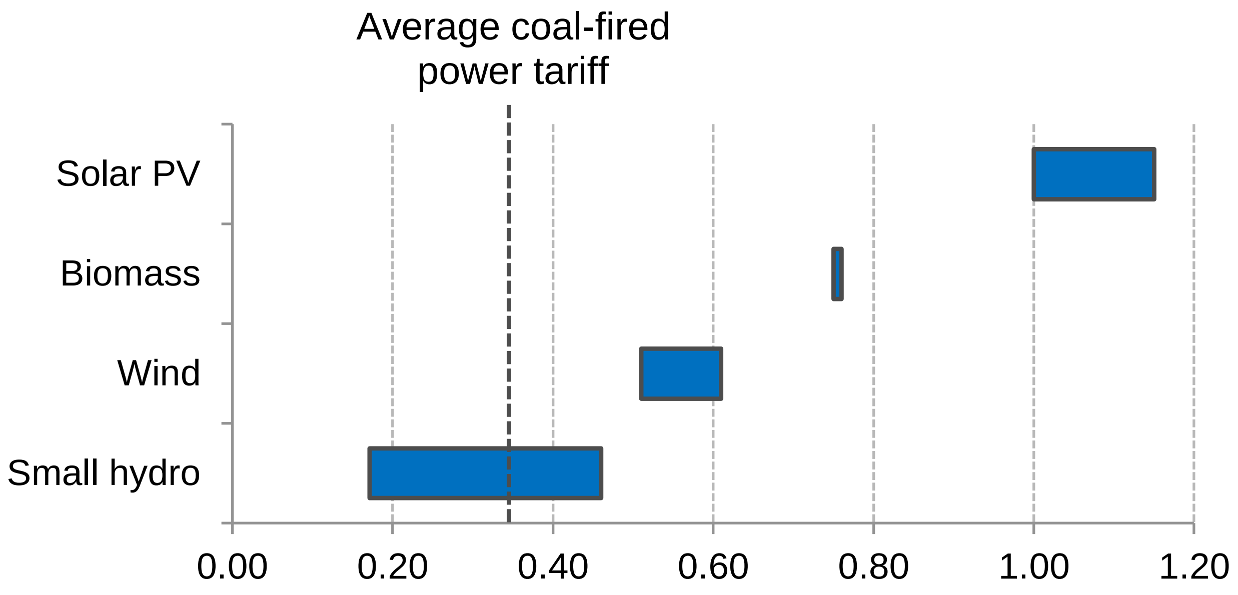

Figure 25: China’s feed-in tariffs for renewable energy as compared with coal-fired power (CNY/kWh)

MOHURD and MOF have also implemented some policies for smaller scale solar PV projects, such as the building integrated PV (BIPV) program and Golden Sun program. The BIPV program is for projects ≥50 kW and provides a CNY 20/W subsidy. The Golden Sun program is for projects ≥300 kW and provides 50% of the total cost for on-grid systems. These new subsidies allow for renewable energy adoption in buildings and city centers, yet many have complained that their projects have not been allowed to connect to the grid.

Beyond its efforts in supporting renewable energy, China’s government has also had increasing interest in the area of distributed generation, particularly as powered by natural gas, a lower carbon alternative to its dependence on coal. While natural gas prices are quite high and supply rather constrained currently, some experts contend that new supply pipelines from Russia, Southeast Asia, and Central Asia as well as China’s potentially large shale gas reserves will cause a boost in natural gas supply and applications. In October 2011, four national ministries issued guidance on the Development of Natural Gas Distributed Energy in October last year, with a plan to build 1,000 natural gas distributed energy projects and about ten various types of distributed energy demonstration areas during the 12th Five-

Year Plan. However, no government has yet been put in charge of implementing this policy for distributed energy.

South Korea

Item	Description
Government agencies involved	KERI
Main demonstration projects	KERI microgrid project, Jeju Island smart grid demonstration
Supportive policies	RPS – 2% by 2012, 4% by 2015, 10% by 2022; focus on smart grid, Green Growth law, 30% below BAU greenhouse gas target for 2020

Table 16: Summary of South Korea's activities and policies surrounding microgrids

South Korea has a number of government policies supporting renewable energy and smart grid development. With the KERI microgrid project and Jeju Island smart grid demonstration, South Korea has emerged as a notable newcomer in the microgrid space.

R&D program and demonstration projects

At present, the Korean Energy Research Institute (KERI) is supporting the first and only pilot microgrid project in South Korea. The test system is a mixture of all kinds of equipment including several types of distributed generation such as solar PV, fuel cell, wind turbines, and diesel generators with critical and controllable loads, storage and PQ devices, and a control system (including weather condition monitoring). This KERI-led microgrid project aims to test and study all aspects of microgrid including performance evaluation, technology development, standardization, and impact of regulations. The project is being carried out in two 100 kW phases from 2010 to 2012. Also of note is the Korean government-supported Jeju Island Smart Grid Test-Bed Project being implemented from 2009 until 2013. Given Jeju Island's abundant wind resource, it and similar islands have been noted as good candidates for microgrid demonstrations.

Policy support

The Korean government introduced a feed-in tariff (FIT) program in the power sector in 2006, which caused power generation from renewable energy sources to grow steadily, but that proportion has not yet reached the required 1%. The RPS system has been revised a number of times. In the beginning, it was mandated that retail electricity suppliers source a minimum percentage of their electricity from eligible renewable resources. In order to increase the utilization of renewable energy and reduce compliance costs, tradable renewable energy certification was permitted. In March 2010, the Korean parliament ratified a new RPS system to be executed from 2012 onwards in place of the previous RPS system. Based on the new RPS system, 14 state-owned or privately-owned power generation utilities, each with the generation capability of over 500 MW, are required to source 2% of their generation portfolio from renewable energy by 2012, increasing to 4% by 2015 and 10% by 2022. This program will mandate 16,481 GWh of additional renewable energy per year through 2015 and 50,248 GWh per year through 2022. In August 2008, Korean President Lee Myung-bak introduced the Green Growth Basic Law as a new vision to guide the nation's long-term development towards a green economy. The law declared the basic concepts, principles, and strategy of green growth, and it also provided a legal framework for the development of renewables and smart grids.

Singapore

Item	Description
Government agencies involved	Energy Market Authority (EMA)
Main demonstration projects	Pulau Ubin, A*STAR Experimental Power Grid Centre
Supportive policies	Singapore Initiative in New Energy Technology (SINERGY), dependence on fossil fuel imports, 16% below BAU greenhouse gas reduction target for 2020

Table 17: Summary of Singapore's activities and policies surrounding microgrids

Singapore is another significant newcomer onto the microgrid scene, announcing late last year that it will establish a microgrid test bed in addition to its ongoing R&D efforts on new energy and intelligent energy distribution.

R&D programs and demonstration projects

The Singapore's Energy Market Authority has appointed a Singapore-based consortium to design, build, and operate a microgrid test-bed with clean and renewable energy resources on Pulau Ubin, a Singaporean island in between Singapore's main territory and Malaysia. There, the island residents and businesses currently rely on expensive, noisy, and polluting diesel generators for their electricity needs. This test-bed aims to assess the reliability of electricity supply from a microgrid using intermittent renewable energy resources; provide cleaner, more reliable, and cost competitive electricity to residents and businesses on the island; and establish local capabilities of smart grid design, system integration, and management of intermittent renewable energy sources. The generation sources in the microgrid will consist of solar PV and biodiesel generators. Construction is set to start in the first half of 2012 and finish by the end of 2012.

This new microgrid project complements Singapore's existing R&D efforts, such as the Singapore Initiative in New Energy Technologies Center, which was established in 2007 with funding of SGD 38.5 million. The center's focus is on distributed energy and microgrid systems and technologies with a sub focus called "Intelligent Energy Distributed Systems" (IEDS), in which 10 projects received a total of SGD 8 million. Singapore's newer R&D effort is its Experimental Power Grid Centre (EPGC) at the A*STAR Institute of Chemical and Engineering Sciences. It is a microgrid simulator with multiple power generation units including solar PV, diesel, energy storage, wind, and grid emulators rated up to a total of 1 MW. It is capable of simulating a wide range of grid conditions and disturbances. The EPGC has three main research focuses:

- iGrid: intelligent and decentralized power distribution networks
- iDERS: intelligent DERS: intelligent control and management of DER
- iEuse: intelligent energy use: smart and interactive energy utilization

Policy support

Singapore has a voluntary greenhouse gas emissions reduction target of 16% below business as usual by 2020. Given the country's nearly complete reliance on fossil fuel imports yet limited land for renewable energy and distributed energy resource development, its focus for microgrids will likely lean towards efficiency, reliability, and smart grid functionality.

U.S.

Item	Description
Government agencies involved	DOE, CEC, DOD, NREL, LBNL
Main demonstration projects	SPIDERS (Hickham AFB, Fort Carson, Camp Smith); RDSI grants (Santa Rita Jail, Borrego Springs, University of Hawaii, University of Nevada Las Vegas, ATK Space Systems, City of Fort Collins, Illinois Institute of Technology, Allegheny Power, ConEd NY)
Other research efforts	Development of CERTS technology and DER-CAM and µGrid software; IEEE 1547 standard development
Supportive policies	30 states with RPS, 44 states with interconnection policy, 44 states with net metering policy, proposed 80% clean energy goal by 2035, 17% reduction in greenhouse gas emissions by 2020, RGGI and California cap and trade programs

Table 18: Summary of U.S.'s activities and policies surrounding microgrids

In recent years, the U.S. has become a leader in microgrid demonstration and technology development. The DOD's flagship microgrid project called SPIDERS and DOE's grants given to nine microgrid demonstration projects have generated a high amount of activity in the space, while other efforts in standards (IEEE 1547), technology (CERTS), and software (DER-CAM) have filled in certain developmental gaps in the microgrid sector. In the absence of a federal clean energy policy, various states have been pursuing clean energy legislation, with some positive developments for microgrids as well.

R&D programs and demonstration projects

The two major R&D and demonstration programs going on in the U.S. are the Smart Power Infrastructure Demonstration for Energy, Reliability, and Security (SPIDERS), co-run by DOE, DOD, and Department of Homeland Security (DHS), and the Renewable and Distributed Systems Integration (RDSI) microgrid grants program, run by DOE. While the goal of the SPIDERS program is to address energy security and reliability concerns, the RDSI grants are primarily focused on increasing the use of distributed energy during peak load periods to prove the value of microgrids for utility load shedding.

The goal of SPIDERS is "to reduce the 'unacceptably high risk' of mission impact from an extended electric grid outage by developing the capability to maintain energy delivery for mission assurance." SPIDERS will seek to demonstrate the following technologies at specific military base locations:

- Cyber-security of electric grid (virtual secure enclave)
- Smart grid technologies & applications (advanced metering infrastructure, substation and distribution automation, two-way communications and control)
- Secure micro-grid generation & distribution (islanding control system, seamless grid synchronization)
- Integration of distributed & intermittent renewable sources (PV, wind, solar, fuel cell, biofuels)

- Demand-side management (automated load shedding, smart sockets)
- Redundant back-up power systems (batteries, vehicle to grid, other fuel sources)

The timeline for the project rollout can be seen in Figure 26, with three project sites planned for Hickam Air Force Base (Hawaii), Fort Carson (Colorado), and Camp Smith (Hawaii). The total three-year budget for the project is $39.5 million. The preliminary design for the Hickam base has been completed, while conceptual designs for Fort Carson and Camp Smith are in progress, with Requests for Information having been issues to dozens of potential industry partners. Once the three demonstrations have been complete, DOD hopes to create a template for implementation across the armed forces, as well as working with NIST on technology transfer for the commercial sector and national grid cyber security. These military projects were preceded by a microgrid project at the Maxwell Air Force Base, which is described in Appendix B.

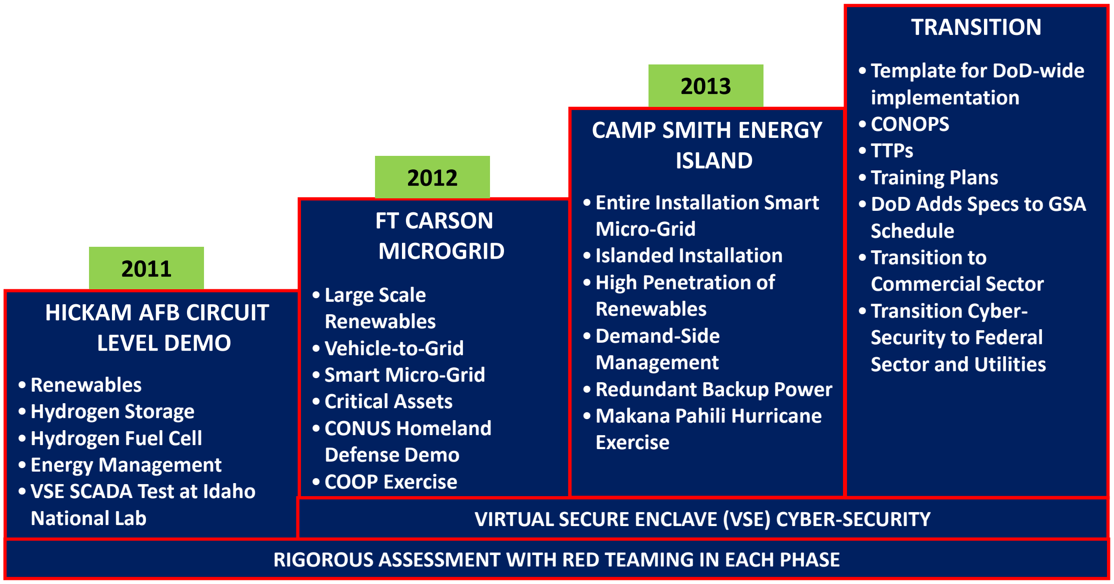

Figure 26: SPIDERS implementation plan

The goal of DOE's RDSI project is to demonstrate at least 15% peak demand reduction on the distribution feeder or substation level through integrating DER and demonstrate micro-grids that can operate in both grid parallel and islanded modes. If these goals are met, then many co-benefits will be realized, including increased grid reliability, deferment of utility T&D investment, increased customer energy efficiency, and decreased carbon emissions. Nine projects were selected in 2008 as part of the RDSI project, which has a total DOE budget of $55 million, with the total value exceeding $100 million with participant cost share. A full outline of the projects, including title, location, and technologies used, can be found in Table 19. Further description of the project by Illinois Institute of Technology can be found in Appendix B, while the detailed case study of Santa Rita jail is located in section 6.3.

Project lead and title	Location	Technologies/features
Chevron Energy Solutions – CERTS microgrid demonstration	Santa Rita Jail, CA	Large-scale energy storage, PV, fuel cell
SDG&E– Beach Cities microgrid	Borrego	DR, storage, outage management system,

	Springs, CA	automated distribution control, AMI
University of Hawaii -- Transmission Congestion Relief	Maui, HI	Intermittency management system, DR, wind turbines, dynamic simulations modeling
University of Nevada Las Vegas – “Hybrid” Homes: Dramatic Residential Demand Reduction in the Desert Southwest	Las Vegas, NV	PV, advanced meters, in-home dashboard, automated DR, storage
ATK Space Systems – Powering a Defense Company with Renewables	Promontory, UT	Hydro-turbines, compressed air storage, solar thermal, wind turbines, waste heat recovery system
City of Fort Collins – Mixed Distribution Resources	Fort Collins, CO	PV, bio-fuel CHP, thermal storage, fuel cell, microturbines, PHEV, DR
Illinois Institute of Technology—The Perfect Power Prototype	Chicago, IL	Advanced meters, intelligent system controller, gas fired generators, DR controller, uninterruptable power supply, energy storage
Allegheny Power—WV Super Circuit Demonstrating the Reliability Benefits of Dynamic Feeder Reconfiguration	Morgantown, WV	Biodiesel combustion engine, microturbine, PV, energy storage, advanced wireless communications, dynamic feeder reconfiguration
Con Ed—Interoperability of DR Resources	New York, NY	DR, PHEVs, fuel cell, combustion engines, intelligent islanding, dynamic reconfiguration, and fault isolation

Table 19: U.S. DOE Renewable and Distributed Systems Integration (RDSI) project list

Other research efforts

Given the strength of the research community among laboratories, universities, and companies in the U.S., a number of other research efforts in technology, software, and standards have helped push the U.S. to the forefront of microgrid development.

The Consortium for Electric Reliability Technology Solutions (CERTS) runs a micro-grid test bed facility in conjunction with American Electric Power in Groveport, OH as well as a laboratory simulator at the University of Wisconsin - Madison. The consortium is currently focused on finding ways to accommodate intermittent, distributed renewable energy sources within existing utility distribution systems and to find ways that microgrids can seamless connect and island from the grid. Currently, CERTS is adding multiple hardware units to its test bed facility, including:

- CERTS compatible conventional synchronous generator
- Flexible energy management system for dispatch
- Intelligent load shedding
- Commercially available, stand-alone electricity storage device with CERTS controls
- PV emulator and inverter with CERTS controls.

CERTS technology has been applied in other microgrid projects around the U.S., such as the Santa Rita jail project led by Chevron Energy Solutions.

In the area of software development, the DER-CAM has been developed by researchers at LBNL to predict and optimize the capacity and minimize the cost of operating distributed generation and CHP for individual customer sites or micro-grids. Based on specific site load (space heat, hot water, gas, cooling, and electricity) and price information (electricity tariffs, fuel costs, operation and maintenance costs, etc.), the model makes economic decisions on the distributed generation or CHP technologies the user should adopt and how that technology should be operated. A schematic for DER-CAM can be seen in Figure 27. The model has been used internationally for about 10 years now.

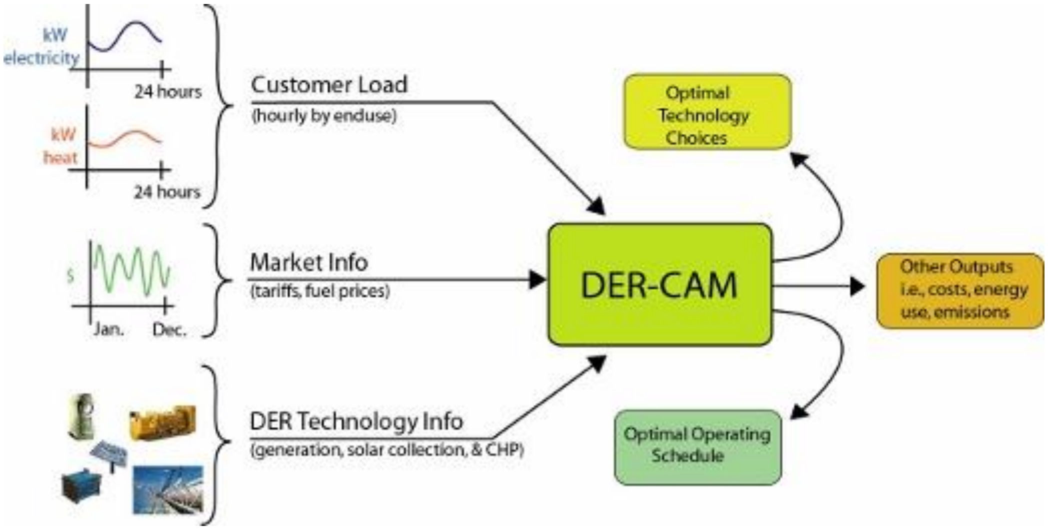

Figure 27: DER-CAM functionality

Also in the area of software development, Energy Surety Micro-grids (ESM) is an assessment tool, with some similarities to DER-CAM and an eye towards assessing a micro-grid possible application at military bases. ESM uses a risk assessment methodology for the critical power delivery functions and needs of a military bases, hospital, or community. To assess the specific military applications, the U.S. Army Engineer Research and Development Center (ERDC) has teamed up with Sandia National Laboratories to look at how micro-grids can be implemented, not only at home bases, but also in field applications, such as forward base camps and tactical operation centers. So far, 12 bases across the U.S. have been evaluated, with more in the pipeline.

Finally, the U.S. has been a leader in common standards development for interconnection of DER to the grid as well as islanding standards for microgrids. The development of these standards has streamlined business and safety operations for many projects and states trying to form regulations in these areas. In 2003, after five years of development, the IEEE 1547 *Standard for Interconnecting Distributed Resources with Electric Power Systems* was published with a goal of creating a unified technical requirement at a nation level. In 2011, also after many years of drafting, the IEEE 1547.4 *Guide for Design, Operation, and Integration of Distributed Resources Island Systems with Electric Power Systems* was published, covering microgrids and intentional islands.

Policy support

Although federal targets for renewable energy, distributed generation, and microgrids are absent (Obama's administration has set a notional goal for 80% clean energy by 2035), federal policies have laid the groundwork for successful state policies in renewable energy and distributed generation. In 1978, PURPA requires that all electric utilities purchase all output of distributed generation projects and provide on-grid and backup services to all qualified distributed generation projects. The U.S. Energy Policy Act of 2005 stipulated standard practice for net-metering and time of use metering. The Federal Energy Regulatory Commission (FERC) stipulated standards for interconnection of distributed energy generation projects (less than 20 MW) in 2006. Over the past decade, 44 states have established net-metering and interconnection policies while 30 states have established RPS's. A handful of states have specific carve-outs for distributed energy including Illinois, New Mexico, and Arizona. Additionally, there are regional cap and trade programs running for the power sector in the northeast U.S. (Regional Greenhouse Gas Initiative) and California (AB-32). In particular, California's cap and trade program may provide a promising environment for more development of CHP and microgrids.

Canada

Item	Description
Government agencies involved	Natural Resources Canada, NSERC Smart Microgrid Network
Main demonstration projects	Hartley Bay, BCIT campus microgrid
Supportive policies	Green Energy and Green Economy Act of Ontario and, Ontario feed in tariff, British Columbia clean energy act (2010), Western Climate Initiative, 17% reduction in greenhouse gas emissions by 2020; notional clean energy standard – 90% from hydro, nuclear, wind, solar, or CCS by 2020

Table 20: Summary of Canada's activities and policies surrounding microgrids

Canada has important initiatives in the smart grid area, which are helping to push its interest in microgrids. There are also many remote communities which microgrids could help serve to increase efficiency and reliability of energy supply. In terms of clean energy targets, Canada produced already 77% of its electricity from no carbon sources in 2009 (largely hydro, nuclear, biomass, and wind) with a notional goal of increasing that proportion to 90% by 2020.

R&D programs and demonstration projects

The NSERC Smart Microgrid Network (NSMG-Net) is Canada's flagship microgrid R&D program, with a total funding of $4.6 million over five years. NSMG-Net is comprised of government research labs and universities as well as partners in industry, provincial hydro utilities, and provincial governments. The themes of the research programs are:

- Operation, control and protection of smart microgrids;
- Smart microgrid planning, optimization and regulatory issues; and
- Smart microgrid communication and information technologies.

There will be a technology and simulations laboratory at the various participating laboratories as well as prototype development and technology demonstration at the British Columbia Institute of Technology (BCIT). The BCIT Campus Microgrid demonstration includes co-generation power plants and several solar

PV systems with a total generation capacity of around 14 kW. Work is also underway to equip the campus with a steam turbine-generator, as well as a wind turbine and biomass-fired boiler (to be fueled by beetle-infested timber).

Canada also has a successful microgrid demonstration project in Hartley Bay, in remote British Columbia. The town has 170 residents with a peak demand of 450 kW. Power is supplied by a 0.9 MW run-of-river hydro project and a 1 MW diesel generator. Smart meters have been installed at 62 residences and 20 commercial buildings, with an extensive communications package for collecting information on energy use. Direct control for hot water heaters, freezers, and thermostats was introduced as well in 2010. The project's main industrial partner is Pulse Energy, an energy management information software company.

Policy support

Beyond Canada's notional clean energy standard of 90% by 2020, many provinces have their own legislative efforts, most notably the Green Energy and Green Economy Act of Ontario which helped to establish a feed-in tariff program for renewable energy (preceded by the Renewable Energy Standard Offer Program of 2006) and the British Columbia Clean Energy Act which has a 93% clean energy goal for 2020 and an 80% GHG reduction target for 2050 (off 2007 levels).

Chile

The University of Chile has developed Chile's first microgrid project in a remote Andes Mountains community of 150 residents (mostly miners and their families) called Huatacondo. The microgrid includes a 150 kW diesel generator, 22 kW tracking solar PV system, a 3 kW wind turbine, a 170 kWh battery, and an energy management system. The wind turbine, located 700 meters away from (and 400 meters higher than) the community, was initially interconnected with a low voltage transmission line. Because voltage drop threatened a smooth and secure power transfer, the transmission line was upgraded to include four microformer units – a device installed in electric systems for medium voltage electricity transmission and low-power distribution. The energy management system provides online set-points for generation units while minimizing operating costs, taking into account renewable resource forecast, load, solar tracking, and water consumption. The project has had some impressive results so far such as consumption of diesel falling by 50% and the solar PV system achieving a capacity factor of 28%. There are many other communities like Huatacondo that could benefit from microgrid installations.

Appendix 2: Selected microgrid case studies

Hachinohe Project (an all-renewable microgrid)

The Hachinohe Project in Aomori Prefecture was part of the *Regional Power Grid with Renewable Energy Resource Project* funded by the NEDO. It operated from October 2005 to March 2008. The project was a collaboration between Hachinohe city, Mitsubishi Research Institute, and Mitsubishi Electric. NEDO's main goal for this project was to develop an optimum operation and control system, evaluate PQR, cost effectiveness, and GHG emission reductions. Meanwhile, the local governments wanted to construct a new industrial innovation zone centered on environmental and energy technologies.

The central feature of the system is that only renewable energy sources are used to supply electricity and heat. The supply sources include two 50 kW and three 10 kW solar PV systems, small wind turbines, a 100 kW lead-acid battery bank, and three 170 kW gas engines fed by sewage and waste gas by-product. At the sewage plant, a 1.0 t/h wood-waste steam boiler was installed to supply heat to protect the bacteria, and exhaust heat from the gas engines was reused in the gas fermentation process. The TOBU sewage plant treatment system was controlled by an information exchange network. The electricity produced was transmitted to schools, the local city hall, and an office building by a private distribution line 5.4-km, 6 kV feeder, and the whole system connected to grid at a PCC. The energy management system was developed to meet demands for both electricity and heat, while minimizing operation costs and CO2 emissions. Islanding operation was performed for one week in 2007, the purpose of which was to evaluate the ability of the system to maintain and control power qualities. The project is no longer in operation due to funding shortage.

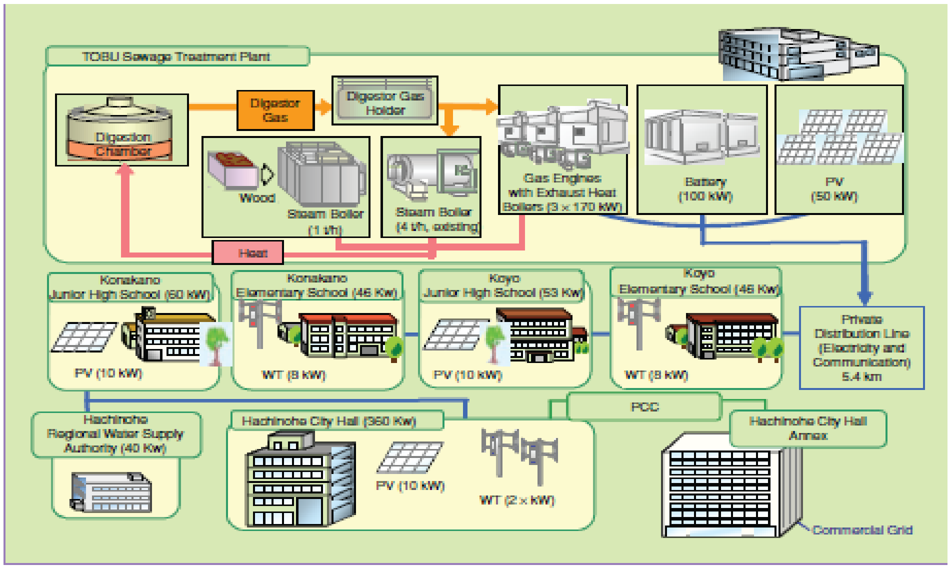

Figure 28: The System of Hachinohe Project (source: Y. Fujioka, et.al. 2006)

Illinois Institute of Technology Project (a perfect power prototype)

There have been a number of drivers for the Illinois Institute of Technology (IIT) to construct the perfect power prototype. First, the occurrence of at least three power outages per year resulted in a series of teaching and research disruptions with an estimated cost of $500,000 annually. The campus was also facing growing demand for energy and the need to add infrastructure to accommodate its growth, update costly old infrastructure, improve energy efficiency, and reduce consumption. IIT, in collaboration with the Galvin Electricity Initiative (GEI) and other key partners, is leading an effort to develop and validate innovative smart grid technologies, and demonstrate smart grid applications, community outreach, and renewed policies for better serving the consumers. This microgrid is sponsored by $7 million of federal funds (DOE) and $5 million of industrial funds together for five years. Its main purpose and objectives are to create a self-healing, learning, and self-aware smart grid that identifies and isolates faults, reroutes power to accommodate load changes and generation, and dispatches generation and reduces demand based on price signals, weather forecasts, and grid disruptions.

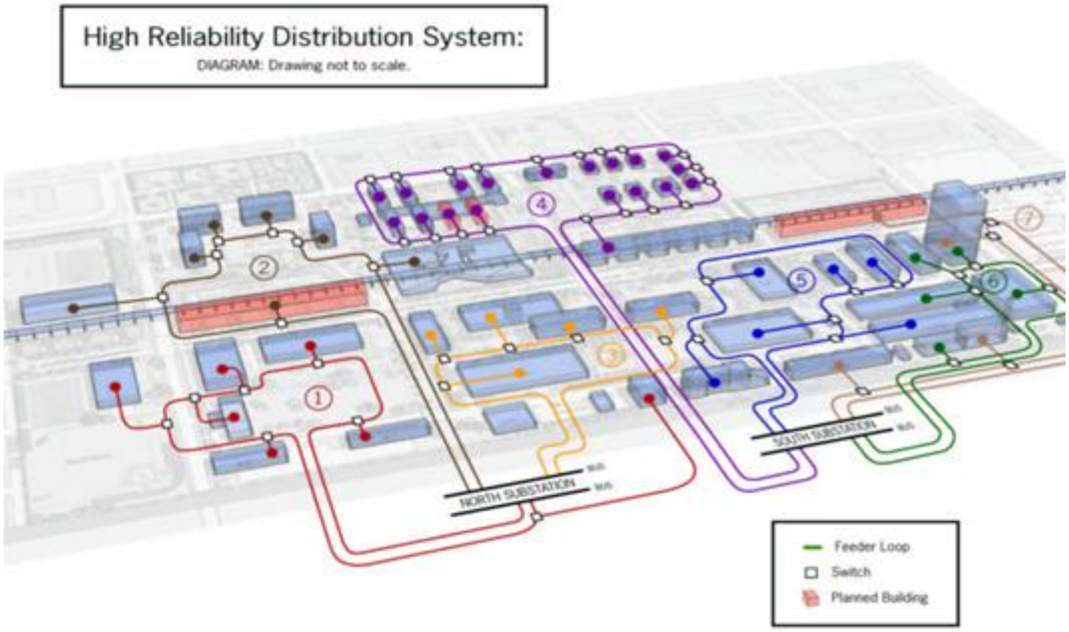

Figure 29: Diagram of IIT perfect power prototype

The IIT prototype will be the first of a kind integrated microgrid system that provides for full islanding of the entire campus load based on PJM[2]/ComEd market signals. Specific innovative technology applications include: high reliability distribution system, intelligent perfect power system controller, advanced ZigBee wireless technology, advanced distribution recovery systems, buried cable fault detection and mitigation.

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[2] PJM is the regional transmission organization (RTO) that Illinois is a part of.

The peak load of IIT's campus is around 10 MW. Their on campus DER includes two 4 MW combined cycle gas units and a small wind turbine, with plans to add rooftop PV this summer as well as a 500 kWh battery. Total DER capacity will be close to 9 MW then, so the campus is able to operate as an island most of the time, not importing any power from the grid. Full islanding capability has also been tested.

The campus is located near Comiskey Park where the Chicago White Sox play, and IIT is involved in their load reduction program during baseball games for which they receive significant payments. IIT invested $3 million in smart meters to be able to record how much load is being used in various buildings. Three levels of hierarchy are being implemented to control loads: a campus controller (being internally developed), building controllers (Siemens), and sub-building controllers (ZigBee). Around 20% of IIT's load can be shed with the potential to reduce peak load by up to 50% on demand, and achieve a 4,000 t/a reduction in carbon emissions. IIT has put out a request for proposal for demand response for 25% of the campus's total load.

Maxwell Air Force Base (a military microgrid)

The Maxwell AFB Microgrid is a research and development project to validate the basic functionality of autonomous engine controls based on the CERTS droop control concept. It does this by modifying the controls of existing diesel gensets and operating those with new generation that are located some distance away from the existing gensets but on the same distribution feeder. The goal is to determine if these generators can share the loads and maintain stability in an islanded mode.

The specifics of the project include two 600 kW diesel backup gensets that are located in one building and installing a new, CERTS-based 100 kW genset in a different building some distance from the first. The existing feeder connecting these two buildings will be sectionalized from the other loads by installing switchgear in the appropriate locations. This switchgear will isolate these two buildings from other loads on the feeder and create an experimental microgrid with two building loads and three generators.

Successfully demonstrating the stability of the controls will allow expansion of this microgrid to include more loads and additional generators that will maintain a stable microgrid, even in the absence of a central command and control architecture common to most microgrids today.

The ability to modify existing generators while adding new gensets with the CERTS droop functionality is an important milestone in the future deployment of microgrids, because a vast majority of existing buildings with mission critical functions already have legacy backup gensets that still have ample operational left life in them. Also, integration of new gensets with CERTS controls and renewable generation sources with inverters that have similar functionality can be readily integrated into such microgrids.

UCSD Project (a large campus microgrid)

The UCSD microgrid project supplies electricity, heating, and cooling for 450 hectare campus with a daily population of 45,000. The main two motivations for constructing the project are:

- After deregulation in California, the campus was able to purchase gas at an attractive rate to generate power by itself, for example, the built CHP plant had a five-year capital cost payback period based on avoided gas purchase costs.
- There is an existing campus steam distribution system for UCSD to have the ability to use steam to drive chilled water for cooling as well as hot water and heating.

The UCSD microgrid consists of two 13.5 MW gas turbines, one 3 MW steam turbine, and a 1.2 MW solar-cell installation that together supply 85% of campus electricity needs, 95% of its heating, and 95% of its cooling. The turbines produce 75% fewer emissions of criteria pollutants than a conventional gas power plant. For HVAC, it uses a 40,000 ton/hour, 3.8 million-gallon capacity thermal energy storage bank, plus three chillers driven by steam turbines and five chillers driven by electricity. A 2.8 MW molten carbonate fuel cell is running on waste methane, which is sponsored by California's self-generation incentive program funds and takes advantage of a 30% federal investment tax credit. The campus is connected to SDG&E by a single 69 kV substation. The UCSD uses a "straight SCADA system" for the building systems and energy supply to ensure their communication with each other. UCSD is installing a new, high-end master controller-Paladin, which will control all generation, storage, and loads with hourly computing to optimize operating conditions. It can receive as many as 260,000 data inputs/second. To support Paladin, UCSD will use VPower software to process market-price signals, weather forecasts, and the availability of resources. About 200 power meters on the main lines and at buildings' main circuit breakers, track use minute-by-minute. The UCSD campus has been installed with power meters throughout the main electrical lines and at the buildings' main circuit breakers. Lastly, DOE just gave USCD a grant to model the effects on the local distribution system from the ramping up and down of the solar PV system's output.

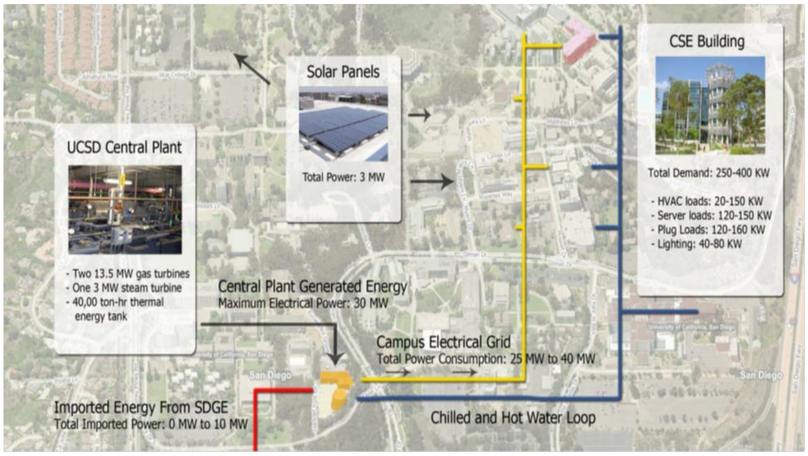

Figure 30: Energy Flow Through UCSD Microgrid (source: Yuvraj Agarwal, et. al., 2011)

Kythnos Island Project (a remote renewable microgrid)

Kythnos Island is located in the Aegean Sea, close to Athens. The Kythnos Island Project was funded by the European FP 5 Microgrids program, the objective of which was to test centralized and decentralized control strategies for islanding.

It is a small village scale autonomous microgrid, composed of a 3-phase low-voltage network, solar PV generation, battery storage, and a backup generator. The grid is composed of overhead power lines and a communication cable running in parallel to serve monitoring and control requirements. There are 10 kW of PV at two locations, a nominal 53 kWh battery bank, and a 5 kW diesel genset. A second PV array of about 2 kW connected to an SMA inverter on the roof of the control system buildings provides power for monitoring and communication, backed up by a nearby 32 kWh battery bank. Three SMA inverters connected in a parallel master-slave configuration supply power to the 12 summer-only residences, whose minimal loads are primarily lighting and water pumping. When more power is demanded by customers than the PV systems can directly provide, one or more of the 3.6 kW battery inverters is activated. The battery inverters can operate in isochronous or droop mode. Operating in frequency droop mode permits passing of information to switching load controllers, which limit loads if the battery state of charge is low and also constrains the power output of the PV inverters if the battery bank is full.

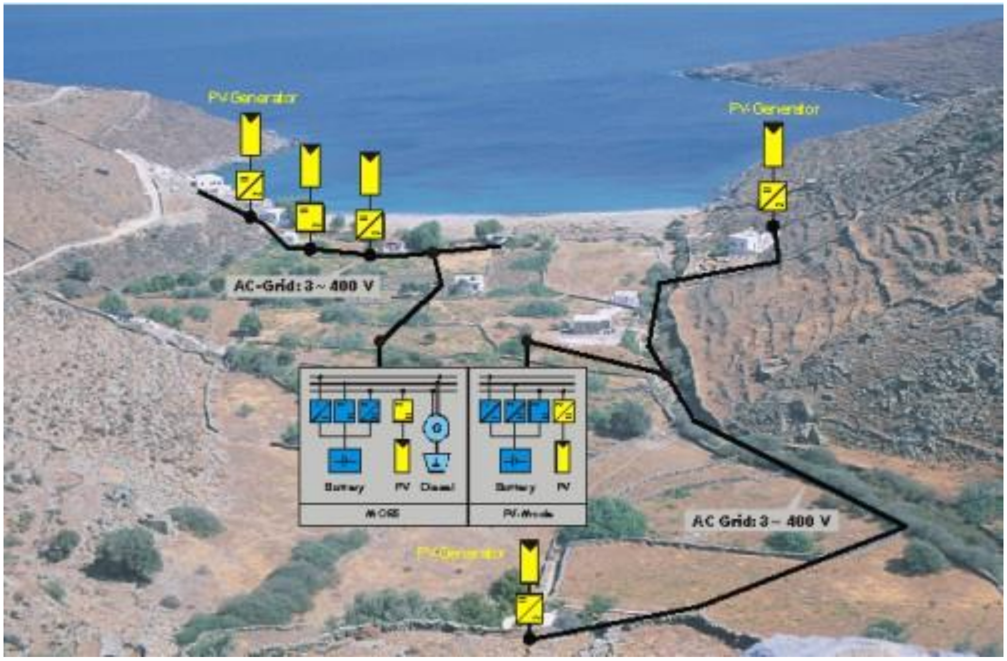

Figure 31: An Overview of Kythnos Island Project (source: EU More Microgrids Project)

MVV Project (a utility microgrid)

The MVV Project is located at Mannheim-Wallstadt in Germany, which is a 1,200 inhabitant ecological estate. It was funded by the “More Microgrids project” of the European FP 6 and private investors.

The proposed system comprises residential and commercial units and load, a 4.7 kW fuel cell, 3.8 kW solar PV system, a 1.2 kW flywheel storage unit, and two CHP units rated at 9 kW and 5.5 kW (electrical). The total on-site load varies between 80 kW to 230 kW. The building’s 60 kW ventilation and 48 kW boiler loads are controlled. At present, five PV systems, a total of 30 kW, and 1 CHP system have also been installed by private investors. The grid structure is suitable for further microgrid operations. The first goal of the experiment has been to involve customers in load management. Based on PV output availability information in their neighborhood, customers shifted their loads to times when they could use solar electricity directly.

Figure 32: Energy demand and supply display at MVV microgrid project

Aperture Center Project (a green field commercial building microgrid)

The Aperture Center in Mesa del Sol, Albuquerque, New Mexico will be the test site for a commercial microgrid. The project is a collaborative effort between U.S. and Japan. It is being carried out by NEDO, along with the State of New Mexico, Mesa del Sol, Public Service Company of New Mexico, Sandia and Los Alamos national labs, and Los Alamos County.

Figure 33: Natural gas generator at the Aperture Center microgrid

This demonstration is bringing Japanese technology to demonstrate how to integrate multiple generation sources including renewable energy resources along with multiple storage sources, and how they can be optimized to interact with the building load. A number of Japanese companies are participating in the project, including Toshiba, Sharp, Fuji Electric, Tokyo Gas, and Mitsubishi. Each of the Japanese companies has specific research they want to do in this project. The Japanese have funneled about $30 million statewide into many smart grid projects in New Mexico, including this project at the Aperture Center. The local utility company is only involved in order to ensure that it interconnects and operates safely within the distribution grid.

Figure 34: Solar PV array at the Aperture Center microgrid

The system comprises a 50 kW solar PV system mounted on a shade structure over a parking lot and utility yard, currently under construction, that will contain an 80 kW fuel cell, a 240 kW natural gas-powered generator, a lead-acid storage battery power system, and hot and cold thermal storage. All parts will be interconnected through a control room and building management system in the Aperture Center. The project is on schedule to be up and running in mid to late spring of 2012.

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