A U.S.-CHINA-EUROPE SMART GRID BENEFITS COMPARISON

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U.S.-China Climate Change Working Group - *Smart Grid*

- Three-year program 2014-2016
- One workshop in each country in each year
- Two sub-groups: Advanced Technology & Benefits
- Benefits Subgroup picked 2+ microgrids on each side for benefits analysis (BA)
- U.S. ones are
    1. Irvine Smart Grid Demonstration Project (ISGD) & U.C. Irvine campus (UCI),
    2. The Philadelphia Navy Yard (TNY)
- China ones are
    1. Sino-Singapore Tianjin Eco-city (TEC)
    2. Shenzhen Bay Technology and Ecology City (B-TEC)
- Contribution from the Joint Research Centre (JRC) of the European Commission via ACEA smart grid demonstration project
- All benefits analysis are completed
- A joint white paper prepared

Benefits Evaluation Subgroup Leads

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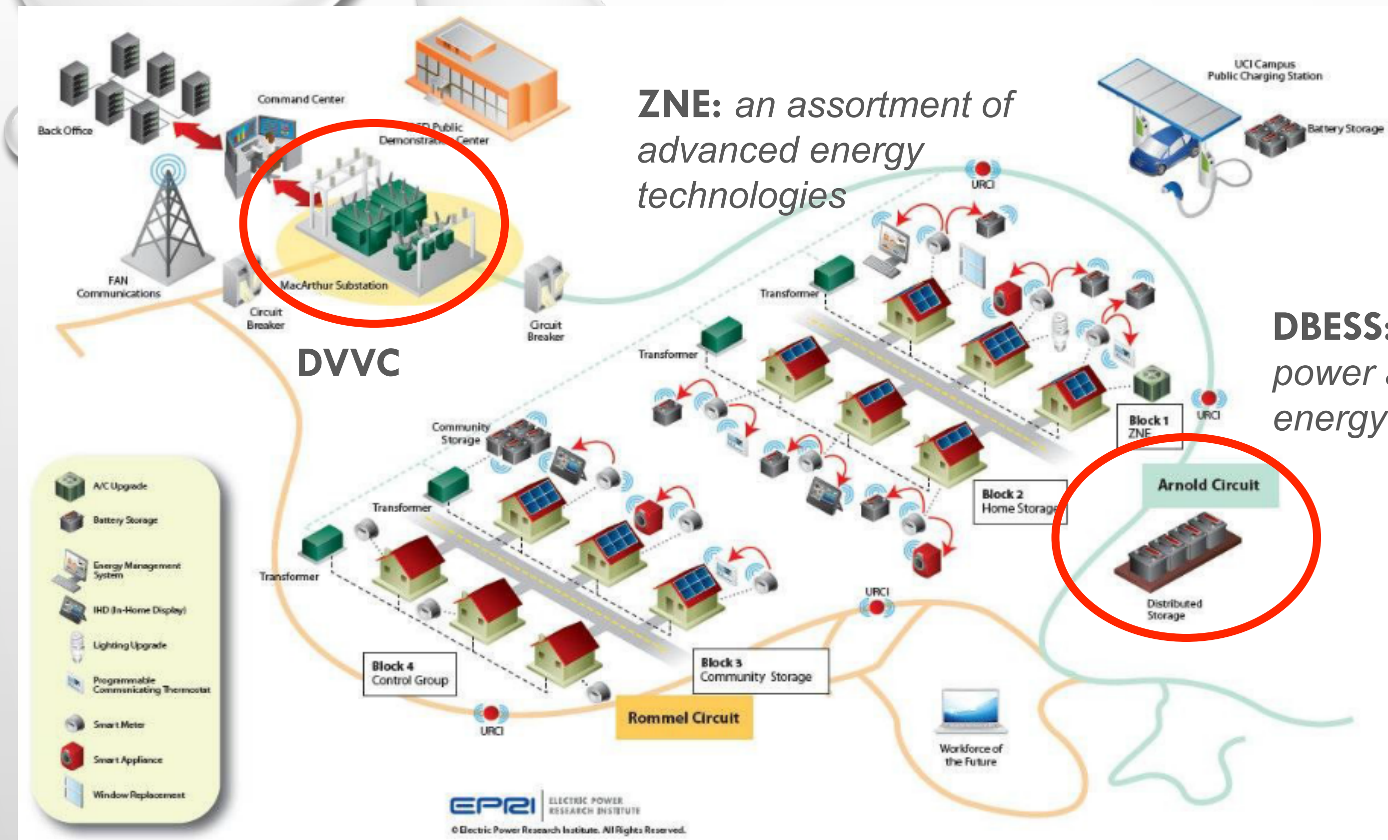
Outline

- Project Overviews
- Approaches
- Results
- Approaches Comparison

Project Overviews

Irvine Smart Grid Demonstration, U.S.



DBESS: *2 MW of real power and 500 kWh of energy storage*

Southern California Edison (SCE) operated the ISGD project, and many of the project components were located on or near UCI

- ZNE: Zero Net Energy (ZNE) Homes Through Smart Grid Technologies
- DBESS: Distribution Circuit Constraint Management Using Energy Storage
- DVVC: Distribution Volt/VAR Control (DVVC)

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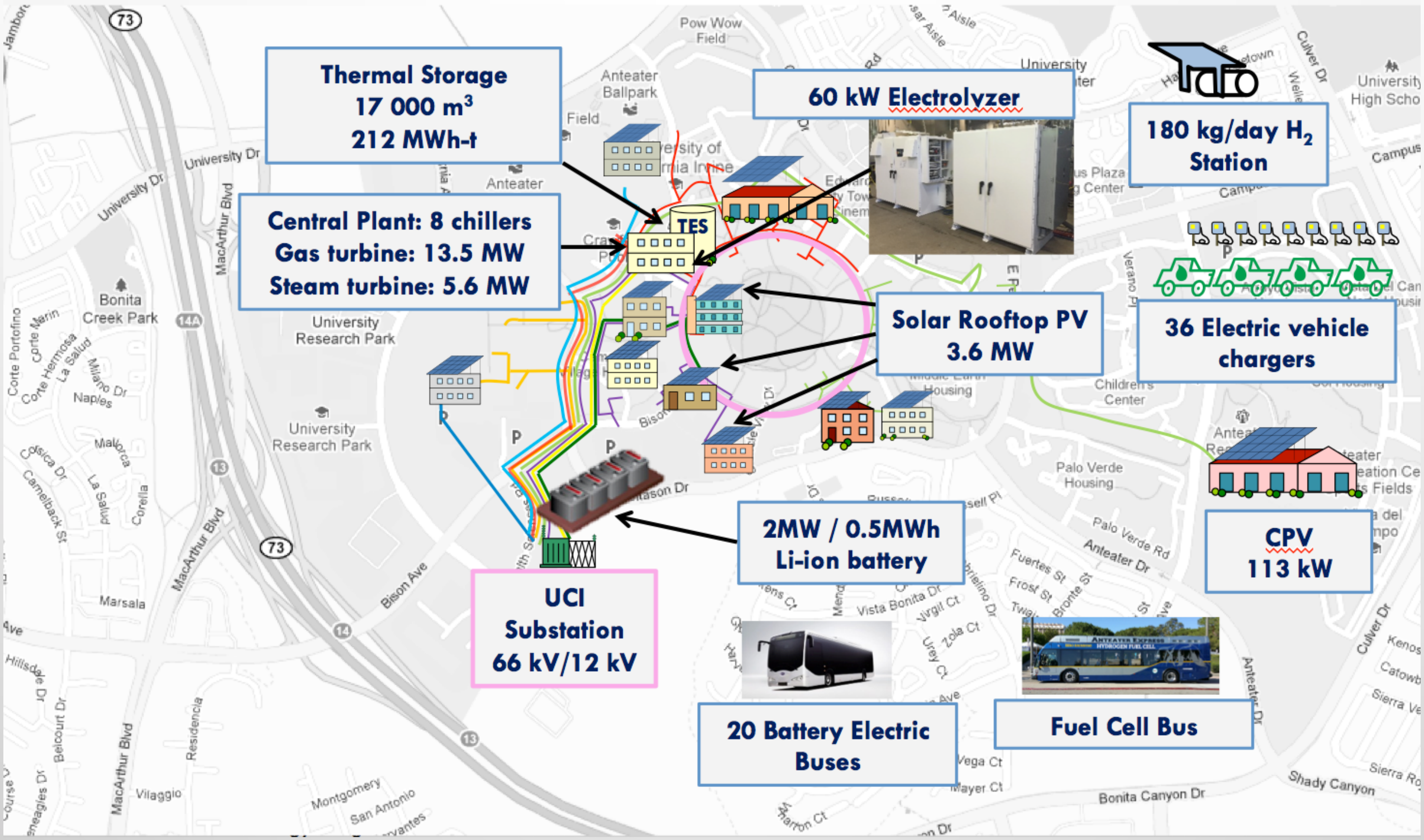
University of California, Irvine, U.S.



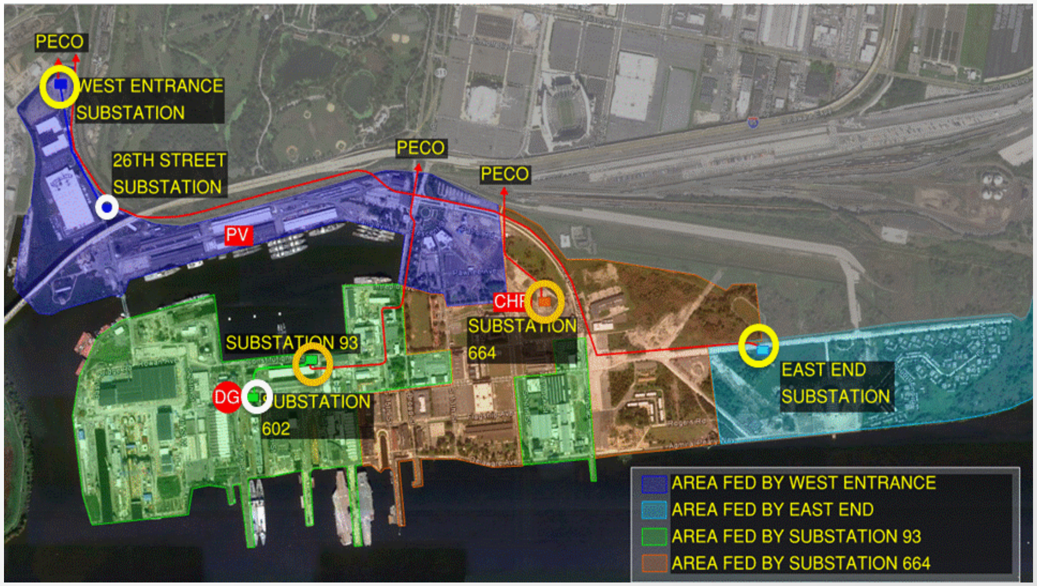
Sub-projects included

- Central 19 MW CHP Plant
- PV Arrays Totaling 3.6 MW
- Microgrid Controller (MgC)
- Lithium-ion battery (LiB)


ZERO
EMISSIONS
MODEL S

The Philadelphia Navy Yard, U.S.

"TNY area was a longstanding military base, which is now being repurposed as a mixed commercial-industrial, and possibly residential, development."



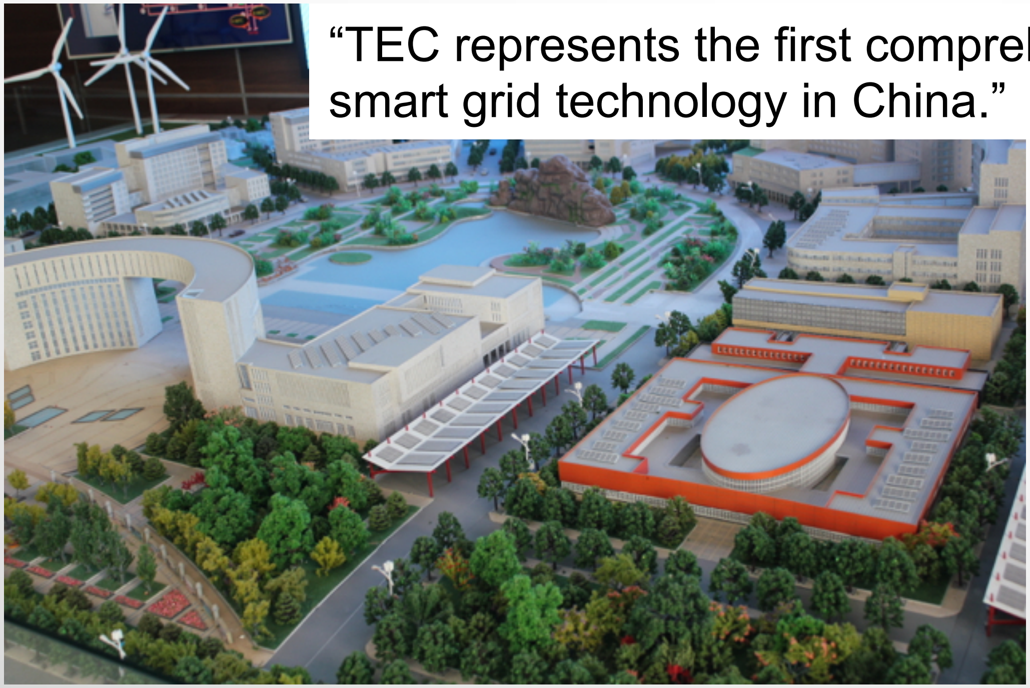
TNY has established a Microgrid Network Operation Center which will serve as the microgrid control room to support following key functions

- Integrated smart metering and communication functions
- SCADA and distribution grid monitoring functions
- Substation data automation and monitoring
- Operation interface with 3rd party owned asset operation
- Operation interface with PECO
- Operation interface with PJM and/or 3rd party PJM aggregator operation
- Platform for the microgrid control system


METER

Sino-Singapore Tianjin Eco-city, China

“TEC represents the first comprehensive study of all aspects of smart grid technology in China.”



“The implementation of key projects focuses on the pilot ecological city zone, a 4 km^2 area located south of the TEC.”

Three sub-projects from TEC are included in this analysis

Microgrid with Storage (MgS)
Smart Substation (SS)
Distribution Automation (DA)

Initial construction in the Cheong Road area included a 110 kV intelligent substation, and a total of 123 planned distribution sites.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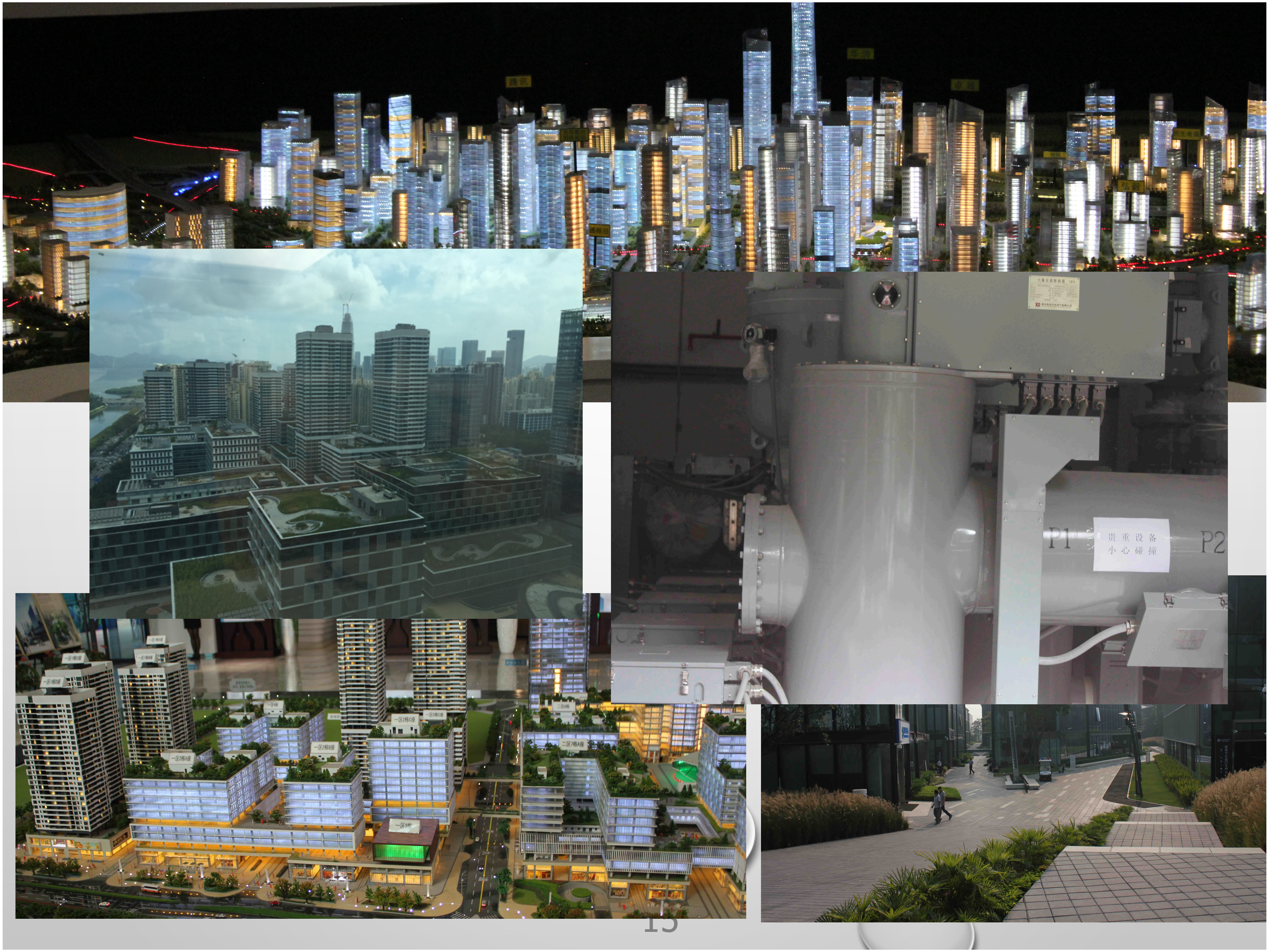
中新生态城 红树湾样板间
智能光伏系统 实时信息
今日发电量
今日用电量
今日上网电量
本月发电量
本月用电量
本月上网电量
当前价阶
当前模式

Shenzhen Bay Technology and Ecology City, China

"Covering an area of 0.2 km2 and a total construction area in excess of 1.2 km2, the B-TEC is the pilot technology demonstration for the huge Qianhai smart power grid."

B-TEC includes optimal scheduling, smart metering with advanced energy services, and distribution network asset life-cycle O&M minimization based on big data. 5 sub-projects included in this study are

- Optimal operation and fault self-recovery system of distribution grid (OOFSS)
- Distributed energy coordination and scheduling (DECS)
- AMI system (AMI)
- Distribution operational state sensory module (OSSM)
- Load center energy storage station (ESS)


P1
贵重设备
小心碰撞
P2

Benefits Approaches

Smart Grid Computational Tool (SGCT), U.S.

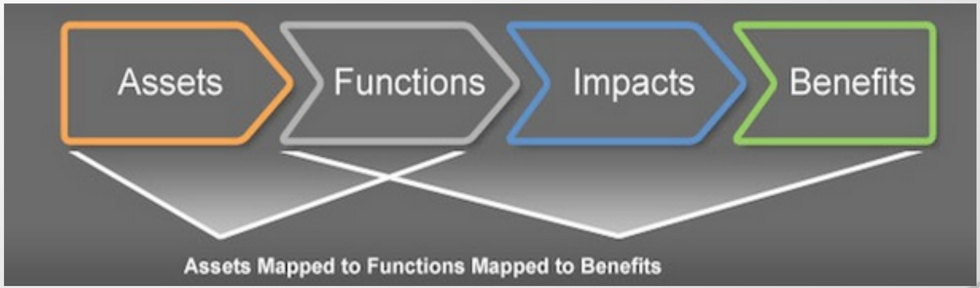
used for ISGD BA Analysis

In order to develop a standard framework that can be applied by anyone interested in assessing the benefits of smart grid projects,

1. *U.S. Department of Energy (DOE),*
2. *Electric Power Research Institute (EPRI),*
3. *DOE's Oak Ridge National Laboratory*

jointly develop a methodology to systematically estimate the benefits of smart grid projects.

Benefits ((1) economic, (2) reliability and power quality, (3) environmental, (4) security and safety) are derived from the types of assets (i.e., components, technologies) deployed in a smart grid project and the types of functions they enable.



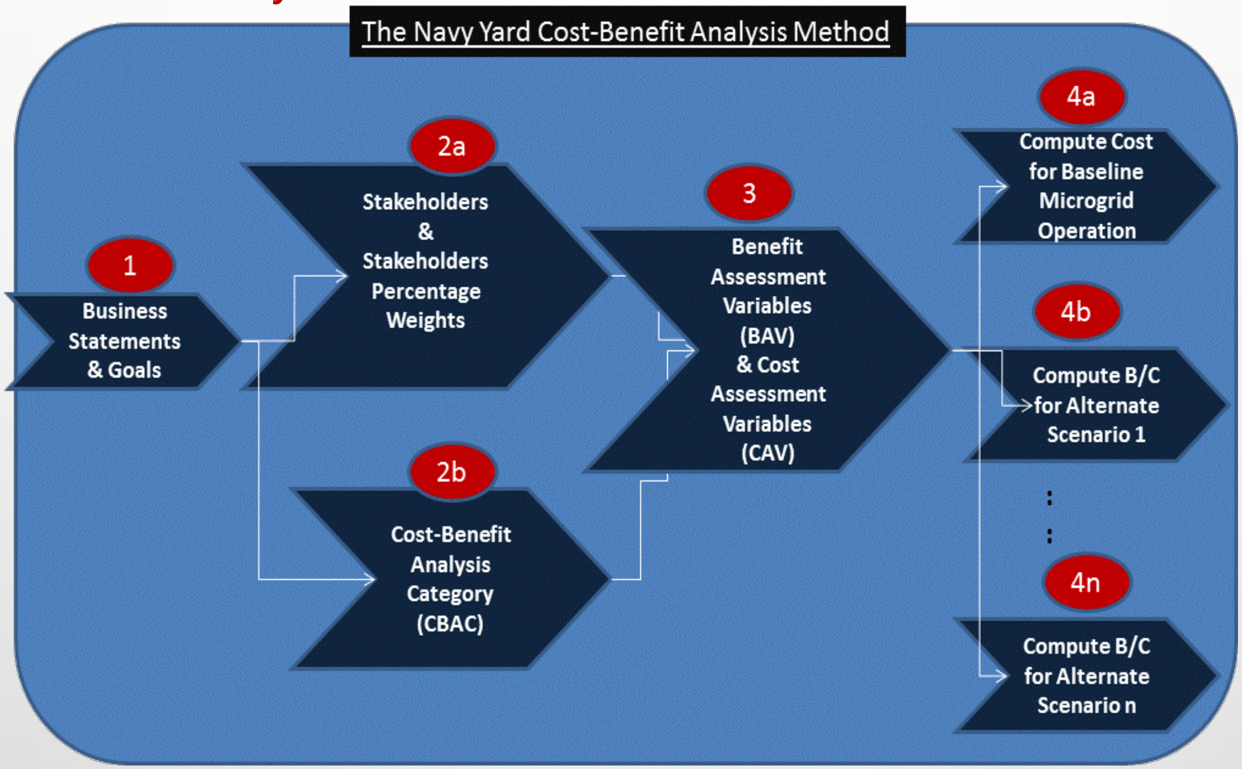
Source: https://www.smartgrid.gov/recovery_act/program_impacts/analytical_approach

Resources:

1. DOE Smart Grid Computational Tool Users Guide 2.0
https://www.smartgrid.gov/document/doe_smart_grid_computational_tool_users_guide_20
2. Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects -
https://www.smartgrid.gov/node/58271

TNY Approach, U.S.

used for TNY BA Analysis



The framework of BA with TNY approach is based on computing a set of project benefits and costs for a given operation scenario compared to a baseline.

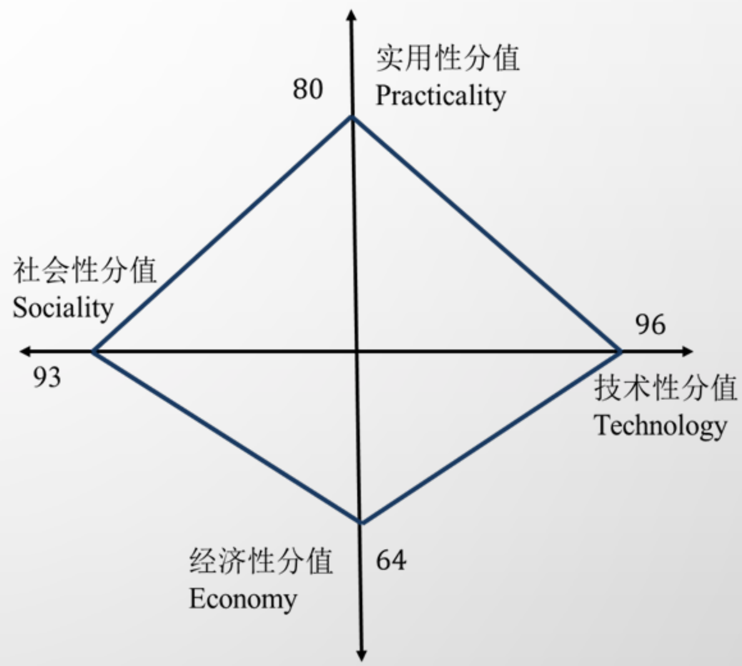
Four Cost-Benefit Analysis Categories (CBAC) are defined: (i) Financial / Economic, (ii) Operational Reliability and Efficiency (iii) Environmental, and (iv) Innovation and Economic Growth.

Smart Grid Multi-Criteria Analysis (SG-MCA), China

used for TEC BA Analysis

SG-MCA method

includes four dimensions:
- technology,
- economy,
- sociality,
- practicality,



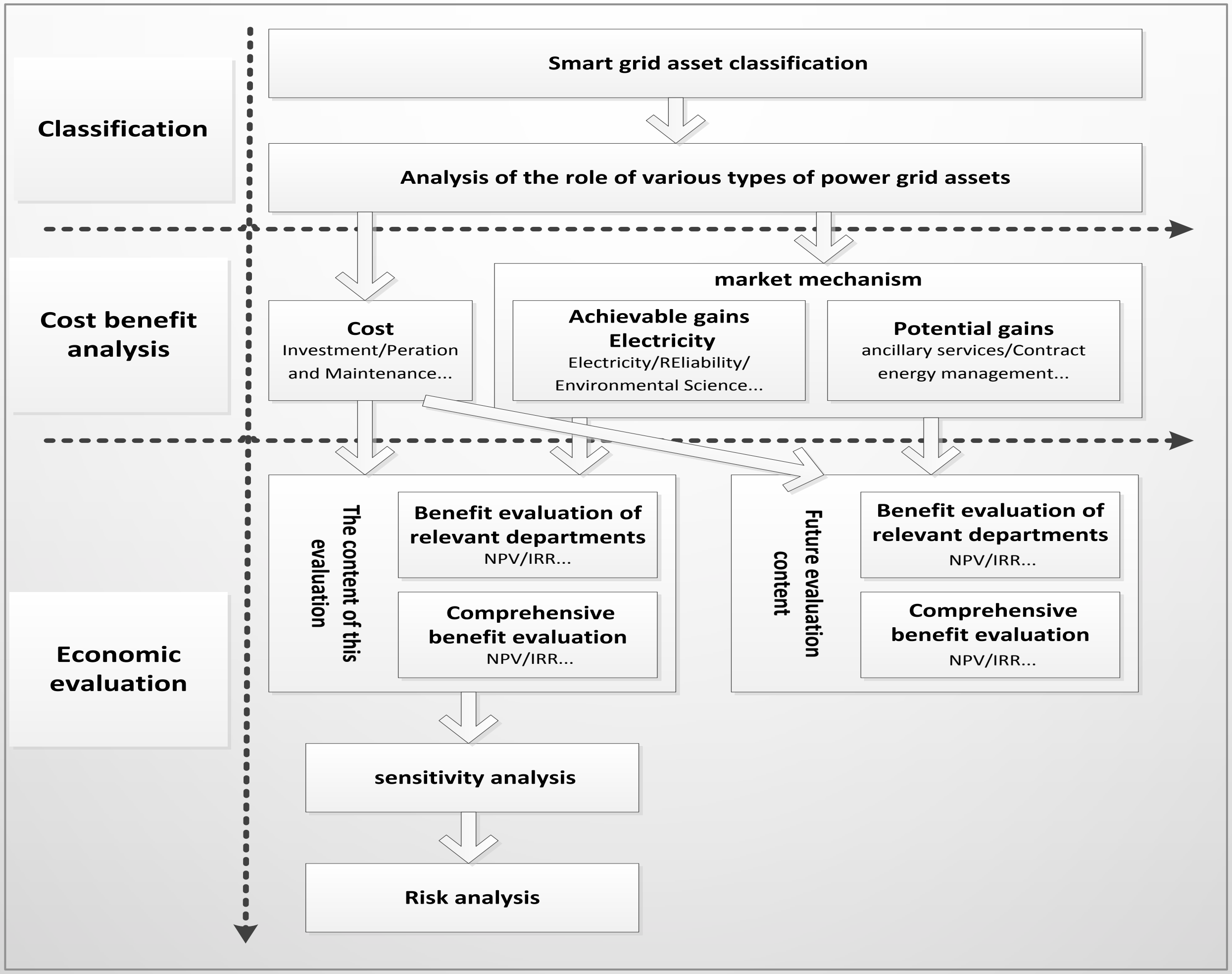
includes two indicators:
- qualitative
- quantitative

employs
- a combined *Analytic Hierarchy Process and fuzzy evaluations* methods.

By combining these 2 evaluation methods, a composite index score is attributed to each smart grid project.

Qianhai Project Approach (QPA), China

used for B-TEC BA Analysis



In the QPA, achievable benefits and potential benefits of smart grid projects are analyzed from two perspectives; (1) stakeholders, e.g. consumers, the Shenzhen Power Supply Bureau, and utility, and (2) investors.

Comparison/Summary of the Methods

	SG-MCA	QPA	EPRI-SGCT	TNY	JRC*
Approach	Multi-criteria Analysis	Single criteria	Single criteria	Single criteria	Single criteria
Decision Criterion	Qualitative	Quantitative	Quantitative	Mixed	Mixed
Benefit types	Economic, Reliability, Environmental/ Social, Security, Technical, Practical	Economic, Reliability, Environmental/ Social	Economic, Reliability, Environmental/ Social, Security	Economic, Reliability, Environmental/ Social, Innovation	Economic, Reliability, Environmental/ Social, Security
Evaluation	weigths/shares	monetary values	monetary values	monetary values/shares	monetary values/ KPIs
Stakeholder involvement	direct involvement	no involvement	no involvement	indirect involvement	no involvement
Data requirement	Moderate	Intense	intense	intense	intense
Project capital cost	not included	Included	included	included	included
Transparency	not transparent	not transparent	transparent	not transparent	transparent
Application feasibility	micro-scale	micro-scale	large-scale	micro-scale	large-scale
Results	performance indicator	NPV, IRR, P_t	NPV	B/C ratio	NPV, B/C ratio, P_t

*JRC Approach is based on EPRI's methodology and uses Key Performance Indicators to capture some quantitative impacts.

CBA Results

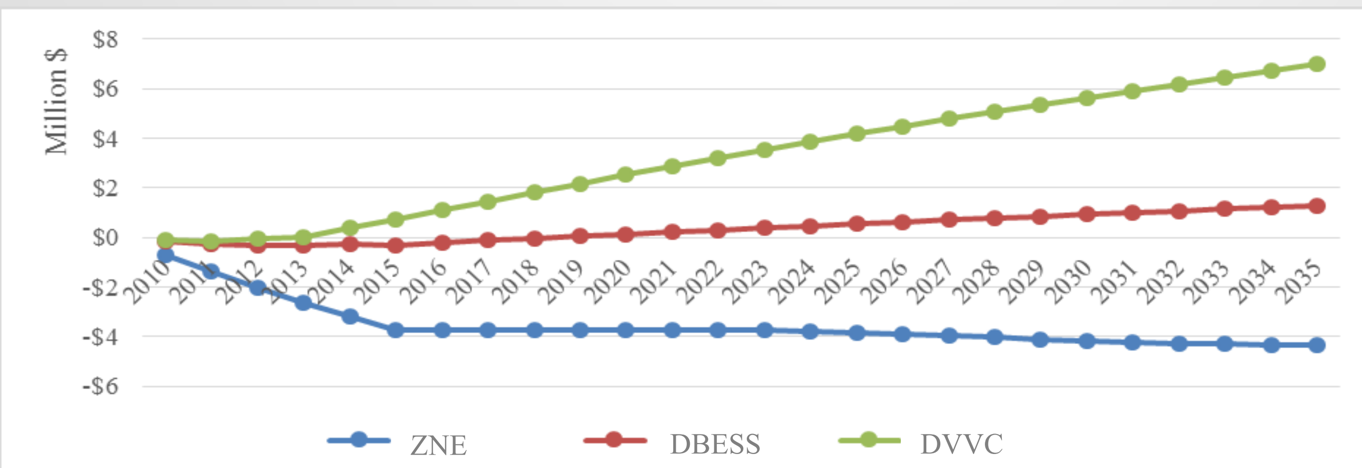
ISGD, U.S.

Benefits, Costs, and B/C Ratios for ISGD Sub-projects via SGCT tool

Net Present Values	ZNE	DBESS	DVVC
Cost	$(4.64M)	$(0.85M)	$(0.59M)
Benefit	$0.30M	$2.14M	$7.58M
Net Benefit	$(4.34)M	$1.30M	$6.99M
B/C Ratio	0.1	2.5	12.9

NOTE: The cost of ZNE needs to be about 94 % lower to achieve a B/C ratio greater than 1, i.e. breakeven. DBESS and DVVC appear to be economic, the latter strongly so.

Cumulative net present benefits of ISGD Sub-projects



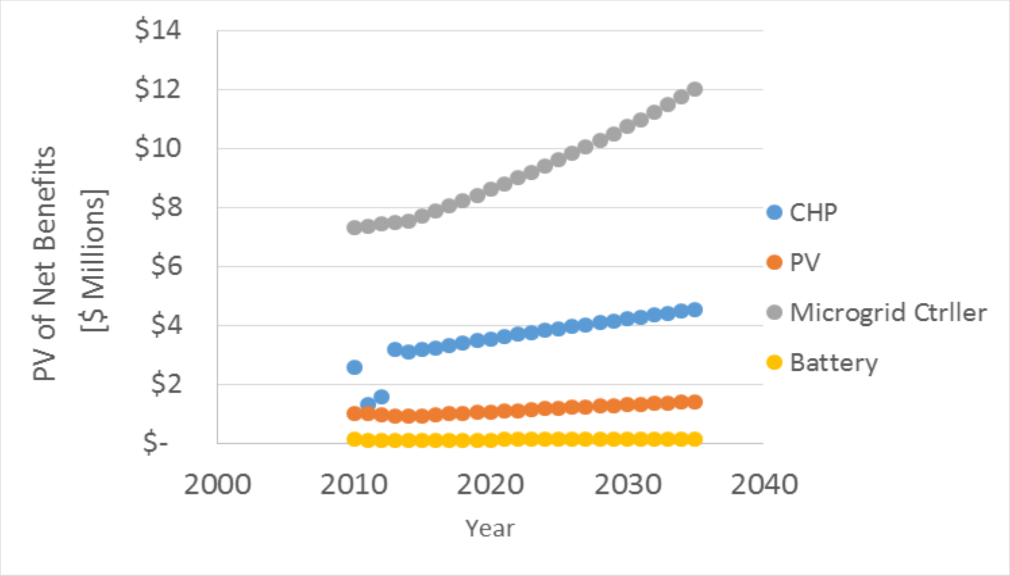
UCI, U.S.

Benefits, Costs, and B/C Ratios for UCI Sub-projects via SGCT tool

	CHP	PV	MgC	LiB
Cost	$(30.6M)	$(13.7M)	$(1.14M)	$(0.51M)
Benefits	$124M	$43.2M	$242M	$3.47M
Net Benefit	$93.1M	$29.5M	$241M	$2.96M
B/C Ratio	4.0	3.2	212	6.8

NOTE: The MgC project shows an extremely high value, driven by its highly valued reliability improvement. It was assumed outages caused by the SCE system would be solved by islanding, yielding a decrease in System Average Interruption Duration Index (SAIDI) from 1.17 to 0.17 h/a. The CHP plant also shows significant value, largely a result of the economic benefit associated with optimized generator operation, and current low gas prices.

Cumulative net present benefits of UCI Sub-projects



TNY, U.S.

Comparison Summary of Scenario Results in the TNY

Scenario Results	**Scenario 1**	**Scenario 2**	**Scenario 3**
Cost	$(2.41)M	$(2.03)M	$(3.18)M
Benefit	$3.61M	$3.63M	$6.82M
Weighted B/C	2.79	4.05	3.87
Non-Weighted B/C	1.5	1.79	2.14

NOTE:

Scenario 1: Microgrid Controller integrated with a 6 MW internal combustion engine. Substation 93 is at or near capacity at certain times of the year, so the 6 MW unit will delay the need to expand the substation and thus avoid significant capital expense. In addition, the asset will provide resiliency benefits and financial benefits through participation in PJM markets.

Scenario 2: Microgrid Controller with 2 MW of Solar PV and 2.5 MW of Battery Storage. Daily solar PV output would coincide with typical peak load periods and the solar-storage asset would provide multiple potential benefits including helping to delay the need to expand the substation, reducing peak loads, and financial benefits through participation in PJM markets.

Scenario 3: Microgrid Controller with 6 MW Internal Combustion Engine and 2 MW Solar PV and 2.5 MW Battery Storage would be interconnected to Substation 93 in the industrial zone of TNY and be operated to shave peak demand, participate in energy markets to earn revenue, and provide resilience to customers served by the area substation.

TEC, China

Results for the Overall TEC Project and Three Sub-projects Using the SG-MCA Approach

	TEC project	DA	Microgrid	SS
Practicality	80	92	90	96
Technology	96	94	98	94
Economy	64	55	58	70
Sociality	93	86	75	80

NOTE: The overall performance of the Eco-city project with the SG-MCA method is good with a score of 87 of 100, but the economy is relatively poor with a score of 64.

(1) Practicability: the TEC project has supported local business development and promoted energy conservation.

(2) Technology: the power supply reliability is over 99.9 %, power quality rate has been increased to 100 %. All the renewable energy resources are controllable including wind turbine and PV, with a utilization rate of over 20 %.

(3) Economy: the TEC project can reduce annual investment of 11.7 million RMB in land cost, line loss, power supply reliability, operation, and maintenance costs. However, many software and hardware capabilities were first developed for the project without solid policy support and appropriate business models.

(4) Sociality: DGs, microgrid, and EV charging facilities have a significant contribution to energy conservation with a reduction of about 1074.32 t of fuel consumption, 5929.7 t of standard coal, 18,488 t of CO2 emissions per year. Also these projects can stimulate technology upgrades and development of equipment manufacturing, electronic information, petrochemicals, new energy, and new materials with significant social benefits.

B-TEC, China

Results of B-TEC Sub-projects via QPA Approach

	OOFSS	DECS	AMI	OSSM	ESS
IRR (%)	17%	-17%	12%	6%	7%
NPV (RMB)	1.05M	-1.75M	1.16M	(0.11)M	
Payback (year)	6	Cannot be paid back	8	10	9

NOTE: OOESS and DECS sub-projects consider social benefits in addition to Power Supply Bureau benefits in the analysis, while the Bureau is the main beneficiary of the AMI, OSSM, and ESS sub-projects.

- Optimal operation and fault self-recovery system of distribution grid (OOFSS)
- Distributed energy coordination and scheduling (DECS)
- AMI system (AMI)
- Distribution operational state sensory module (OSSM)
- Load center energy storage station (ESS)

Comparison of the Methods after the Real Cases

Method	Strengths	Weaknesses	Stakeholders	Applicability
SG-MCA	- Systematic - Simple and practical - Direct stakeholder involvement - Less data need - More realistic	- Subjective judgments of experts - Poor evaluation of project cost - Data need increases with index numbers - Decision matrix becomes too complex to solve if many indexes	- Utility - Power suppliers - Consumer - Government - Society	Could be applied to most of the smart grid projects
QPA	- Modular thinking - Simple principles - Easy expansion - Clear quantification & objective conclusions - Stratified analysis (from individual devices to large-scale projects) - Analysis from perspectives of different stakeholders	- Method's analysis framework only applicable to a few examples, i.e. projects with technical frameworks similar to Qianhai's - Excludes non-monetary values - No stakeholder involvement	- Utility - Power suppliers - Consumer - Government - Load integrators	Applicable to other projects by initially selecting a subproject or module, then establishing the analytical framework
TNY	- Business Model Driven - Multi-Stakeholder involvement - Integration Framework	- Elements of Subjective/ Qualitative Approach - Excludes non-monetary values	- Direct Project Participating Entities	Applicable, but only after customization
JRC	- Flexibility - Well-understood theoretical foundation for economical analysis - KPIs and qualitative analysis	- Large set of data need - No stakeholder involvement	- Utility - Power suppliers - Consumer - Society	Can be tailored to virtually any project
EPRI-SGCT	- Simple, explicit, and transparent mappings - Clear definition of technologies, impacts, and benefits - Well-understood theoretical foundation for economical analysis - Same set up for all projects makes it easier for comparison	- Excludes non-monetary values - Large set of data need - Inflexibility - No stakeholder involvement	- Utility - Power suppliers - Consumer - Society	EPRI method can be applicable to all types of projects. However, SGCT is locked against any changes, making it poorly applicable to projects beyond straightforward technology deployment or outside U.S. conditions.

Thank you!

Motivation for Benefits Subgroup

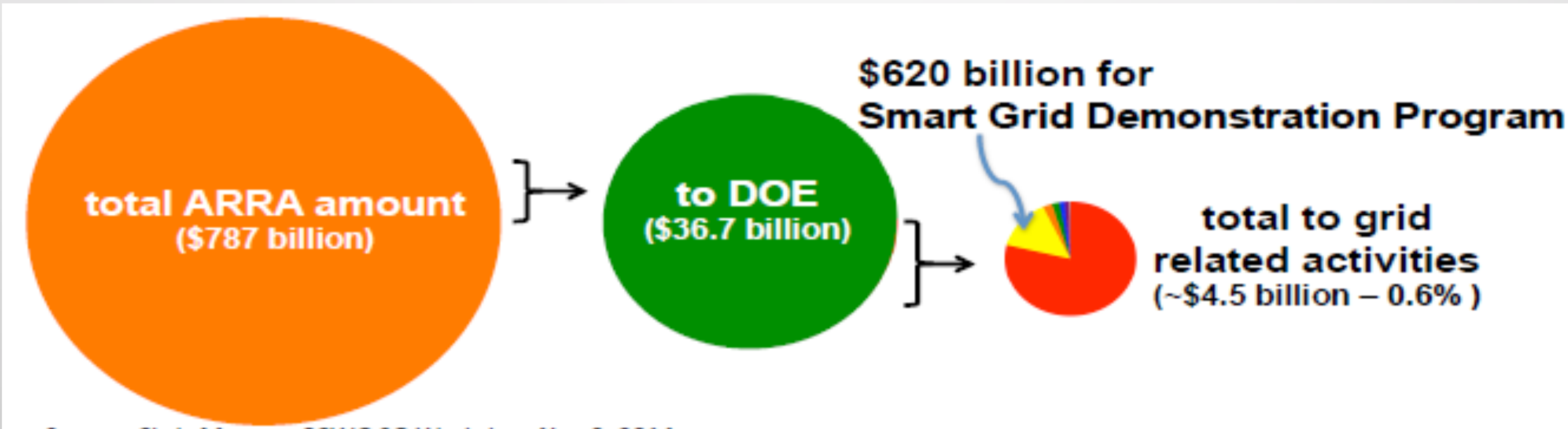
- “Multiple approaches to benefits analysis have accompanied projects around the world, and there is a clear need for an understanding of their differences, and for movement towards a common approach.”

- “A coherent basis for international evaluation of project performance can facilitate comparison and transfer of results, and accelerate smart grid deployment.”

“The goal of *Benefits Subgroup* is to advance the development of a coherent international basis for evaluation of smart grid projects.”

Intro and Background on ARRA

- ARRA enacted February 2009
- $787 billion distributed via contracts/jobs, grants, loans, and tax relief
- $36.7 billion (~5%) available to U.S. Department of Energy (DOE) programs, including ~$4 billion for Smart Grid development
- $0.6 billion for Smart Grid Demonstration Program (32 projects)



Source: Chris Marnay, CCWG SG Workshop Nov 9, 2014

ZNE at ISGD: Three Levels of Retrofits

Total of 22 single family detached homes with different characteristics:

1. Zero Net Energy (ZNE) Block (9 Homes)
   a. Demand Response Devices
   b. Energy Efficiency Upgrades
   c. Residential Energy Storage Units (4 kW)
   d. Solar PV Arrays (~3.9 kW)
2. Residential Energy Storage (RESU) Block (6 Homes)
   a. Demand Response Devices
   b. Residential Energy Storage Units (4 kW)
   c. Solar PV Arrays (3.2-3.6 kW)
3. Community Energy Storage (CES) Block (7 Homes)
   a. Demand Response Devices
   b. Community Energy Storage Unit (25 kW)
   c. Solar PV Arrays (3.2-3.6 kW)

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ACEA, Europe

Results of JRC BA on Malagrotta pilot project and its scale up to Rome (Private investor BA)

	Smart Grid project		Automation		MV/LV monitoring		New management criteria	
	NPV(2014)	IRR	NPV(2014)	IRR	NPV(2014)	IRR	NPV(2014)	IRR
Malagrotta (Pilot)	€(1.26)M	1.2%	€(0.37)M	1.9%	€(0.46)M	0.6%	€(0.43)M	1.1%
Rome (Scale-up)	€35.9M	16.6%	€10.0M	12.6%	€24.6M	21.2%	€1.41M	12.3%

NOTE: The outcome of the analysis points to an IRR for Malagrotta of 1.2 % that however becomes 16.6 % when the solutions tested are scaled up from the pilot to the whole Rome grid. The most promising sub-project, in terms of contribution to total benefits, is the LV monitoring and remote control.

ACEA, Europe

"ACEA, the third largest Distribution System Operator in Italy, tested some Smart Grid solutions on a pilot project in Malagrotta."

"The project involved the installation of new technologies on 6 feeders, about 69.5 km of medium voltage (20 kV) and low voltage (8.4 kV) lines, both underground and aerial."

The project is made up of 3 main components, that are additive:

- Medium Voltage (MV) grid automation
- At both Medium Voltage (MV) and Low Voltage (LV) levels, ACEA set up a remote control and monitoring system that allows remote operation of more than 60,000 switches. This sub-project included real time measurements at secondary substations.
- At the central level, the development and set up of a new grid management algorithm will allow capture of further benefits of the first two sub-projects, such as load flow management, optimization of load profiles, and minimization of technical losses.

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Summary of ARRA SGDP Projects: Regional Demonstrations

	Project	Project Type*	ARRA Award Amount	Total Project Value
1	Battelle Memorial Institute (Pacific Northwest Division Smart Grid Demonstration Project)	AMI, CS, DER, DS	$88,821,251	$177,642,503
2	AEP Ohio (gridSMARTSM Demonstration Project)	AMI, CS, DER, DS, P	$75,161,246	$148,821,823
3	Los Angeles Department of Water and Power (Smart Grid Regional Demonstration)	AMI, CS, DER, DS, P	$60,280,000	$120,560,000
4	Consolidated Edison Company of New York, Inc. (Secure Interoperable Open Smart Grid Demonstration Project)	CS, DER, DS, TS	$45,388,291	$92,388,217
5	Southern California Edison Company (Irvine Smart Grid Demonstration)	AMI, CS, DER, DS, P	$39,621,208	$79,242,416
6	National Rural Electric Cooperative Association (Enhanced Demand and Distribution Management Regional Demonstration)	AMI, CS, DER, DS, P	$33,932,146	$67,864,292
7	Kansas City Power and Light (Green Impact Zone SmartGrid Demonstration)	AMI, CS, DER, DS, P	$23,940,112	$49,830,280
8	CCET (Technology Solutions for Wind Integration)	CS, DER, DS, P, TS	$13,516,546	$27,075,457
9	Long Island Power Authority (Long Island Smart Energy Corridor)	AMI, CS, DER, DS, P	$12,496,047	$25,293,801
10	Pecan Street Project Inc (Energy Internet Demonstration)	AMI, CS, DER, P	$10,403,570	$24,657,078
11	Waukesha Electric Systems Inc (Fault Current Limiting Superconducting Transformer)	TR	$10,239,411	$20,478,822
12	The Boeing Company (Boeing Smart Grid Solution)	TS	$8,561,396	$17,172,844
13	NSTAR Electric and Gas Corporation (Urban Grid Monitoring and Renewables Integration)	AMI, DER, DS	$5,267,592	$10,591,934
14	Oncor Electric Delivery Company (Dynamic Line Rating)	TS	$3,471,681	$7,136,552
15	NSTAR Electric and Gas Corporation (Automated Meter Reading-Based Dynamic Pricing)	CS, P	$2,362,000	$4,877,989
16	New York Power Authority (Evaluation of Instrumentation and Dynamic Thermal Ratings for Overhead Lines)	TS	$720,000	$1,440,000

*AMI: *Advanced Metering Infrastructure*, CS: *Costumer Systems (i.e., in-home displays, direct load control devices, smart appliances, etc.)*, DER: *Distributed Energy Resource*, DS: *Distribution Systems*, P: *Dynamic pricing*, TS: *transmission System*, TR: *Transformer*