Disclaimer

This presentation and analysis were prepared for the 2015 EIA Energy Conference. All results and any errors are the responsibility of the author and do not represent the opinion of The Brattle Group, Inc. or its clients.

This presentation discusses some global energy trends with the aim of stimulating debate. It is intended to describe just one possible scenario among many, based on assumptions with respect to conditions that may exist or events that may occur in the future. No representation or warranty is being made as to the accuracy or completeness of the presentation. Indeed, other reasonable assumptions exist that would create different scenarios. Actual future outcomes are significantly dependent upon future events that are outside of the Presenter's control, and therefore may differ, perhaps materially, from the scenario described.

Agenda

Trends in Distributed Energy Costs

The Economics of Going Off the Grid

Evaluating Distributed Energy Options

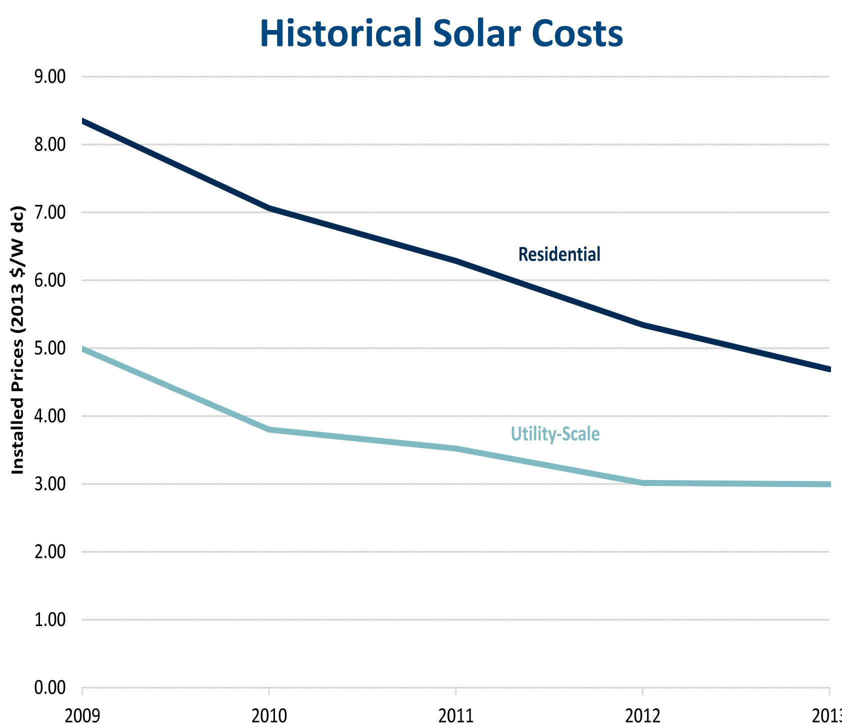
Will Off-Grid Electricity Be Cost Competitive with Future Cost Declines?

The purpose of this presentation is to examine whether projected declines in the cost of distributed storage and solar PV will make it economically feasible for large numbers of customers to defect

- The analysis presented here is a "stress test" designed around an extremely positive environment for off-grid resources
- Assumptions about future cost declines in solar PV and batteries are aggressive and represent substantial declines from the present
- The weather and solar insolation data used is weather normalized
  - Any given level of reliability is less expensive in a weather normalized world
  - This lowers off-grid smaller system sizes and lower system costs
- This analysis represents a best case scenario for an idealized 2025 installation

Costs for Solar Have Fallen Rapidly

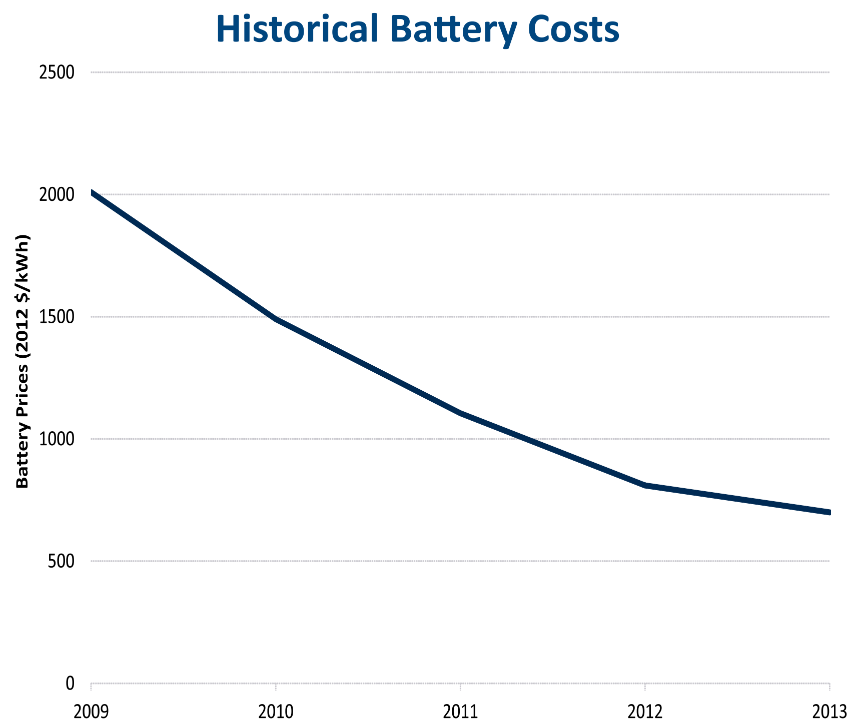
- Over the last 5 years the cost of solar PV has fallen by over 40%
- Although falling module costs are not expected to contribute as much to cost declines, further cost reductions are expected in the balance of plant
- Rooftop PV costs are still higher than central station costs
- In the case of rooftop PV, installation costs are expected to fall as contractors gain experience
- In mature markets (i.e Germany) costs may already be as low as $2,000/kW



Source: Lawrence Berkeley National Laboratory

Costs for Storage Have Also Fallen Sharply

- Over the last five years the cost of batteries has fallen by ~65%
- While expensive as backup power for most homeowners and businesses, costs are expected to decline
- Tesla's recent announcement of the 10 kWh Powerwall battery (costing $200/kW) has further increased popular excitement about the sector
  - SolarCity is selling the battery for $7,140, including installation costs and the inverter



Source: Rocky Mountain Institute

The Economics of Cutting the Power Line

With sufficient cost declines, customers could conceivably meet their loads without any reliance on the transmission and distribution grid

- If grid independence becomes widely economically feasible, it would dramatically change the power industry and result in stranded costs for utilities
- Customers are eager to explore this possibility for a variety of reasons
  - Lower energy costs
  - Improve reliability
  - Reduce carbon emissions
  - Eliminate reliance on regulated utilities
  - Prestige/Conspicuous consumption
- This raises an obvious question – Is severing grid connectivity likely to be an economic possibility for large numbers of consumers?

Description of Modeling Approach

- Excel-based minimization model designed to find the smallest off-grid solar PV array needed to meet load in every hour given a battery with 3 days of storage (at average load levels)
- Examined both residential load and commercial load (a large office building)
- Solar and load data analyzed:
  - Los Angeles, California
  - Houston, Texas
  - Westchester County, New York
- The 20 year levelized cost of off-grid energy is compared to the AEO 2015 reference case forecasts for California, Texas, and Westchester County (on a levelized basis)
- The model uses weather normalized data – as a result it tends to underestimate the amount of solar PV required (relative to the real world)

Cost Assumptions

Since the analysis is a stress test, costs for solar PV and batteries are assumed consistent with the low end of future forecasts – actual costs are likely to be higher (perhaps significantly)

Residential Customers

	Capital Cost ($/kW or $/kWh)	FOM ($/kW or kWh)
Solar	$ 1,500	$ 25
Battery	$ 100	$ 22

Commercial Customers

	Capital Cost ($/kW or $/kWh)	FOM ($/kW or kWh)
Solar	$ 1,000	$ 13
Battery	$ 100	$ 22

Note: Costs presented in real 2013$. Capital costs represent the full installed cost per kW/kWh.

Customer Characteristics

For similar reasons, customer characteristics and solar output is based on weather normalized data

Residential Customers

	Avg Hourly Peak Load (kW)	Annual Energy (kWh)	Load Factor	Solar AC Capacity Factor
Texas	7.0	14,988	24.57%	20.8%
California	2.0	7,930	45.18%	24.4%
Westchester	3.8	11,948	36.10%	19.2%

Commercial Customers

	Avg Hourly Peak Load (MW)	Annual Energy (MWh)	Load Factor	Solar AC Capacity Factor
Texas	1.7	7,667	50.49%	20.8%
California	1.5	6,511	48.92%	24.4%
Westchester	1.6	6,562	45.54%	19.2%

Source: NREL SAM and DOE Open Data Catalogue

Critical Assumptions (1)

- Load – TMY3 weather normalized load data from DOE
- Retail rates – AEO 2015 forecasts for 2025 – 2040 with assumed annual increases through 2044 based on 5 year CAGR from 2035-2040
  - These rates include transmission and distribution costs
- Solar Profile – TMY3 weather normalized solar output from NREL SAM:
  - Module/inverter ratio of 1.37
  - Inverter efficiency of 96%
  - Fixed roof mount
  - Tilt 20 degrees, azimuth 180 degrees
  - System losses of 14.08%

Critical Assumptions (2)

- Solar systems and batteries have a 20 year useful life
- Batteries have 92% efficiency with no limitations on discharge
- Batteries are sized to meet 72 hours of average hourly load
- Real discount rate of 5.88% (nominal discount rate of 8% and 2% inflation)
- Installation date/analysis date is 2025

Summary of Results

Residential Customers

	Solar Array (kW, DC)	Battery (kWh)	Total Capital Cost ($)	LCOE (Cents/kWh)	AEO (Cents/kWh)
Texas	27.0	123.2	52,810	31.1	7.2
California	8.2	65.2	18,785	24.2	10.0
Westchester County	22.1	98.2	42,904	31.5	22.5

Commercial Customers (Large Office Building)

	Solar Array (kW, DC)	Battery (kWh)	Total Capital Cost ($)	LCOE (Cents/kWh)	AEO (Cents/kWh)
Texas	7,881	63,014	14,182,623	20.8	6.7
California	6,198	53,514	11,548,866	20.4	8.5
Westchester County	9,086	53,937	14,479,367	22.9	9.4

Source: Brattle Analysis

Note: Costs presented in real 2013$

Off-Grid with Natural Gas Backup

The possibility of integrating natural gas backup generation with solar and storage could potentially lower the cost of going off the grid

- Such a system could create challenges for the natural gas distribution network
- There are also environmental concerns associated with widespread use of relatively inefficient fossil fuel generators
- However, assuming such technical challenges are surmountable, emergency reliance on a fossil fuel backup could be an attractive option
- The following sensitivity analyzes the cost of going off grid with an 8 kW back-up generator for residential customers (a common size for backup generator) and a backup generator sized to peak load for commercial customers
- Gas backup is limited to 200 hours of generation per year
- Relied on very conservative (i.e. low) cost and operating assumptions

Cost Assumptions Including Backup Generation

Consistent with the previous analysis, low end cost estimates for the cost of natural gas back-up generation are used

Residential Customers

	Capital Cost ($/kW or $/kWh)	FOM ($/kW or kWh)	Heat Rate (btu/kWh)	Fuel Cost ($/MMBtu)
Solar	$ 1,500	$ 25	N/A	N/A
Battery	$ 100	$ 22	N/A	N/A
Gas Backup	$ 500	$ 10	12,000	$ 10

Commercial Customers

	Capital Cost ($/kW or $/kWh)	FOM ($/kW or kWh)	Heat Rate (btu/kWh)	Fuel Cost ($/MMBtu)
Solar	$ 1,000	$ 13	N/A	N/A
Battery	$ 100	$ 22	N/A	N/A
Gas Backup	$ 500	$ 10	12,000	$ 10

Note: Costs presented in real 2013$. Capital costs represent the full installed cost per kW/kWh.

Summary of Results With Backup Generation

Residential Customers

	Solar Array (kW, DC)	Battery (kWh)	Gas Backup (kW, AC)	Total Capital Cost ($)	LCOE (Cents/kWh)	AEO (Cents/kWh)
Texas	16.5	123.2	8.0	41,014	26.6	7.2
California	7.1	65.2	8.0	21,236	26.2	10.0
Westchester County	14.5	98.2	8.0	35,622	28.0	22.5

Commercial Customers (Large Office Building)

	Solar Array (kW, DC)	Battery (kWh)	Gas Backup (kW, AC)	Total Capital Cost ($)	LCOE (Cents/kWh)	AEO (Cents/kWh)
Texas	6,494	63,014	1,736	13,663,112	20.6	6.7
California	5,217	53,514	1,520	11,328,818	20.3	8.5
Westchester County	6,470	53,937	1,648	12,688,161	21.5	9.4

Source: Brattle Analysis

Note: Costs presented in real 2013$

Impact of Integration of Backup Generator

- Back-up generation has the potential to lower costs by reducing the size of the necessary solar PV array
- Back-up generation would likely increase the reliability of an off-grid system
- However, in the cases analyzed, off-grid electricity costs were still higher than the AEO forecasts

Residential Customers

LCOE Cents/kWh	LCOE without Backup	LCOE with Backup	AEO
Texas	31.1	26.6	7.2
California	24.2	26.2	10.0
Westchester County	31.5	28.0	22.5

Commercial Customers (Large Office Building)

LCOE Cents/kWh	LCOE without Backup	LCOE with Backup	AEO
Texas	20.8	20.6	6.7
California	20.4	20.3	8.5
Westchester County	22.9	21.5	9.4

Source: Brattle Analysis

Note: Costs presented in real 2013$

Economic Conclusions – Load Factor

While going-off the grid may become more economically attractive as solar PV and storage costs decline, even with major cost declines it is unlikely to be the least expensive option for most consumers

- The grid allows consumers to benefit from the fact that peaks for individual customers are not perfectly coincident; since customers' loads do not occur simultaneously, less capacity is needed to serve load
  - For example, the residential load we modeled in Westchester county had a load factor of 36%,* while NYCA as a whole has a load factor of ~54%
  - Load smoothing could mitigate this issue

*Calculation based on hourly average peak. The load factor would be even lower if calculated using instantaneous peak.

Economic Conclusions – Intermittency

There may be environmental benefits to remaining grid connected

- Intermittent resources benefit particularly from grid access
- Off-grid solar/battery packages need to be sized to provide energy during prolonged periods of low insolation (such as a rainy week)
- As a result, off-grid solar systems that ensure reliability will frequently generate more energy than needed to serve load and charge the battery
  - This excess energy is wasted without a grid connection

Reliability considerations

In addition to economic considerations, it is unlikely that completely off-grid systems will be able to achieve the same level of reliability as grid-connected customers

- The grid has multiple backups and redundancies, an off-grid system would likely have less ability to meet load during an equipment failure (of course, an off-grid system would not be subject to distribution network failures)
- In the event of an equipment failure, it would likely take longer to bring an off-grid system back online than it takes a utility – with a dedicated staff – to restore service to a typical grid connected customer
- Back-up from a fossil generator can increase off-grid reliability, but it may serve to increase total costs

Future of the Electricity Grid

From an economic perspective, the grid remains an important asset

- For both economic reasons and for reliability reasons, most customers will continue to want a connection to the electricity grid
- Distributed energy resources are a complement to the grid rather than a substitute
- While it may be possible to use distributed energy resources to reduce some grid costs, ensuring the financial viability of the grid is critical
- As distributed energy resources fall in cost, customers will increasingly want to integrate them into the electric system
- Programs designed to encourage the development of distributed energy resources may inadvertently shift the cost of maintaining the grid to a smaller subset of customers – raising concerns about equity
- These concerns will grow as penetration levels rise

Evaluating Distributed Energy Resources – Costs and Benefits

While distributed energy resources are sometimes discussed as a homogenous class of resources, in reality distributed energy resources include many different assets classes with different potential benefits and different potential challenges for the grid

- Solar provides clean energy, but integrating it into a grid designed to deliver power in a single direction creates challenges at high penetration levels
- Batteries and other storage devices provide no energy, but they serve as demand resources that can also be used to delay or avoid distribution network improvements – and to reduce the cost of integrating solar
- Demand response and energy efficiency could serve somewhat similar roles to batteries
- Microgrids increase reliability, but may also increase costs

Evaluating Distributed Energy Resources – Grid Parity

When evaluating the levelized cost of energy from distributed resources, analysts commonly use the retail rate of electricity as a benchmark

- From the perspective of consumers, this is an economically relevant comparison in regions with net metering policies
- Even without net metering, the comparison is economically relevant for consumers that are considering leaving the grid entirely (though this is likely to be a small group)
- However, for policy makers considering the relative costs and benefits of distributed generation a more relevant benchmark may be the costs and benefits of energy efficiency, demand response, storage or central station alternatives

Pricing Distributed Energy Resources

Regulators and industry have spent years designing the pricing mechanisms for central station generators – and those markets are still evolving

- Designing markets for distributed energy resources is just beginning
- At a minimum, distributed energy resources should receive the fair value of any energy or capacity services they provide
- Additionally, distributed energy resources should be compensated (charged) for any additional benefits (costs) they bring to the grid
- Some of the benefits may not be purely financial in nature (i.e. environmental), but the quantification of those benefits will be challenging
  - Similar or perhaps greater environmental benefits are available at utility scale
- Since distributed energy resources could be provided by millions of relatively unsophisticated entities, some degree of economic efficiency in pricing will likely need to be sacrificed in favor of simplicity

About Brattle

The Brattle Group provides consulting and expert testimony in economics, finance, and regulation to corporations, law firms, and governments around the world. We aim for the highest level of client service and quality in our industry.

We are distinguished by our credibility and the clarity of our insights, which arise from the stature of our experts, affiliations with leading international academics and industry specialists, and thoughtful, timely, and transparent work. Our clients value our commitment to providing clear, independent results that withstand critical review.

Presenter Information

MICHAEL KLINE
Senior Associate
The Brattle Group, Washington, DC
Michael.Kline@brattle.com
+1.202.419.3356

Mr. Kline is a Senior Associate at the Brattle Group. His areas of expertise include retail and wholesale electricity markets, financial accounting, corporate finance, asset valuation, international arbitration, market manipulation, and fraud. He has provided both commercial advice and litigation support to private equity firms, investment banks, merchant developers, and utilities. His work has included assessment of the impact of environmental and regulatory proposals on consumers and generators of electricity, valuation of merchant and contracted electric generating and transmission assets, evaluation of the adjusted production cost benefits of new transmission, analysis of the economic substance of structured financial transactions, and damages analyses. His modeling experience includes locational marginal pricing models, environmental policy and long term planning models, and loss of load expectation models. He has worked on projects throughout the Eastern Interconnection, the Western Electricity Coordinating Council, and the Electric Reliability Council of Texas. Prior to joining The Brattle Group, Mr. Kline was a Principal at the Berkeley Research Group and an Associate Principal at Charles River Associates. He holds an MBA in Finance and Accounting from the University of Pennsylvania and a BS in Economics from Georgetown University.

Our Practices

PRACTICES

- Antitrust/Competition
- Bankruptcy and Restructuring Analysis
- Commercial Damages
- Data Analytics
- Environmental Litigation and Regulation
- Intellectual Property
- International Arbitration
- International Trade
- Mergers & Acquisitions Litigation
- Product Liability
- Regulatory Finance and Accounting
- Risk Management
- Securities
- Tax
- Utility Regulatory Policy and Ratemaking
- Valuation

INDUSTRIES

- Electric Power
- Financial Institutions
- Health Care Products and Services
- Natural Gas and Petroleum
- Telecommunications and Media
- Transportation

Offices

NORTH AMERICA

Cambridge

New York

San Francisco

Washington, DC

EUROPE

London

Madrid

Rome