Reinventing Demand Response for the Age of Renewable Energy

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THE Brattle GROUP

The Age of Renewable Energy

Why reinvent demand response?

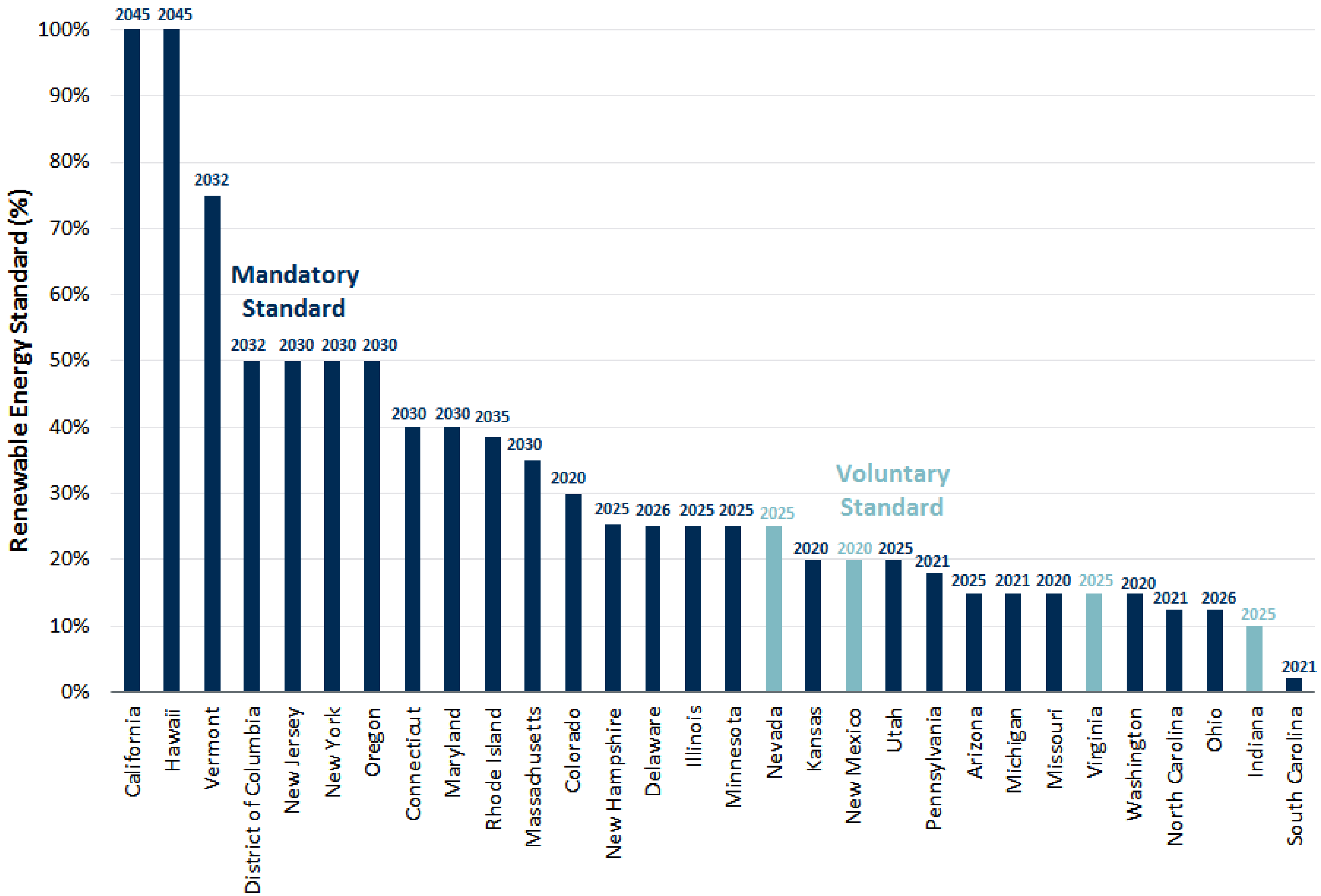
Renewable energy is getting high priority in most markets, driven by a desire to protect the climate of the planet, while also giving customers a chance to generate their own power

The primary sources of renewable energy today are solar and wind; others include geothermal, small-scale hydro; in some cases, large-scale solar and nuclear energy are also regarded as renewable energy resources

Battery storage, coupled with demand response, facilitates the integration of renewable energy into the grid

State governments in the US have established clean energy goals for renewable energy

Some states have set very aggressive targets for meeting their energy needs through renewable energy resources



Notes: Standards for Colorado, Minnesota, New Mexico, and North Carolina only apply to IOUs. Data labels represent the year by which each standard must be met.

The CEO of Xcel Energy just announced a landmark initiative

He wants his company to generate all its power from carbon-free energy resources by 2050

- Carbon-free includes nuclear energy, which accounts for 11 percent of the company’s resource mix today

Xcel Energy serves 3.6 million electricity and 1.8 million natural gas customers in 8 states

- About 80% of them are located in two states: Colorado and Minnesota

There are three issues with integrating renewables into the grid

1. **Intermittency:** wind and solar generation are highly variable, which leads to reliability concerns
   - Power plants have high startup and shutdown costs, so it is not easy for them to fill in when variable generation lags

2. **Ramping**: wind and solar both have morning and evening production "ramps"
   - Fortunately, wind and solar have complementary load profiles

3. **Over-generation:** wind poses significant risk of over-generation because wind farms produce the most electricity at night when loads are low

Source: Integrating Renewable Resources in California and the Role of Automated Demand Response. Lawrence Berkeley National Laboratory. November 2010.

Grid-integration requires dynamic load response at all hours of the day

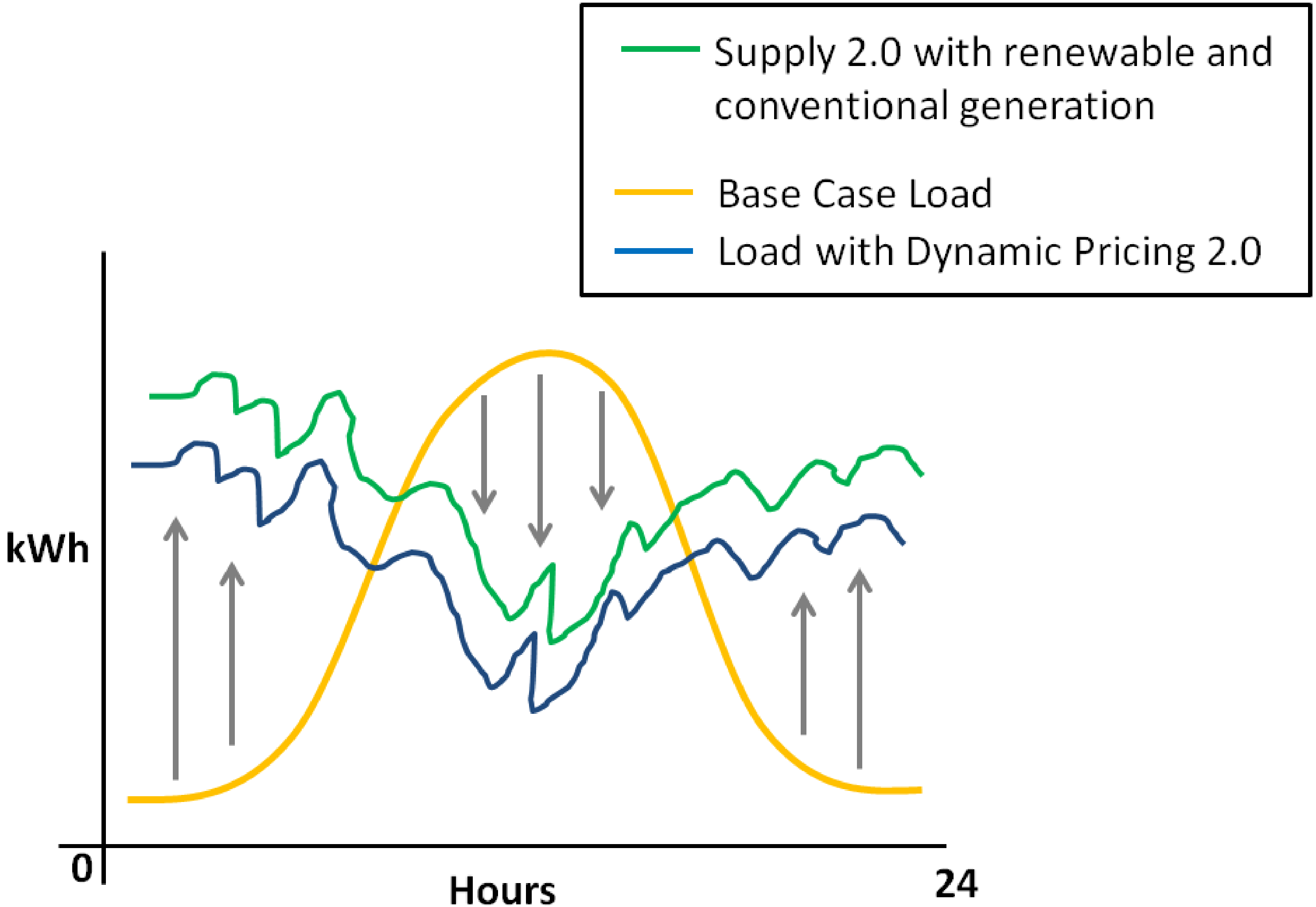
This dynamic load response is achievable through load flexibility on a 24/7 basis and that can be achieved by a transition from *Dynamic Pricing 1.0* to *Dynamic Pricing 2.0*

***Dynamic Pricing 1.0*: Critical peak pricing and peak-time rebates, sometimes with enabling technology**

↓ ↓ ↓

***Dynamic Pricing 2.0*: Widespread real-time pricing (RTP) with enabling technology and automation, including advanced metering infrastructure (AMI) and set-it-and-forget-it heating, ventilating, and air condition (HVAC) equipment**

RTP can help integrate renewables by creating around-the-clock flexibility in load



Dynamic Pricing 2.0 = RTP + fast response technologies

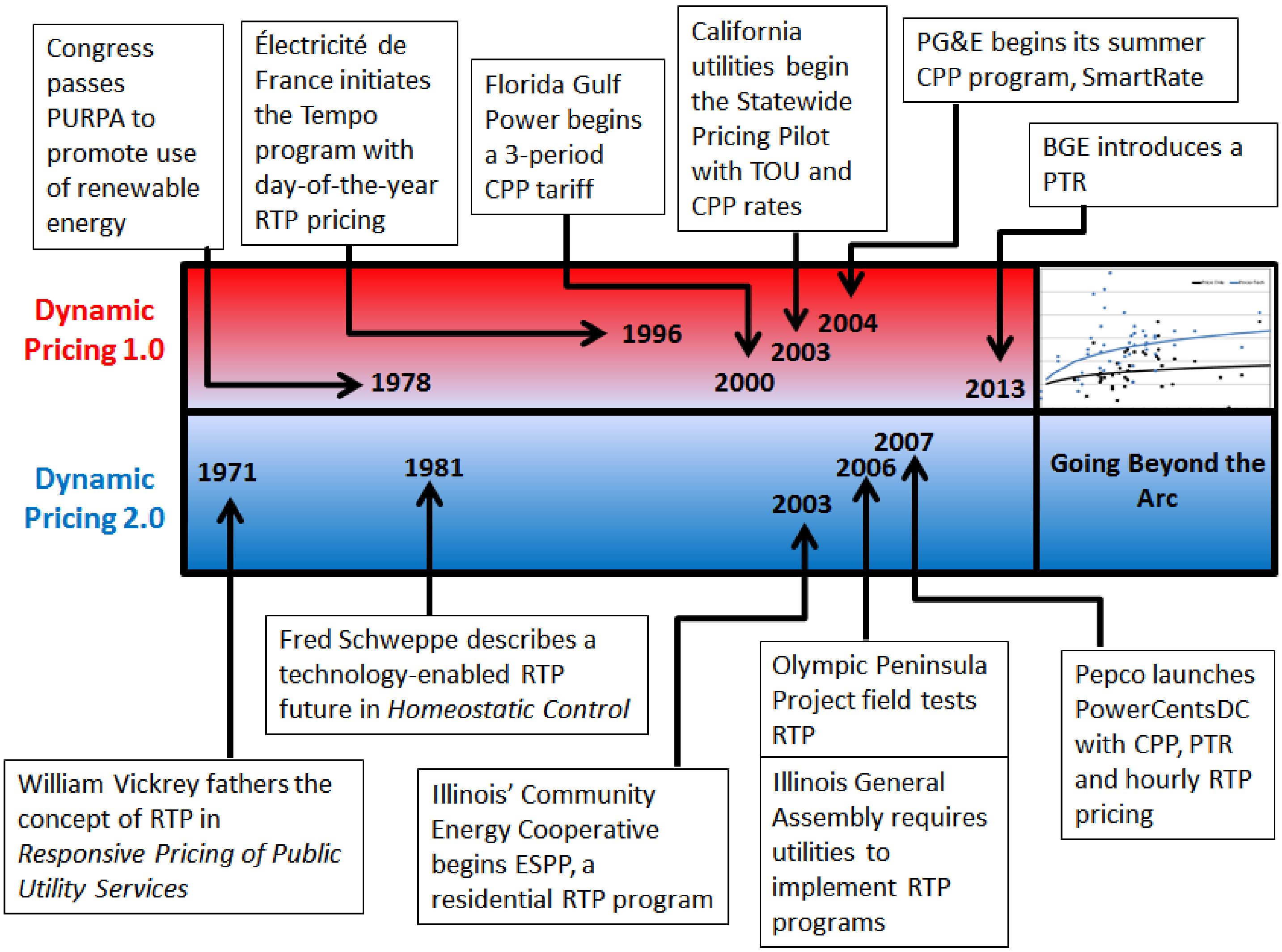
Fast response technologies include:

- Advanced metering infrastructure
- Smart appliances
- Home energy controllers
- Energy storage
- Electric vehicles
- Batteries

Integration requires the provision of ancillary services which include:

- Spinning reserves
- Non-spinning reserves
- Regulation up and regulation down

A pocket history of dynamic pricing

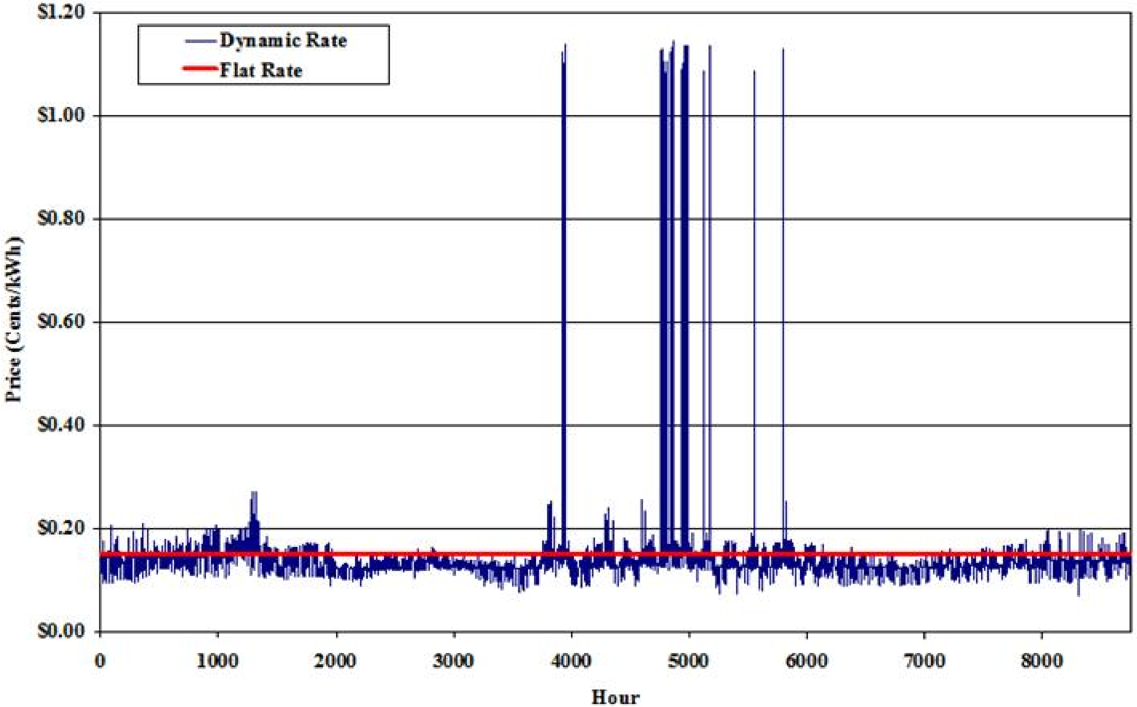


We simulated the application of RTP in New York state

We used price elasticities from the Illinois RTP program to simulate the impact of an RTP rate structure in New York

In an average year, the top 1% of hours of electric demand (~90 hours) in New York State account for more than 10% of system peak demand

Comparison of Flat and Hypothetical Dynamic Rates in New York City for 2010



Source: Potential Wholesale Market Benefits in New York State. ISO NY. Samuel Newell and Ahmad Faruqui. October 27, 2009

Using the PRISM software, we showed that RTP can reduce the peak load in New York City by 13-16%

Base Case: No technology; elasticities unchanged

Conservation Case: Customers provided with in-home displays

High Capacity Price: Capacity prices are increased to reflect higher cost of entry

High Elasticity: Elasticities are twice as high as the base case to represent impact of enabling technology facilitating load shifting

Dynamic Pricing Scenario	**Change in System Peak**		**Change in New York City Peak**		**Change in Long Island Peak**		**Change in Average Load**			
	All Hours		***All Hours***		***All Hours***		***All Hours***		***150 Hours w/Max Δ Load***	
	(MW)	**(%)**	**(MW)**	**(%)**	**(MW)**	**(%)**	**(MW)**	**(%)**	**(MW)**	**(%)**
Base Case	(3,418)	(10%)	(1,514)	(13%)	(590)	(11%)	84	0.4%	(1,897)	(6%)
Conservation	(3,751)	(11%)	(1,514)	(13%)	(604)	(11%)	(288)	(1.5%)	(2,158)	(7%)
High Capacity Price	(4,282)	(13%)	(1,671)	(14%)	(776)	(14%)	176	1.0%	(3,147)	(11%)
High Elasticity	(4,603)	(14%)	(1,961)	(16%)	(779)	(14%)	130	0.7%	(3,606)	(12%)

Source: Potential Wholesale Market Benefits in New York State. ISO NY. Samuel Newell and Ahmad Faruqui. October 27, 2009.

Back to the future

In 1981, MIT's Fred Schweppe published *Homeostatic Control: The Utility/Customer Marketplace for Electric Power*

In Schweppe's formulation, *homeostatic control* is the ability to maintain internal equilibrium between electricity supply and electricity demand through technological and economic means

It is based on two principles

- Customer independence
- Feedback between the customer and utility

The idea of flexible load shapes was also discussed in Clark Gellings' 1982 paper on Demand-Side Planning; he also emphasized the need to "get prices to devices"

The Schweppian future

6:00 am	Computer gets hot water ready for shower when consumer wakes up
7:00 am	Computer displays its energy use plan for next 24 hours based on predicted weather, spot price patterns and owner's average lifestyle, which computer has learned (think *Nest* thermostat)
10:00 am	Latest spot price and weather forecasts cause computer to pre-cool parts of the house so it can "coast" during the afternoon
12:00 pm	Consumer calls computer to say guests are spending the night. Computer incorporates air conditioning the guest room into its strategy
3:00 pm	A large quantity of supply is lost due to a storm. Computer reacts to very high spot prices by turning off everything except the refrigerator, freezer and itself

The Evolution of Demand Response

Demand Response has evolved dramatically over the past five decades

About five decades ago, it was simply called load management

- The policy driver was peak clipping

It was implemented through two mechanisms

- Direct load control of water heaters and central air conditioners for residential customers and curtailable and interruptible rates for commercial and industrial customers

After the California energy crisis of 2000-01, the name load management was replaced with demand response

- The intent was to use demand response to connect retail and wholesale markets.

The Federal Energy Regulatory Commission (FERC) published a “National Assessment of Demand Response” in 2009

The FERC sized up the current state of play in demand response an identified a wide range of programs, including traditional curtailment programs and innovative price-responsive programs

It also estimated the potential for expanding demand response and projected the likely impact of demand response under different scenarios

A year later, the FERC published a national action plan for demand response; this was followed by an implementation plan for demand response, which was co-authored with the U.S. Department of Energy

The National Assessment modeled potential DR impacts for four scenarios, each designed to answer a different question

Business-as-Usual (BAU)

- How much DR exists today?

Expanded DR (EDR)

- How much DR could be achieved if cost-effective reliability-based programs all reached today’s “best practices” levels?

Achievable Market Potential (AMP)

- How much DR could be achieved if all cost-effective DR options were pursued (including price-based DR), while accounting for realistic market acceptance levels?

Economic Potential (EP)

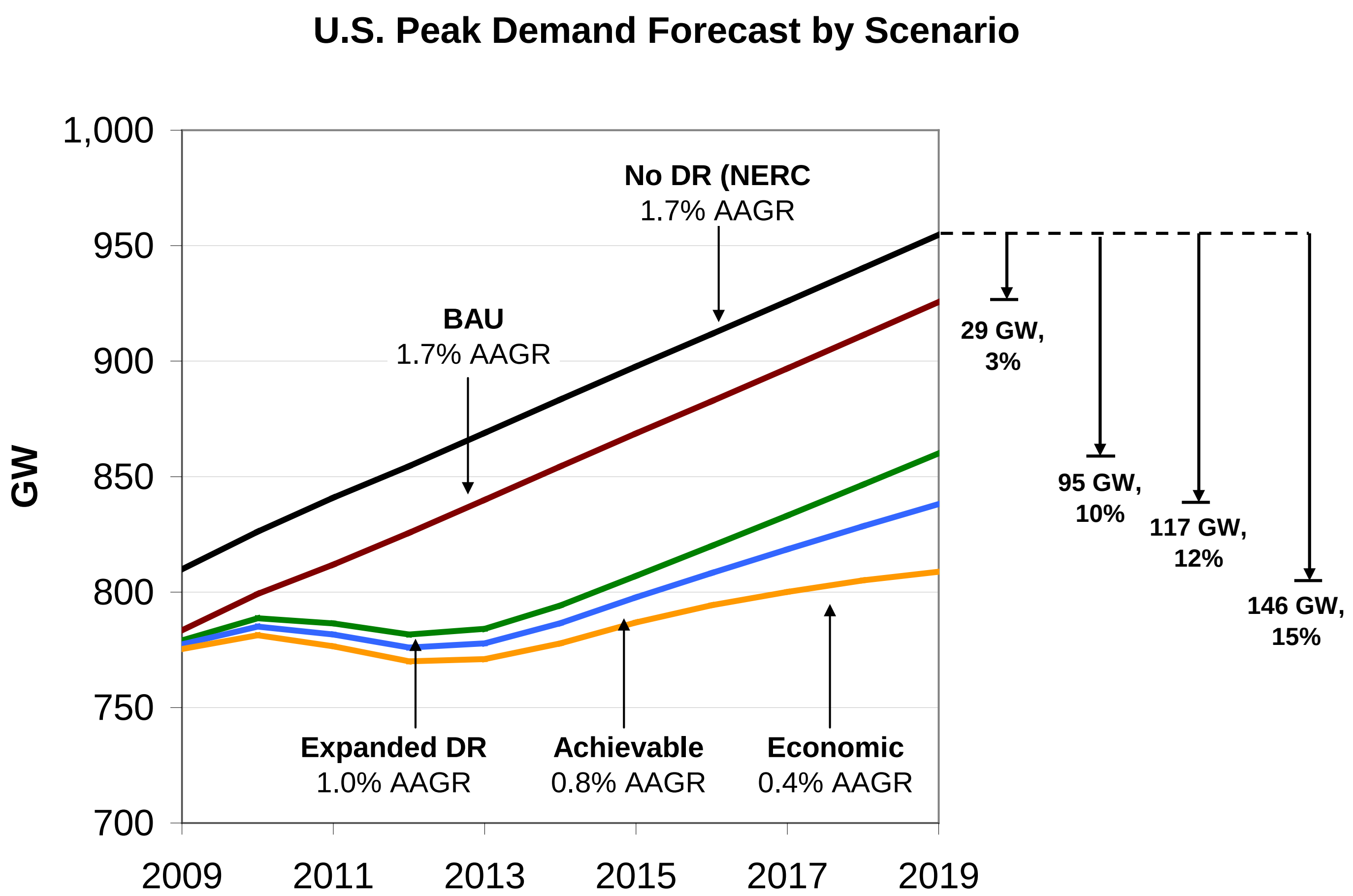
- What is the total amount of cost-effective DR that could be achieved?

It identified some key differences in the assumptions across the four potential scenarios

Key Differences in Scenario Assumptions

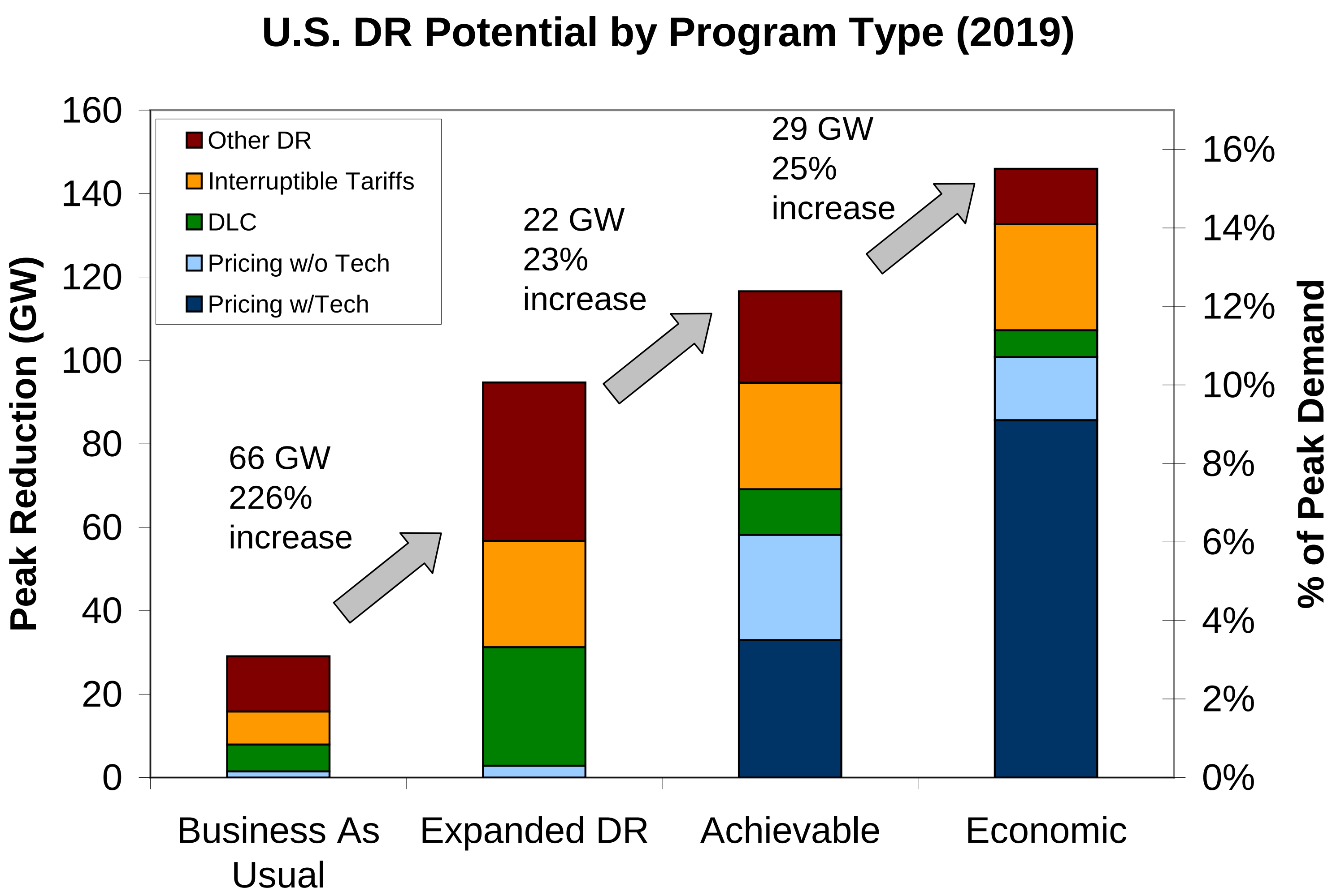
Assumption	Business-as-Usual	Expanded DR	Achievable Market Potential	Economic Potential
AMI deployment	Today's level	Partial deployment	Full deployment	Full deployment
Dynamic pricing participation (of eligible)	Today's level	Voluntary (opt-in); 5%	Default (opt-out); 60% to 75%	Universal (mandatory); 100%
Eligible customers offered enabling tech	None	None	80%	100%
Eligible customers accepting enabling tech	None	None	60%	90%
Basis for non-pricing participation rate	Today's level	"Best practices" estimate	"Best practices" estimate	"Best practices" estimate

FERC projected that demand response could range between 3% and 15% in 2019



Estimates are in the final stages of revision and are subject to change

Aggressive pursuit of price-based programs can lead to the largest amount of demand response



Demand Response 2.0 and Load Flexibility

Enter demand (load) flexibility

The ability to flex the load shape 24/7 in response to system conditions

Lower demand during peak times, for example when there is a shortage of energy supply

- Use self-generated power from solar panels (PVs), microturbines, or co-generation (CHP); curtail consumption through energy efficiency (EE)

To build demand during off-peak times, for example when there is an excess of energy supply

- Charge electric vehicles (EVs)

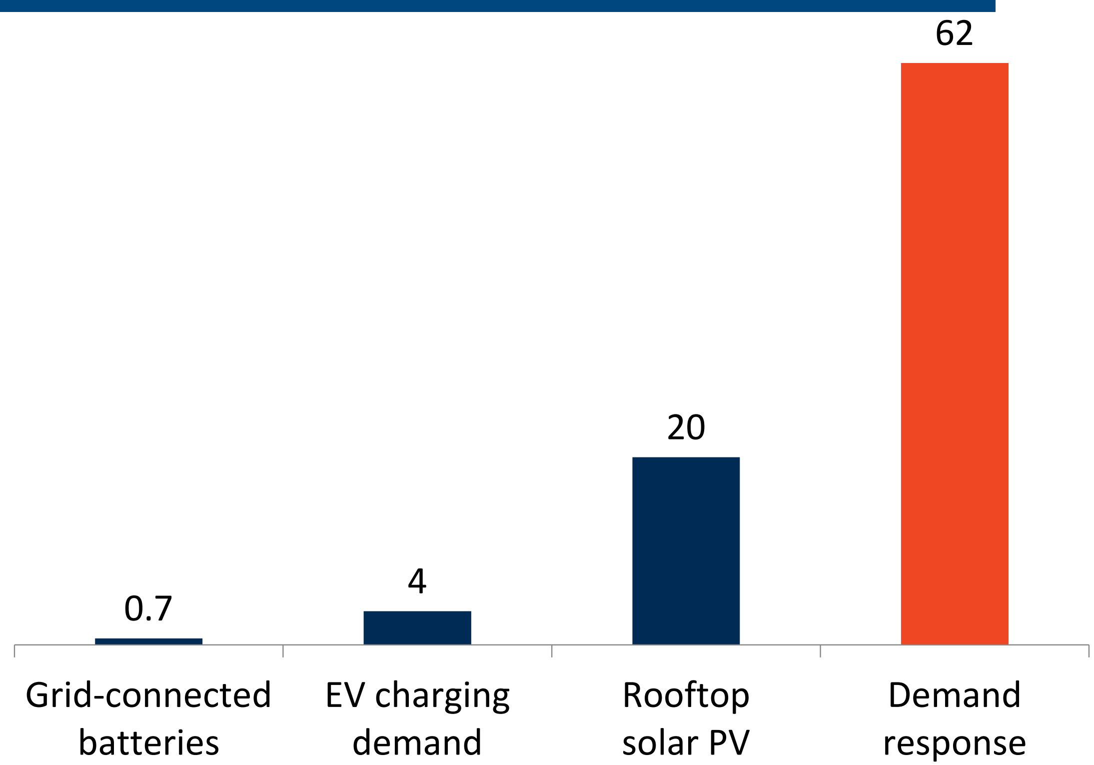
And shift load from peak to off-peak at other times

- Thermal storage, such as smart water heating

You can't spell "DER" without "DR"

DR is the largest distributed energy resource in the U.S.

Total U.S. Installed Capacity (GW), 2017

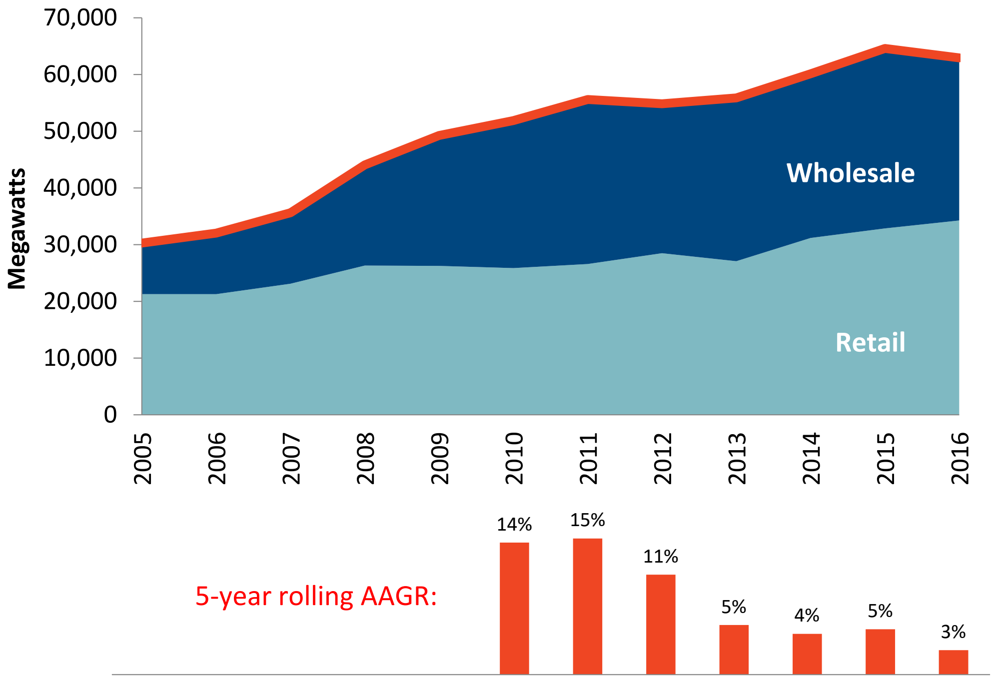


Notes: EV charging demand assumes 6 kW charging demand per EV, does not account for coincidence of charging patterns. Rooftop solar PV estimate is installed capacity, does not account for derated availability during peak.

"DR 1.0" has matured

Once a rapidly growing resource, conventional DR is reaching a saturation point in markets where load growth has stalled

Total U.S. DR Peak Reduction Capability



Contributing Factors

- Increasingly stringent wholesale market participation rules
- Low capacity market prices
- Flat/depressed hourly energy price profile
- 5 to 10 years of excess peaking capacity projected by many utilities

"DR 2.0" provides improved system flexibility

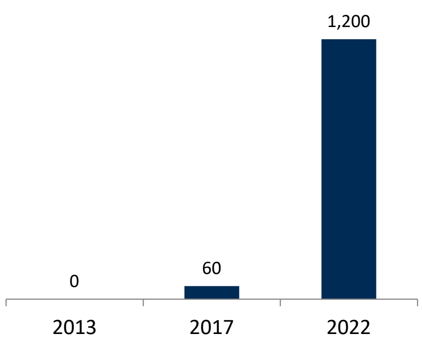
DR can be repurposed to address three emerging industry trends

Mega-trend	Challenges	DR 2.0 Solution
Renewables growth	• Low net load leads to renewables curtailment and/or inefficient operation of thermal generation • Intermittency in supply contributes to increased need for ancillary services	• Electricity consumption can be shifted to times of low net load • Fast-responding DR can provide ancillary services
Grid modernization	• Costly upgrades are needed to improve resiliency and accommodate growth in distributed energy resources	• Geographically-targeted DR can help to defer capacity upgrades
Electrification	• Rapid growth in electricity demand may introduce new capacity constraints	• Controlling new sources of load can reduce system costs while maintaining customer comfort and adding value to smart appliances and EVs

Consumer technologies drive the DR 2.0 transition

Adoption of behind-the-meter (BTM) energy technology is accelerating; these technologies are enabling the provision of DR 2.0

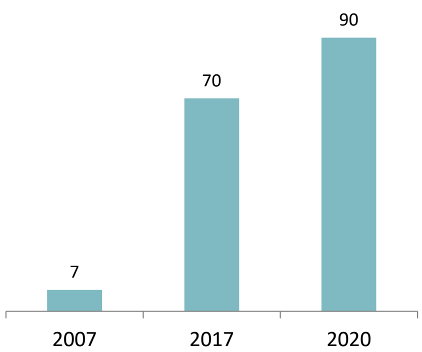
BTM Storage
(U.S. capacity, MW)



Source: GTM Research, 2018

CAGR: 82% (2017-22)
20x total growth in 5 yrs

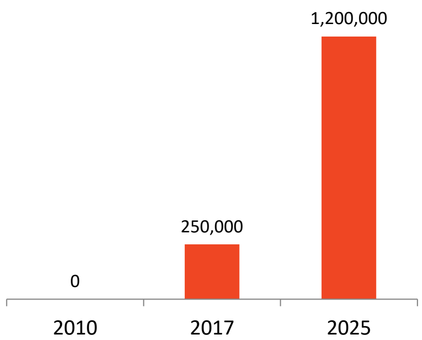
Smart Meters
(U.S. meters, millions)



Institute for Energy Innovation (IEI), 201X

CAGR: 22% (2007-20)
13x total growth in 13 yrs

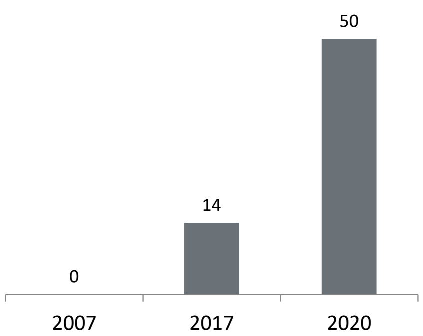
Electric Vehicles
(U.S. annual sales)



Edison Electric Institute and IEI, 2017

CAGR: 22% (2017-25)
5x total growth in 8 yrs

Smart Appliances
(U.S. homes, millions)



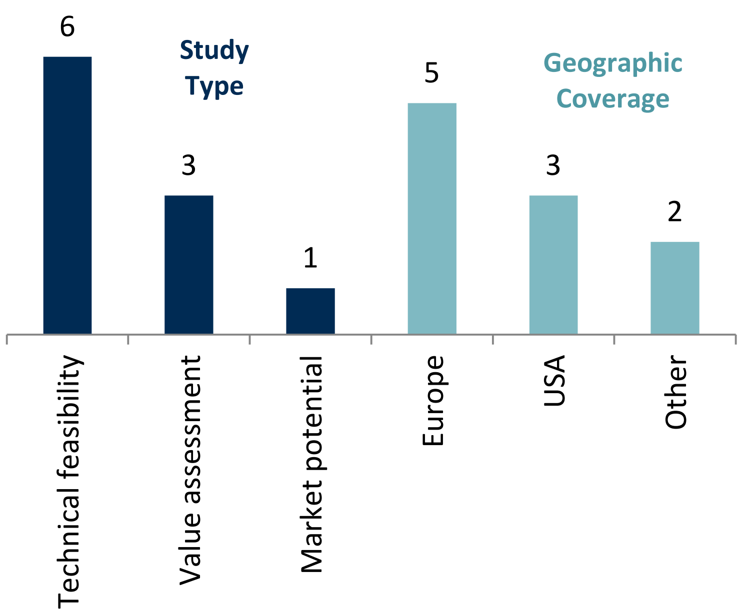
Parks Associates and GreenTech Media, 2018

CAGR: 53% (2017-20)
4x total growth in 3 yrs

What is the market potential for DR 2.0?

Recent "load flexibility" studies are informative but have limitations

Load Flexibility Studies (10 total)



Research Limitations

- Geographically limited
- No accounting for "value stacking"
- Ignore many emerging DR 2.0 opportunities (e.g., EV charging, battery storage)
- Do not quantify local distribution capacity deferral value
- Largely focused on engineering estimates of end-use flexibility rather than utilizing experience-based DR program data

Understanding DR 2.0 market potential & value

DR 1.0 market potential studies took a narrow view of DR capabilities. They need to be expanded to capture the full value of DR 2.0

Scope of "DR 1.0" Market Studies

	Generation capacity avoidance	Reduced peak energy costs	System peak related T&D deferral
HVAC load control	X	X	X
Interruptible tariff	X	X	X
Time-of-use (TOU) rates	X	X	X
Dynamic pricing	X	X	X

Programs typically focus on demand reductions during a limited peak window and are constrained to a small number of hours per year

Quantified value and associated market potential are derived only from reductions in system peak demand

DR 2.0 will be used to address a range of power system management challenges, not just to shave the peak

1 Extend DR value streams

	Generation capacity avoidance	Reduced peak energy costs	System peak related T&D deferral	Targeted distribution capacity deferral	Valley filling/ Load building	Ancillary services
HVAC load control	X	X	X	X		
Interruptible tariff	X	X	X			
Time-of-use (TOU) rates	X	X	X			
Dynamic pricing	X	X	X			

Several new uses of DR are possible, but existing programs are limited in their ability to provide those services

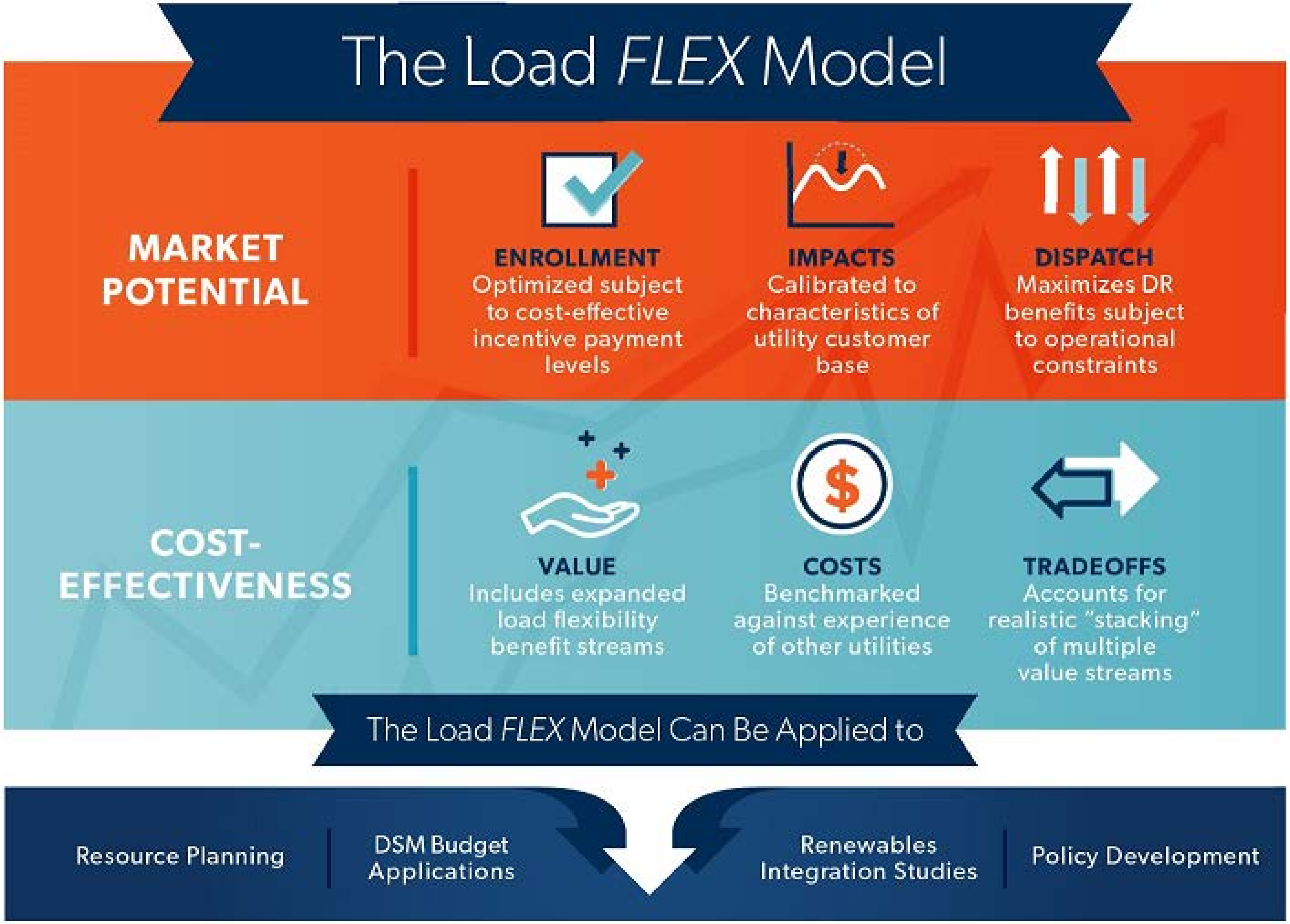
New DR 2.0 programs and technologies have the potential to provide higher value at a lower cost

1 Extend DR value streams

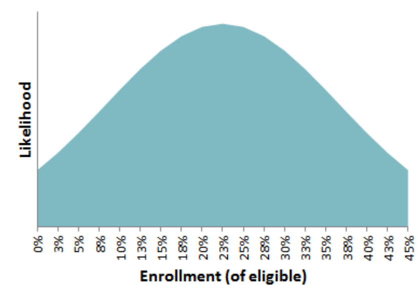
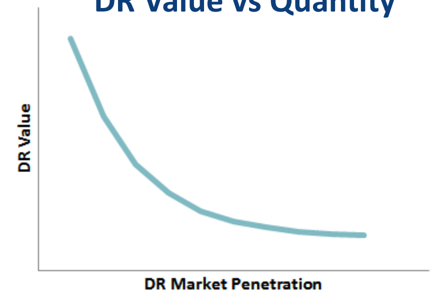
2 Broaden definition of DR

	Generation capacity avoidance	Reduced peak energy costs	System peak related T&D deferral	Targeted distribution capacity deferral	Valley filling/ Load building	Ancillary services
HVAC load control	X	X	X	X		
Interruptible tariff	X	X	X			
Time-of-use (TOU) rates	X	X	X			
Dynamic pricing	X	X	X			
Behavioral DR	X	X	X			
EV charging control	X	X	X	X	X	X
Grid-interactive water heating	X	X	X	X	X	X
BTM battery storage	X	X	X	X	X	X
Smart thermostat	X	X	X	X		
C&I load building					X	
C&I Auto-DR	X		X	X		X

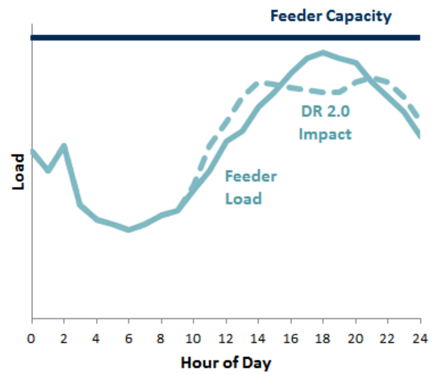
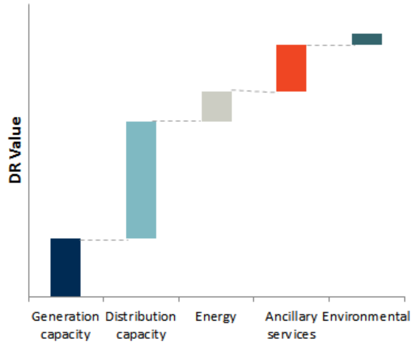
Brattle developed the Load*Flex* Model to comprehensively assess DR 2.0 potential



DR 2.0 analytical challenges and solutions

DR 2.0 Analytical Challenge	Load*Flex* Approach	Illustration
Reliably estimating impacts of nascent programs & technologies	• Brattle maintains a database of DR 2.0 programs and their associated costs, impacts, and adoption rates • Supplementary interviews are conducted to fill in gaps where publicly available data is limited • Primary market research can establish tailored estimates of customer adoption • Probabilistic analysis (i.e., Monte Carlo simulation) accounts for uncertainty	**DR Enrollment Probability** 
Accounting for “depth” of resource need	• Some of the new DR 2.0 value streams are sensitive to the quantity of the DR resource that is participating; for instance, frequency regulation is valuable but has very limited need on most systems • Modeling establishes the “depth” of each value opportunity and quantifies the relationship between incremental value and DR resource additions	**DR Value vs Quantity** 

DR 2.0 analytical challenges and solutions

DR 2.0 Analytical Challenge	Load*Flex* Approach	Illustration
Quantifying deferred distribution capacity value	• Distribution capacity deferral is a highly system-specific calculation, requiring locational assessment of utility distribution system data • Initial screening identifies grid locations at risk of capacity constraints • The performance profile of the DR 2.0 resource is compared to the load profile of the distribution system component • Capacity deferral value is assigned based on the probability that constraints can be relieved through deployment of the DR 2.0 resource	**DR Impact on Distribution System** 
Accounting for "stacked value"	• DR 2.0 can provide multiple sources of value, but analysis must account for realistic operational constraints associated with capturing this value • Each value stream is converted to an hourly price series based on appropriate allocation factors • DR 2.0 resource is "dispatched" against the price series based on realistic utilization algorithms	**DR Stacked Value** 

Illustrating the potential for DR 2.0

Electric water heating is a compelling example of DR 2.0

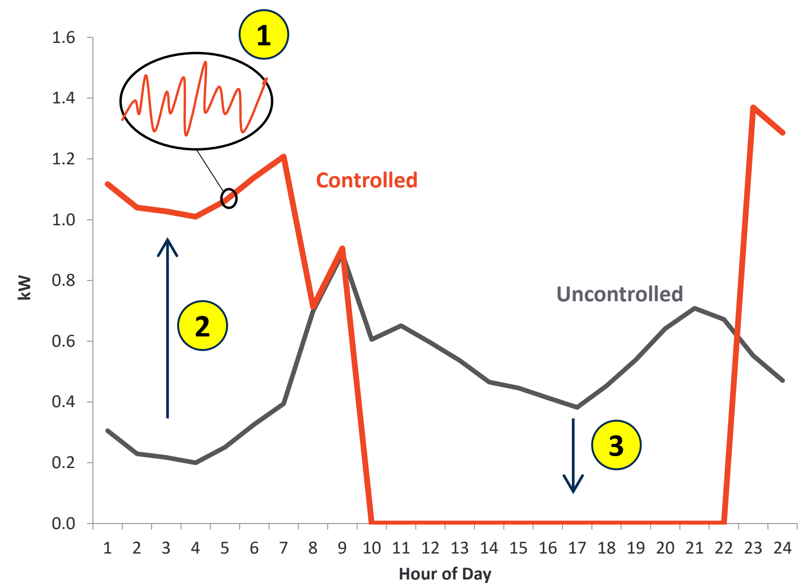
Electric resistance water heating load can be controlled to provide several grid services. The thermal energy storage properties of the water tank work similar to a battery

While water heaters have been used to reduce peak capacity for decades, recent technological developments now allow for more flexibility in load control, including the provision of frequency regulation

In the past few years, “grid-connected water heating” programs have been introduced in Arizona, California, Hawaii, Minnesota, Oregon, Vermont, and across PJM

In recognition of the potential renewables integration benefits, 2015 federal legislation made grid-connected water heaters exempt from prohibitive energy efficiency standards

Water Heating Load Profile

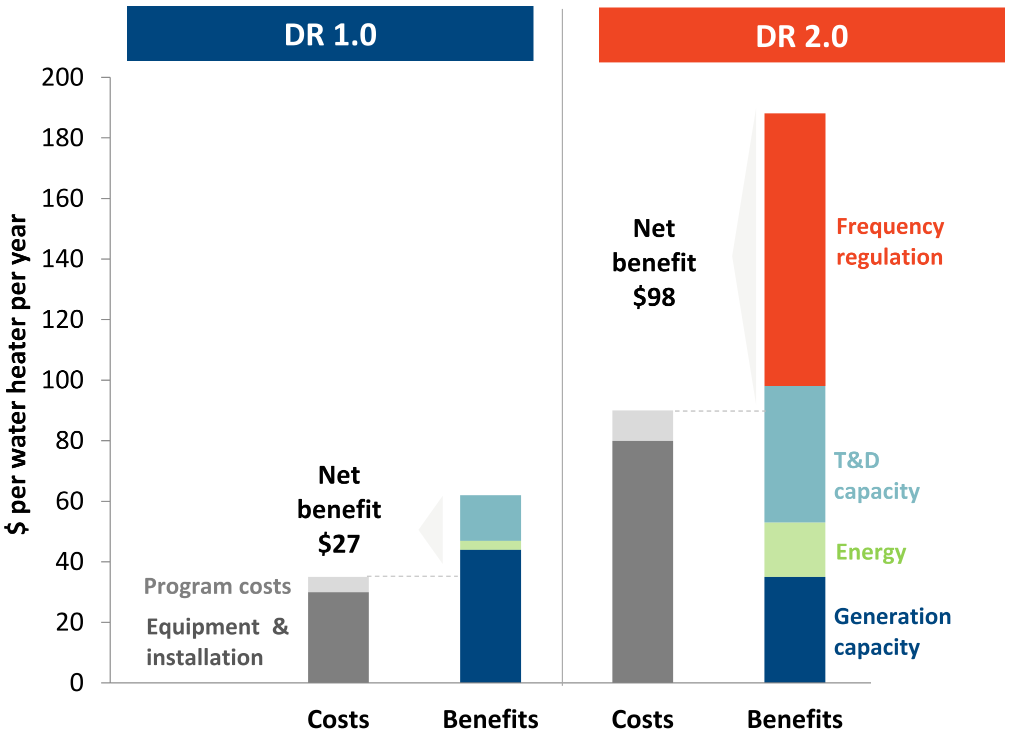


1. Heating element controlled with near-instantaneous response to provide **balancing services**
2. Off-peak **load building** to reduce wind curtailments or reduce ramping of thermal generation
3. **Peak demand reduction** to reduce need for generation capacity and/or T&D capacity, and to avoid peak energy prices

Electric water heating: DR 1.0 versus DR 2.0

For a single electric resistance water heater, the system benefits of providing DR 2.0 grid services can significantly outweigh the costs

Costs & Benefits of Single Water Heater

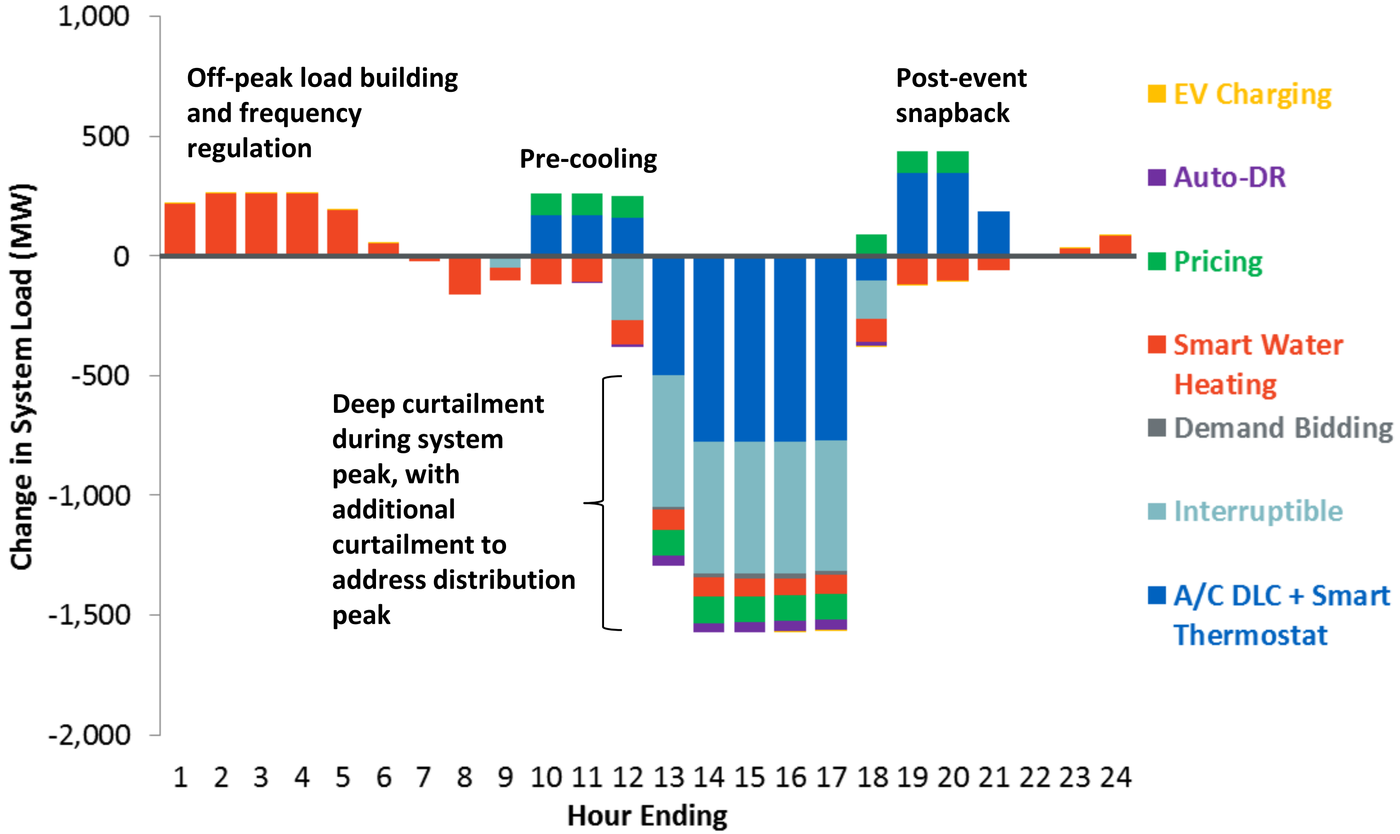


Observations

- Relative to a simple peak shaving program, which is only utilized during 100 hours of the year, grid-connected water heaters provide higher benefits in the form of grid balancing and avoided energy costs
- In this example, the grid-connected water heater is also assumed to target capacity-constrained locations on the distribution grid; this results in an increase in avoided distribution costs and a decrease in avoided generation capacity costs due to non-coincidence of the peaks

An expanded DR 2.0 portfolio would reshape the load profile subject to system needs

Illustrative Load Impacts of a DR 2.0 Portfolio on Top Load Days



Notes: Shown for cost-effective programs identified in 2030, accounting for portfolio overlap.

Modernizing Tariffs

Utilities have begun modernizing tariffs in North America

Ontario, Canada. Flat bill applies for distribution, Time-of-Use (TOU) charge for default energy supply

Arizona. 20% of customers on opt-in demand charges for one utility; mandatory demand charges for DG customers for another utility; TOU energy rates very popular for both

California. Mandatory TOU rates plus minimum bill for DG customers; Moving all other customers to default TOU in 2019/20; SMUD has already begun moving its customers to default TOU; LADWP has introduced a fixed monthly charge that varies with customer kWh usage

Tariff modernization in North America (continued)

Colorado: Fort Collins moved all customers to mandatory TOU rates in October

Idaho: DG customers have been designated a separate rate class

Kansas: Mandatory three-part rates for DG customers; opt-in for others

Montana: Utility has filed for designating DG customers as a separate rate class and for moving them to mandatory three-part rates

Tariff modernization in North America (concluded)

New York: Considering moving DG customers to demand charges or TOU energy rates or a combination of the two

Oklahoma: 20% of customers on a dynamic pricing rate with smart thermostats

Texas: Considering moving distribution charges to a flat bill, similar to Ontario's

Tariff modernization in Great Britain

UK Power Networks in London is piloting a peak-time rebate (PTR) targeted specifically at low-income customers

A couple of pilots have tested other types of time-varying rates

- One rate featured a “wind twinning” tariff, which was intended to encourage consumption increases/decreases at times of unexpectedly high/low output from wind generation
- Some of the rates tested were dynamic in nature

Ofgem, the regulator, is examining new ways to increase the role of price responsive demand, including the possible introduction of Amazon and Google

Tariff modernization in Great Britain (concluded)

13% of customers are on a TOU rate (Economy 7) designed for customers with thermal energy storage

- The rate that has been offered for many years, is based on old technology, and the number of participants is in decline but provides a conclusive evidence of customer acceptance and response to time-varying tariffs

A start-up retailer has introduced a TOU tariff with a strong price signal

British Gas offers a FreeTime tariff, which allows customers to pick one weekend day during which their electricity is free

A pilot tested the “Sunshine Tariff,” which charged a lower price during mid-day hours to alleviate local distribution system constraints due to net excess solar generation

Tariff modernization in Hong Kong

CLP Power ran a pilot with peak-time rebates (PTR) for its residential customers

The pilot found that customers understand price incentives and respond to them

The utility, which has universal deployment of smart meters, has begun deploying PTR to several thousand customers

Tariff modernization in the EU

Millions of customers in Spain are on a real-time pricing tariff, which represents the default energy supply option

In Estonia, real-time pricing is also the default energy supply option and thousands of customers are on it

In Italy, millions of customers are on a default time-of-use rate

In Italy, Spain and France, customers pay a capacity charge for being connected to the grid

Some general themes have begun to emerge

Modern tariff designs are being introduced throughout the globe

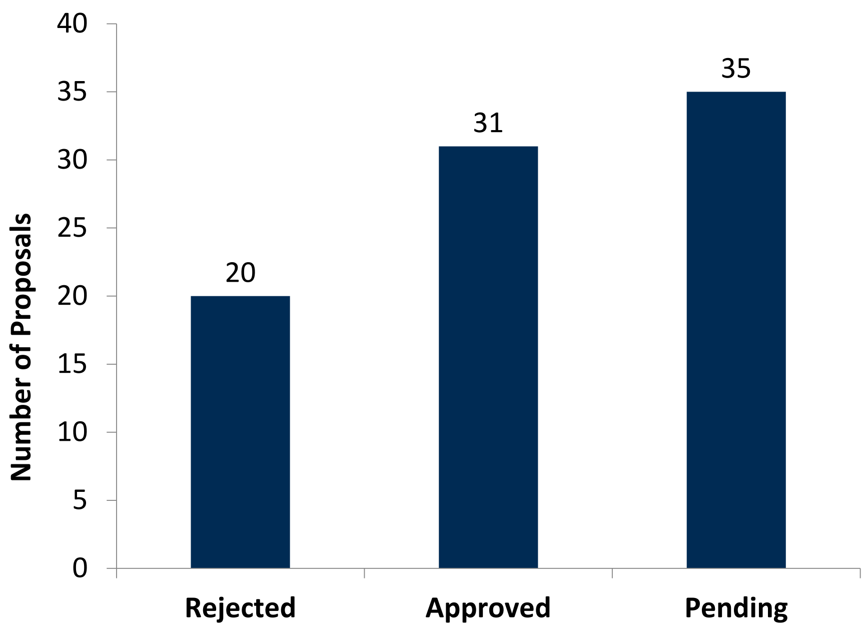
Customers understand modern tariffs and respond to them, enhancing economic efficiency in the use of scarce financial and energy resources, and promoting equity between customers

Modern tariff design encompasses three elements: time-varying energy rates, demand charges to recover capacity costs, and fixed charges to recover the costs of “revenue cycle” services

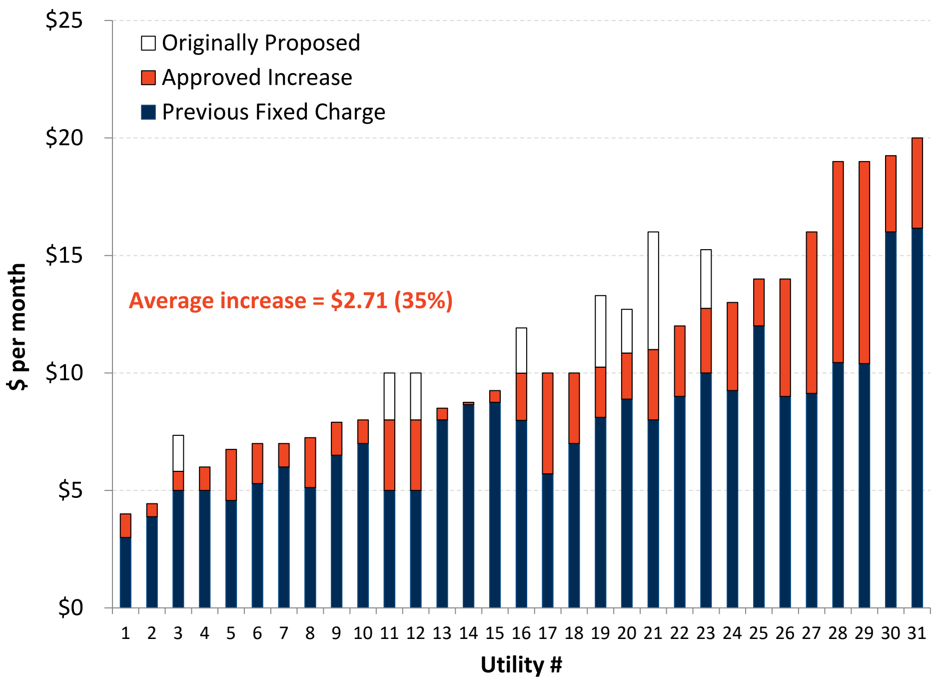
There is a desire to move Fixed Charges closer to fixed costs

Many utilities have proposed to increase the fixed charge, with varying degrees of success

Recent Proposals to Increase Fixed Charge



Amount of Approved Increase



Data sources: NC Clean Energy, "The 50 States of Solar," Q2 2015. Supplemented with review of additional utility rate filings.

Demand charges

Capacity charges based on the size of the connection are mandatory for residential customers in France, Italy, and Spain

Demand charges are being offered by more than 30 utilities in the United States, including a few rural cooperatives

Utilities such as Arizona Public Service, NV Energy, and Westar Energy have filed applications to make them a mandatory tariff for customers with PVs on their roof

- Salt River Project in Arizona, a municipally owned system, has instituted a mandatory tariff for DG customers
- Commissions in Idaho and Kansas have ruled that DG customers can be considered a separate class
- Kansas is rolling out three-part rates for DG customers

Will residential customers understand demand charges?

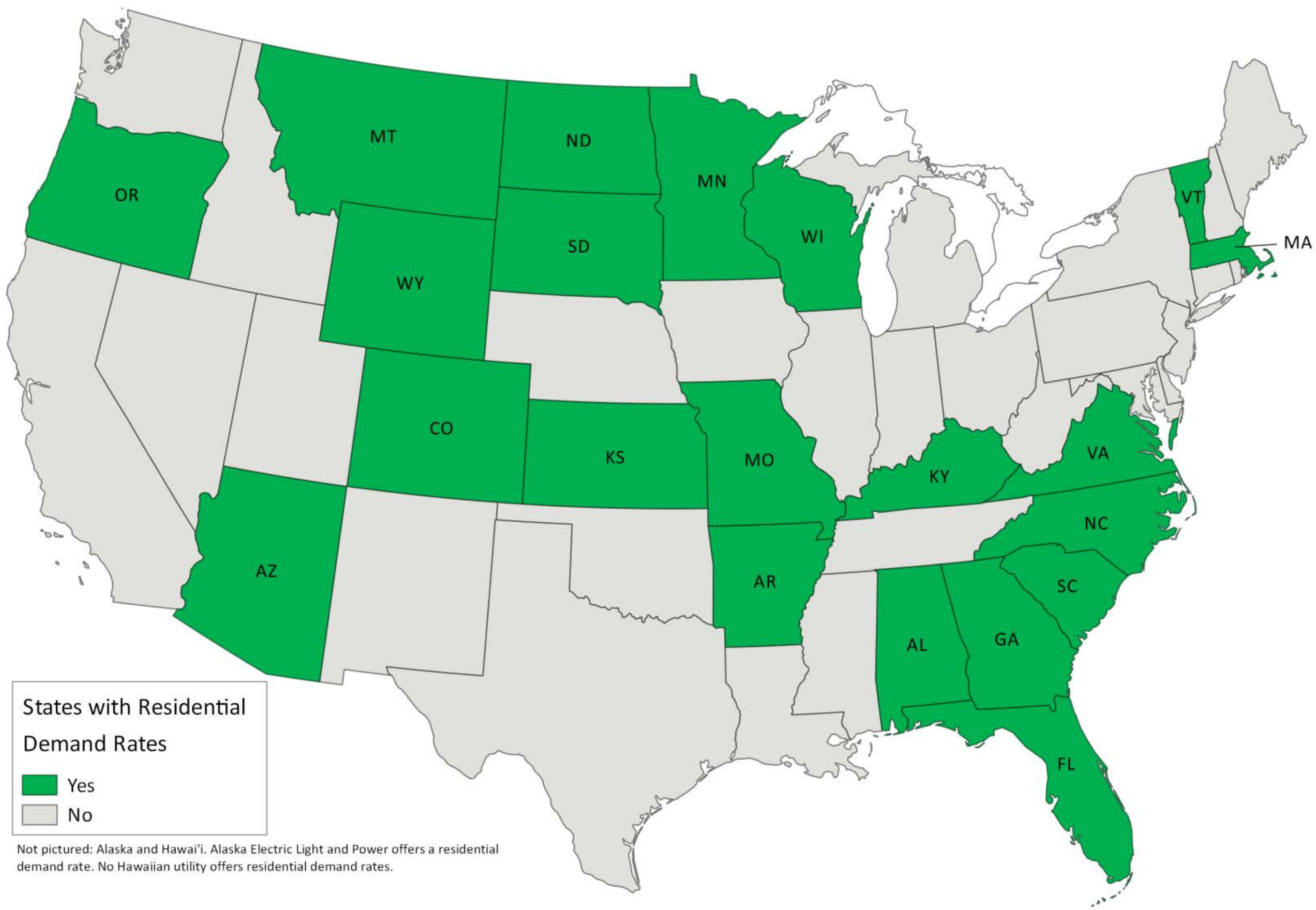
Demand charges can be easily explained to customers using the example of a light bulb, which is expressed in watts, and by referring to the circuit breaker as an example of a household-specific capacity constraint

Customers can be provided typical demand ratings of major appliances and loads in their house

The message, successfully expressed by utilities in Arizona, needs to be simple: “Don’t use all your major appliances at the same time.”

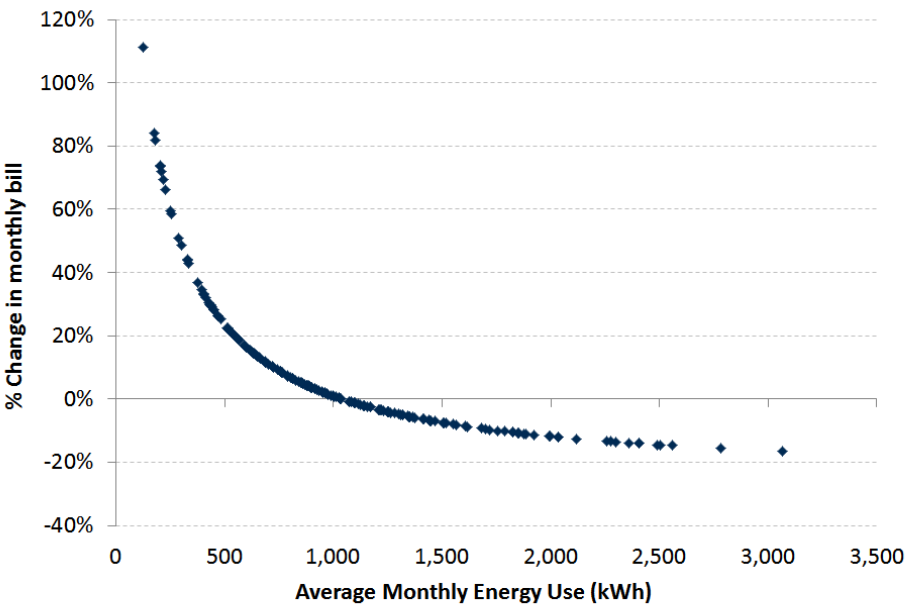
Residential demand charges in the U.S.

22 states are offering demand charges to residential customers



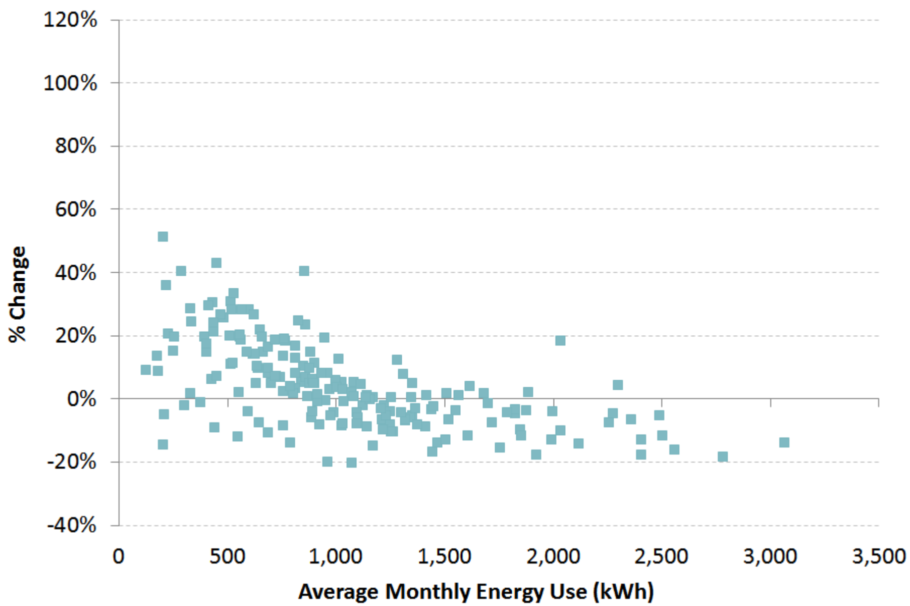
While increased fixed charges raise bills for small customers, demand charges do not

With Increased Fixed Charge



Note: The three-part rate includes a monthly fixed charge of $10, an energy charge of $0.077/kWh, and a demand charge of $6/kW. The revenue-neutral two-part rate includes a monthly fixed charge of $40 and an energy charge of $0.083/kWh.

With New Demand Charge



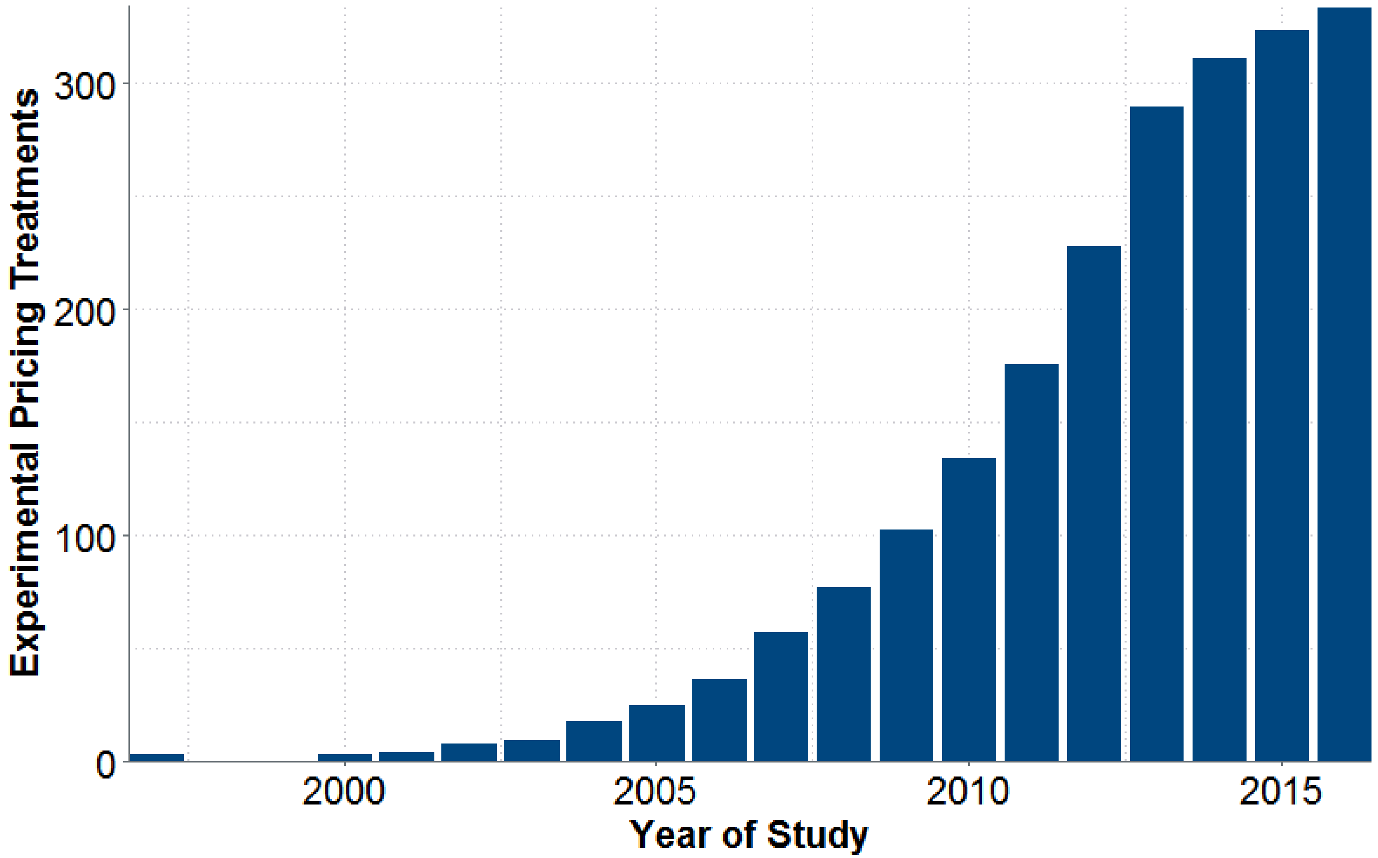
Note: The three-part rate includes a monthly fixed charge of $10, an energy charge of $0.060/kWh, and a demand charge of $9/kW. The revenue-neutral two-part rate includes a monthly fixed charge of $40 and an energy charge of $0.083/kWh.

- Correlation between bill impact and customer size is stronger with increased fixed charge.
- Whether small customers are low income customers is another question entirely…

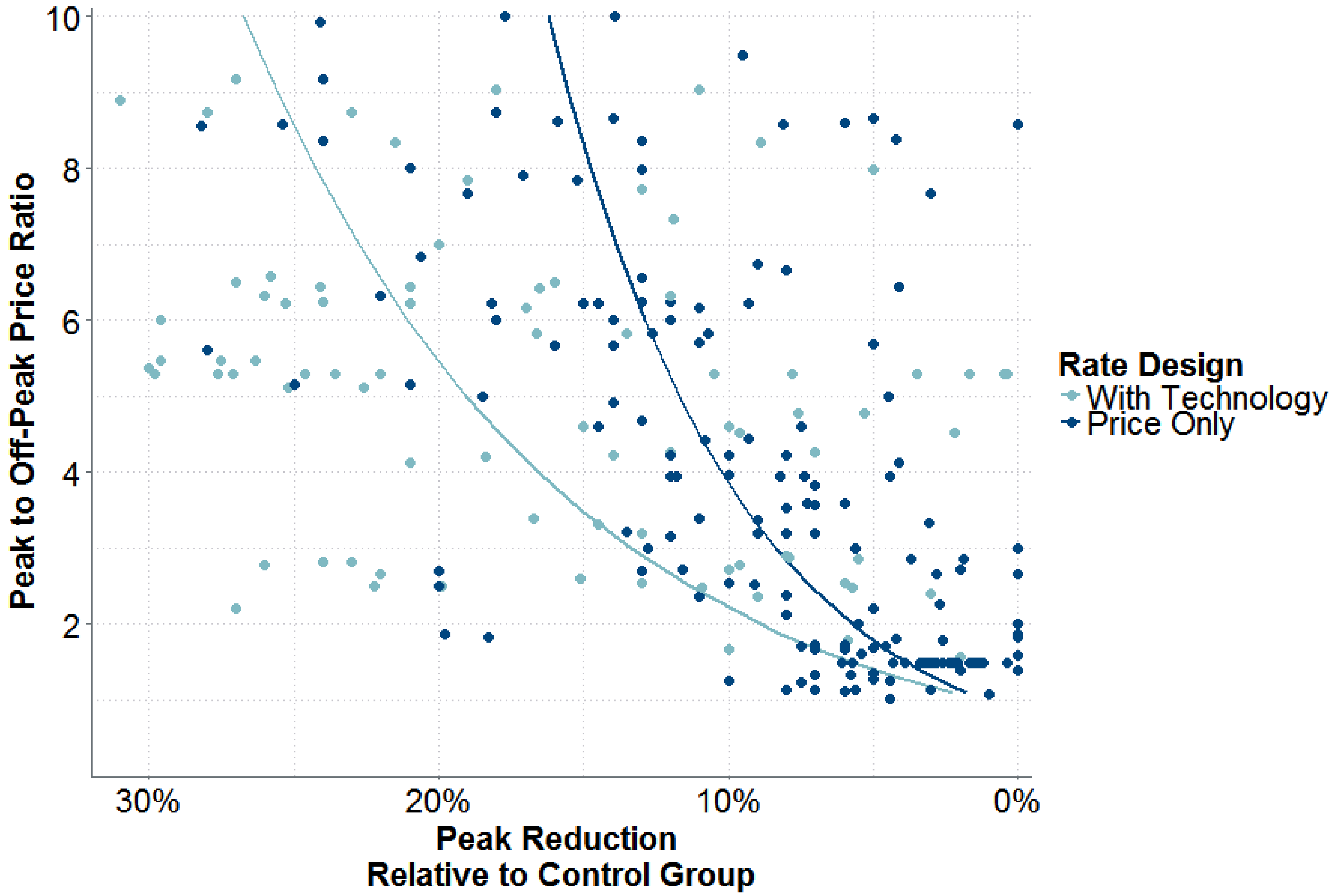
Modern rate designs will be an essential component of DR 2. 0 and indispensable to the grid-integration of renewables

Rate Design	Definition
Critical Peak Pricing (CPP)	Customers pay higher prices during critical events when system costs are highest or when the power grid is severely stressed.
Demand Charges	Customers are charged based on peak electricity consumption, typically over a span of 15, 30, or 60 minutes.
Inclining Block Rates (IBR)	Customers are charged a higher rate for each incremental block of consumption.
Peak Time Rebates (PTR)	Customers are paid for load reductions on critical days, estimated relative to a forecast of what the customer would have otherwise consumed (their “baseline”).
Real-Time Pricing (RTP)	Customers pay prices that vary by the hour to reflect the actual cost of electricity.
Seasonal Rates	The year is divided into different seasons, commonly winter and summer, each of which have distinct rates. Prices are higher in peak seasons to reflect seasonal variation in the cost of supplying energy.
Time-of-Use (TOU)	The day is divided into time periods which define peak and off-peak hours. Prices are higher during the peak period hours to reflect the higher cost of supplying energy during that period.
Variable Peak Pricing (VPP)	During pre-defined peak periods, customers pay a rate that varies by utility to reflect the actual cost of electricity.

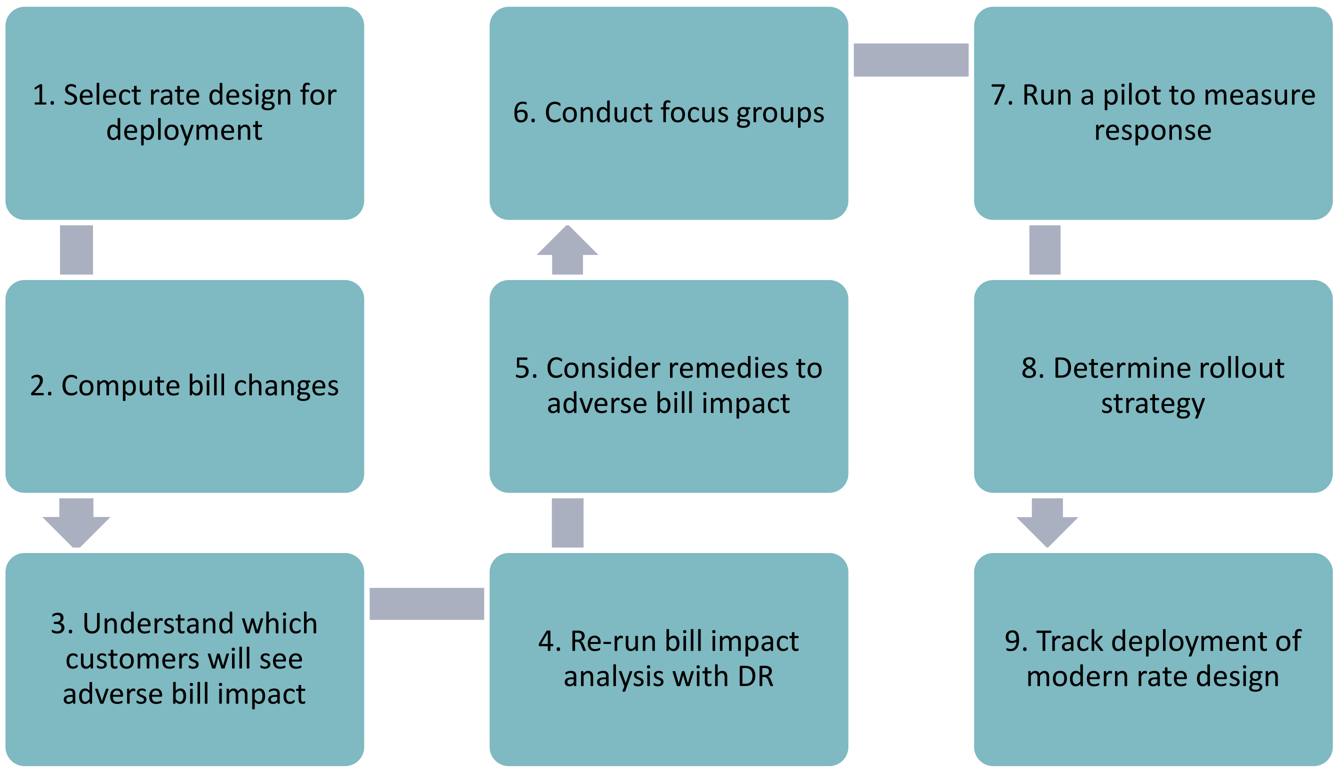
300+ trials have been conducted with time-varying rates to see if customers respond to price incentives



There is compelling evidence from 300+ pilots showing that customers respond to price changes

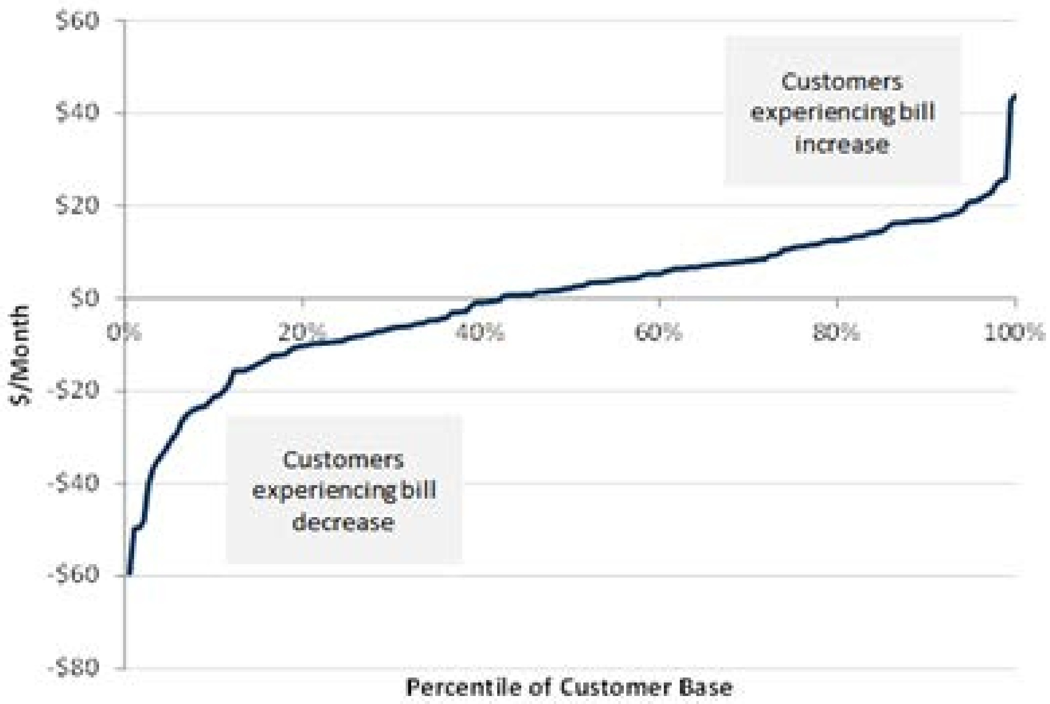


Transitioning to modern rate designs will require a careful process



It will be essential to know how modern rate designs will affect customer bills

Some customers will see higher bills while others will see lower bills (unless they change their load shape)



If the adverse bill impacts are significant for certain customers, consider instituting one of these remedies

Remedy	Implementation
Gradualism	Roll out the new rates gradually for each rate design element. For example, to introduce a TOU rate, if the peak price will be 25 ¢/kWh and the current tariff is 15 ¢/kWh, implement a peak price of 17 ¢/kWh in the first year and increase it annually by 2 ¢/kWh until it reaches 25 ¢/kWh.
Bill Protection	Provide customers with bill protection for a limited period of time so that they pay the lower of their old and new bill.
Optional Rates	Make the new rate design optional for vulnerable customers, mandatory for the largest customers, and the default for all other customers.
Financial Assistance	Provide customers with adverse bill impacts financial assistance for a limited period of time.
Enabling Technologies	Install enabling technologies such as smart thermostats on customer premises.
Two-staged Rollout	Structure the rate into two stages, where the first stage charges customers the current rate if their usage resembles a historical reference period, and the second stage exposes them to the new rate.

Conclusions

Renewable energy is going to play a significant role in the grid of the future

Demand response is undergoing revolutionary change, evolving from load management and peak clipping into DR 2.0, centered on load flexibility which will optimize the integration of renewable energy into the grid, while lowering customer bills

Modern rate designs are an essential component of DR 2.0 and they can be rolled out without creating a customer backlash

Appendix A:
The Load*Flex* Model

The Load*Flex* Modeling Framework

1

Parameterize DR programs

- Build database of new DR and flexible load programs
- Estimate per-participant costs and participation
- Identify value proposition and applicable grid services
- Establish load impacts and operational constraints

2

Establish marginal costs and market depth

- Generation capacity value
- Frequency regulation value
- Generic & targeted T&D value
- Energy value

3

Develop 8,760 hourly avoided costs

Allocate marginal costs based on hourly LOLP

Combine hourly costs to create stacked value profile

4

Optimally dispatch programs and calculate B/C metrics

Simulate hourly optimized dispatch

Calculate total benefits across value streams

5

Identify cost-effective incentive and participation

Establish relationship between adoption and incentives

Identify economic incentive level and associated participation

6

Estimate incremental cost-effective DR potential

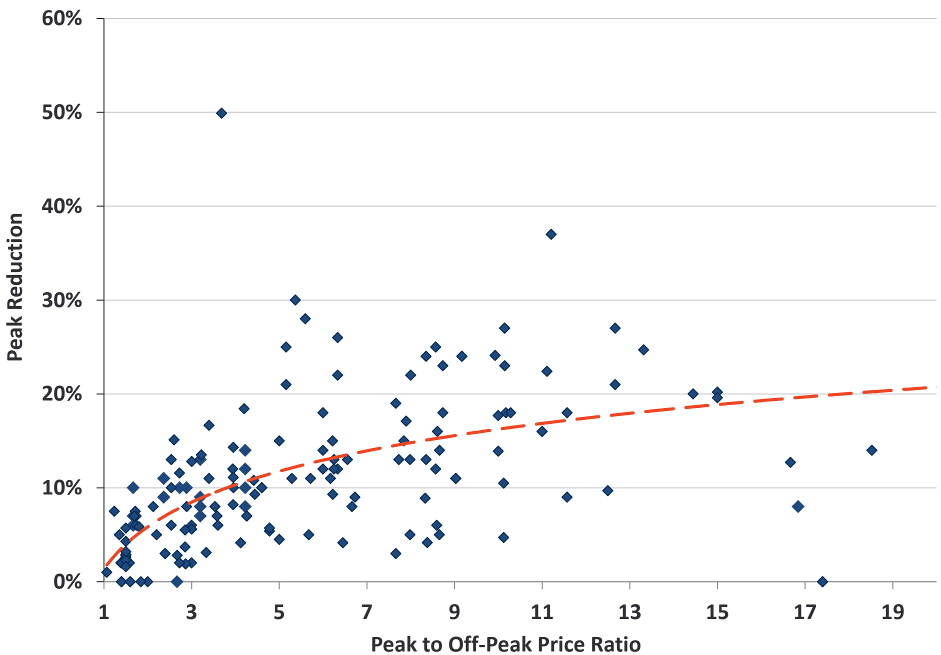
Calculate cost-effective potential by program

Estimate portfolio impacts after participation overlap

Per-participant impacts

Per-participant impacts are derived from program experience, the experience of programs in other jurisdictions, and a review of engineering studies that identify theoretical load flexibility potential

Relationship Between Price Ratio and Response



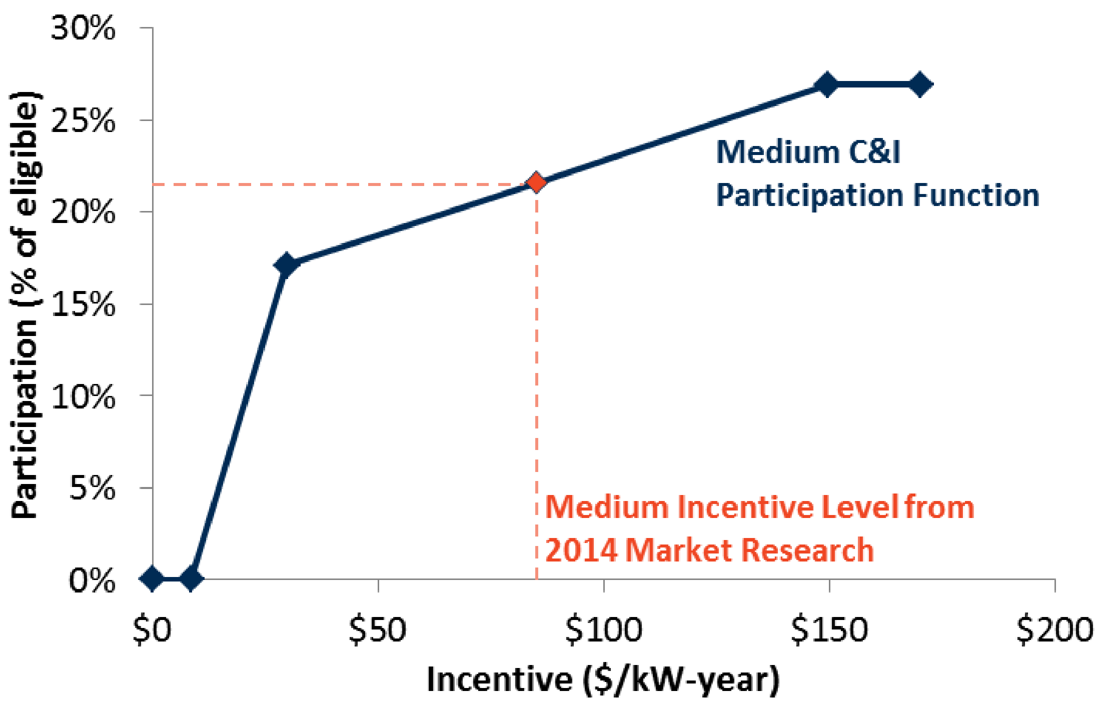
Results shown only for price ratios less than 20-to-1 and for treatments that did not include automating technology such as smart thermostats.

For example, the impacts of time-varying pricing programs are based on a review of more than 300 experimental and non-experimental pricing treatments across over 60 pilot programs. Price response is expressed as a function of the assumed peak-to-off-peak price ratio in the time-varying rates

Participation is modeled as a function of each program's participation incentive level

This allows for identification of the incentive level (and associated enrollment rate) that produces a benefit-cost ratio of 1.0

Relationship Between Adoption and Incentive

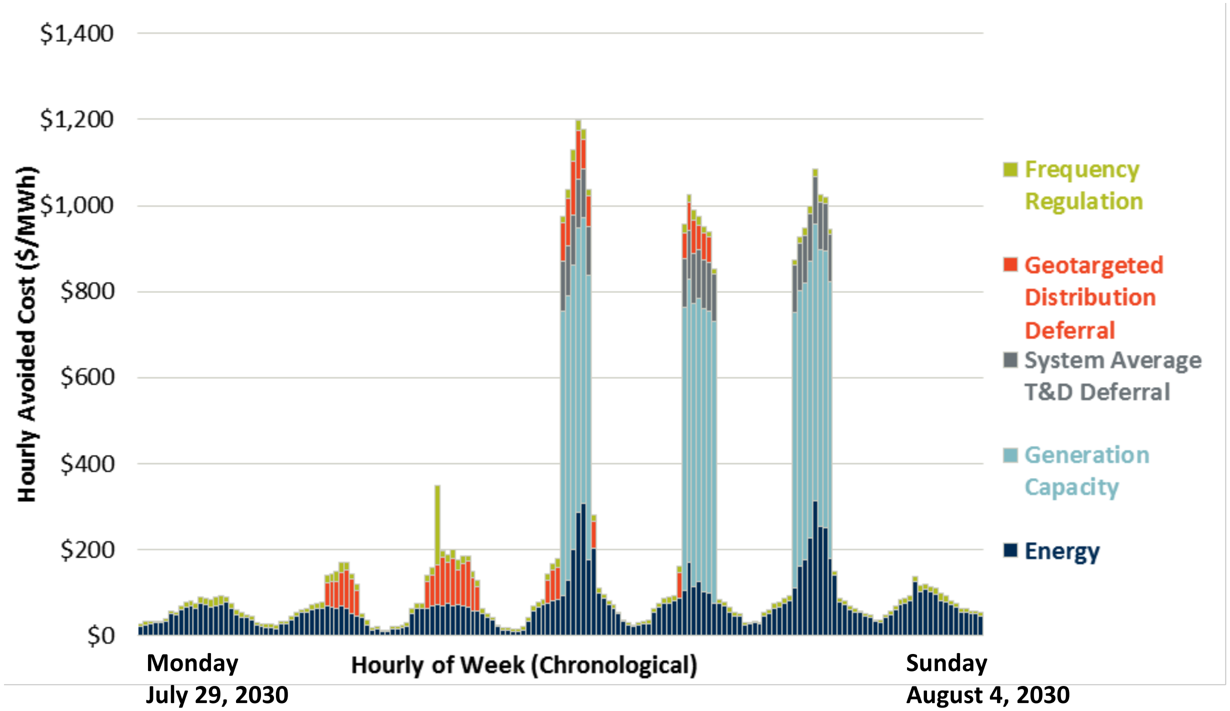


Relationships from market research are combined with observed participation rates from other jurisdictions to establish adoption functions for each DR program

DR program dispatch maximizes "stacked benefits" subject to operational constraints

Each DR program is dispatched against an hourly price series that includes an allocation of energy and capacity costs (based on LOLP)

Chronological Allocation of Marginal Costs (Illustration for Week of July 29)



Unique operational characteristics of each DR program are accounted for in the dispatch. For instance, curtailment of air-conditioning load is limited to 75 hours during summer months. Other program types, such as C&I Auto-DR, are less constrained but subject to hourly and seasonal variability in curtailable load.

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Mr. Hledik has supported utilities, policymakers, law firms, technology firms, research organizations, and wholesale market operators in matters related to retail rate design, energy efficiency, demand response, distributed generation, and smart grid investments. He has worked with more than 50 clients across 30 states and seven countries.

A frequent presenter on the benefits of smarter energy management, Mr. Hledik has spoken at events throughout the United States, as well as in Belgium, Brazil, Canada, Korea, Poland, Saudi Arabia, and Vietnam. He regularly publishes on complex retail electricity issues.

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