Solving real problems with technology

Future PV Roundtable – Solar Power International 2019

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Agenda

Part I

10:00	**Welcome and introductions**
10:05	**PRESENTATION C&I Value stacking: the role of inverters in managing the underlying distributed energy resources and grid interaction and support, including virtual power plants.**
10:15	**PANEL DISCUSSION Meeting grid needs with solar & inverters: examining how inverters can supply essential grid services such as frequency & voltage regulation, as the grid moves from large spinning masses to electronic controls, as well as how solar & storage behind the meter can serve as flexible demand**

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Agenda

Part II

11:05 **PANEL DISCUSSION Explosion of cell & module technology: which designs can meet the challenges of mass production & stand the test of time?**

11:55 **Closing remarks**

Networking

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C&I Value stacking

The role of inverters in managing the underlying distributed energy resources and grid interaction and support, including virtual power plants

Lior Handelsman

VP of Marketing and Product Strategy

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Opportunity for C&I in Grid Services

Lior Handelsman

September 25th, 2019

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Meet SolarEdge

SolarEdge in Numbers Q2 2019

13.1GW
of our systems shipped worldwide

Over **1.1M** monitored systems around the world

40.8M
power optimizers shipped

Presence in **28** countries

1.7M
inverters shipped

$325M
Q2 2019 revenue

2,078 employees

303 awarded patents and **240** additional patent applications

One-Stop-Shop for Smart Energy Solutions

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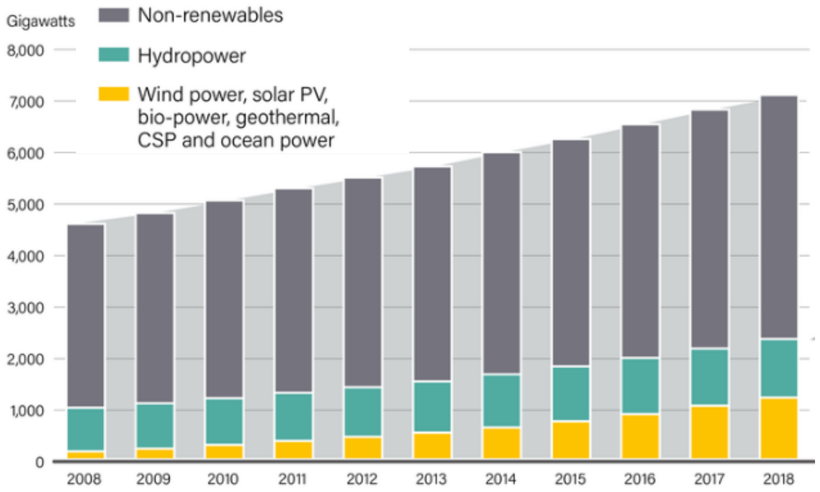
Grid Challenges

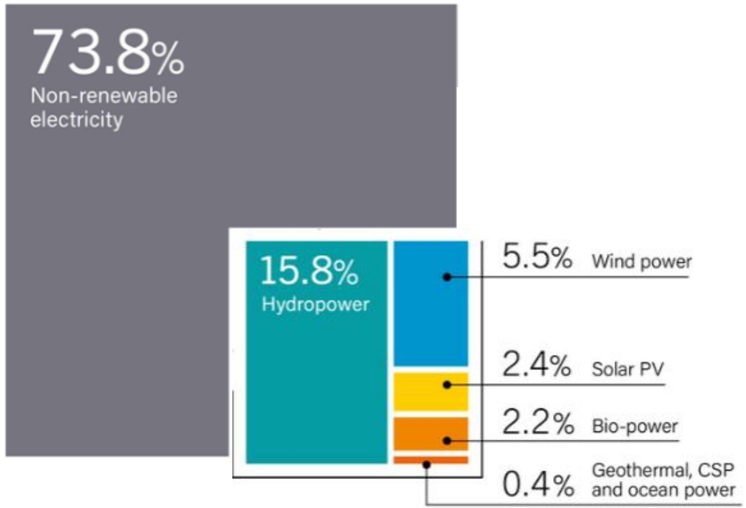
Renewable Penetration

- Each year, more electricity is generated from renewable energy than in the previous year.
- Solar PV has exceeded 20% of the renewable share

Global Power Generating Capacity, by Source, 2008-2018



Estimated Renewable Energy Share of Global Electricity Production, End-2018



Source: https://www.ren21.net/gsr-2019/chapters/chapter_01/chapter_01/#target_192

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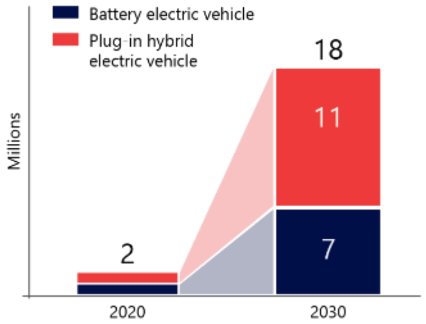
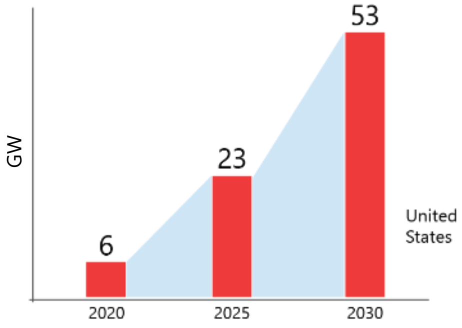
Electrification of Transportation

- Approximately 18M EVs and hybrids will be on U.S. roads by 2030
  - 900% increase from 2020
- Leading to 53 GW of increased energy demand for charging, up from only 6 GW in 2020
- Potentially causing EV charging peaks that could surpass total capacity

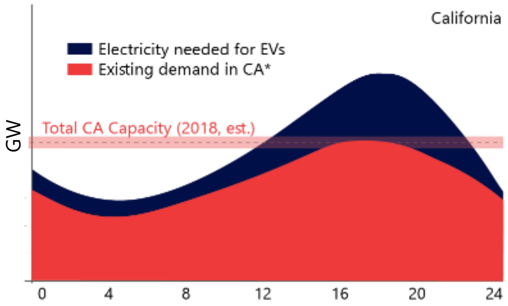
EV Adoption Rate in U.S.



Charging Energy Demand for EVs in U.S.



Electricity Demand for 100% EV Scenario (High Peak Charging scenario)



 Source: McKinsey, Citylab

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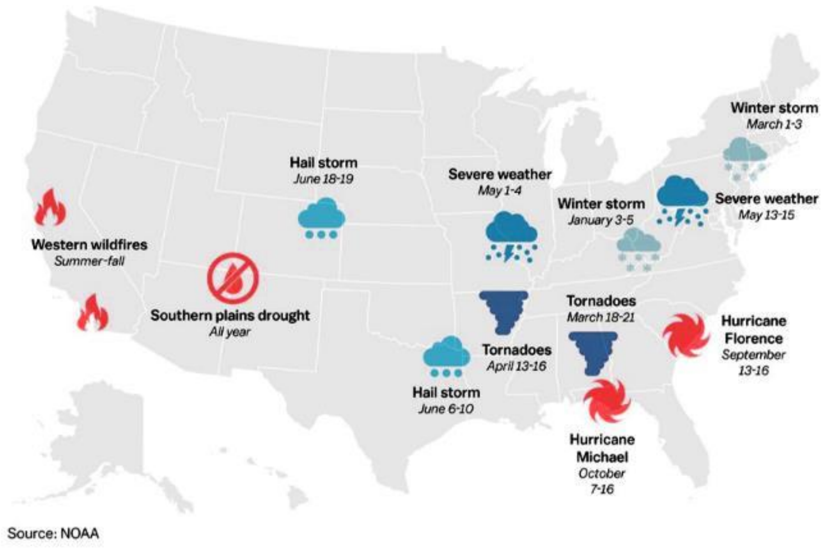
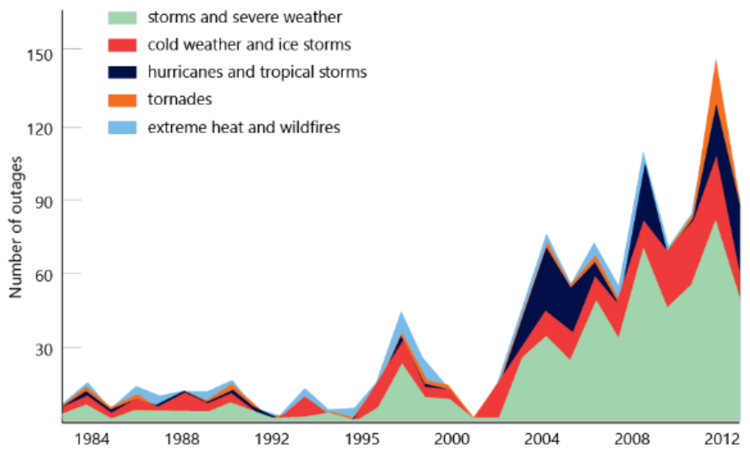
Extreme Weather

- A variety of extreme weather is occurring at increasing frequency, intensity, and duration
- Severe weather is among the leading causes of large-scale power outages in the U.S.

Billion-dollar weather disasters in the U.S. in 2018



Extreme Weather Is Causing More Major Power Outages
(major = at least 50,000 customers affected)

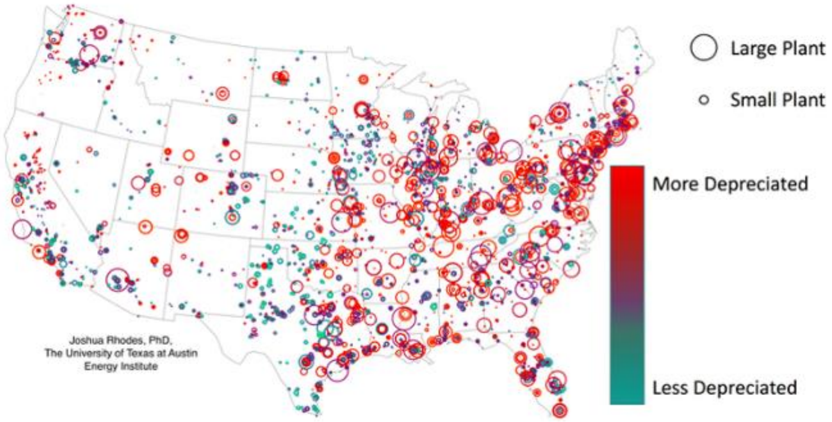


 Source: Vox, Our Energy Policy

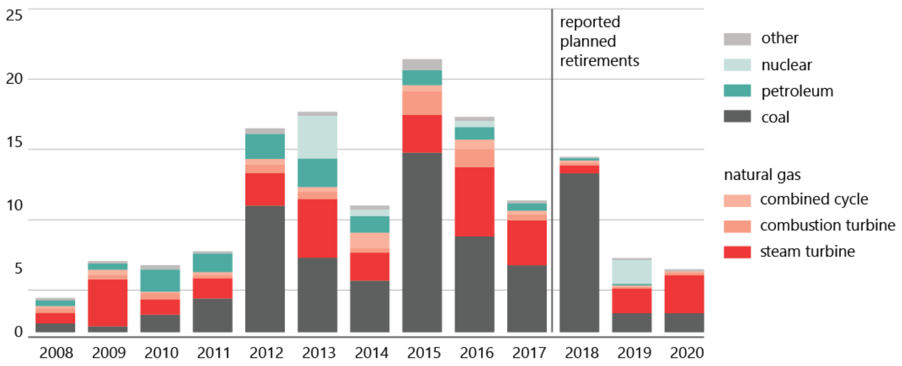
Aging Infrastructure and Network

- Parts of the energy network are >100 years old, 70% of transmission lines and power transformers are >25 years old
- Average power plant age is >30 years; plants built during the rapid expansion of power sector after WW2 are >40 years old
- Traditional generators are being retired, effecting an increasing amount of capacity

Location and Depreciated Status of all U.S. Power Plants



U.S. Utility-Scale Electric Generating Capacity Retirements (2008-2020, GW)



 Source: Grid Resiliency Report from the White House Report, Energy.gov, The Conversation, US Energy Information Administration

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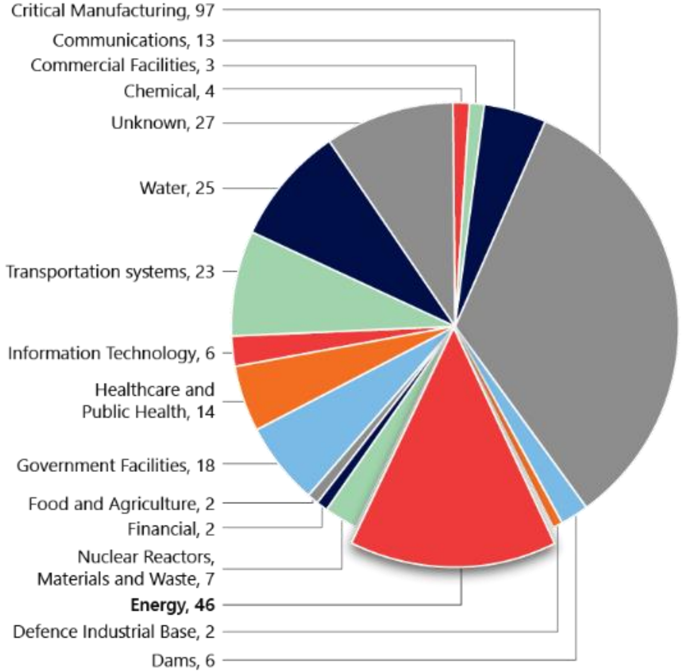
Cyber Security

- Energy sector is one of the larger targets for cyber attacks
- Objective to cause equipment malfunction or failure, physical equipment damage, power disruptions, or blackouts
- U.S. Example:
  - March 5, 2019
  - Utility reported a 'cyber event' to the DOE
  - Blind spots caused by denial-of-service attack at a grid control center and several small power generation sites in California, Utah, and Wyoming
  - May not have been a full attack, but demonstrates grid vulnerabilities (i.e. in firewall interfaces)

FY 2015 Incidents by Sector (295 total)

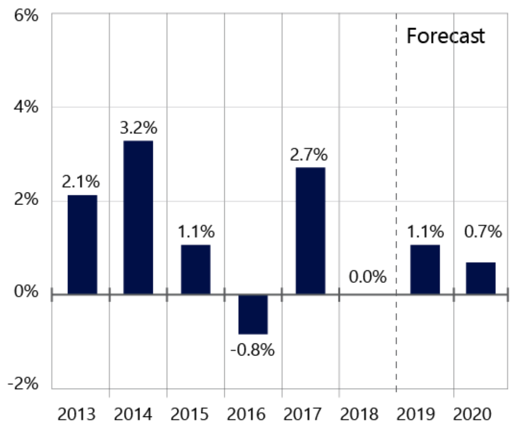


 Source: Energy.gov, E&E News, NPR

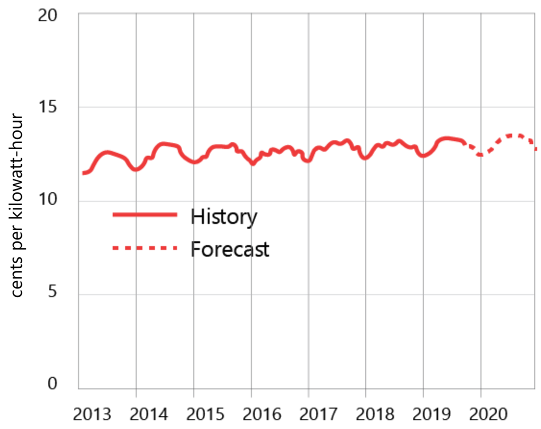
Fluctuating Energy Prices

- General trend of increasing annual energy prices
- Seasonal fluctuations with peaks in summer months
- Variation by customer type

Annual Growth in Residential Electricity Prices



U.S. Monthly Residential Electricity Price



residential
12.89¢
per kWh

commercial
10.66¢
per kWh

industrial
6.93¢
per kWh

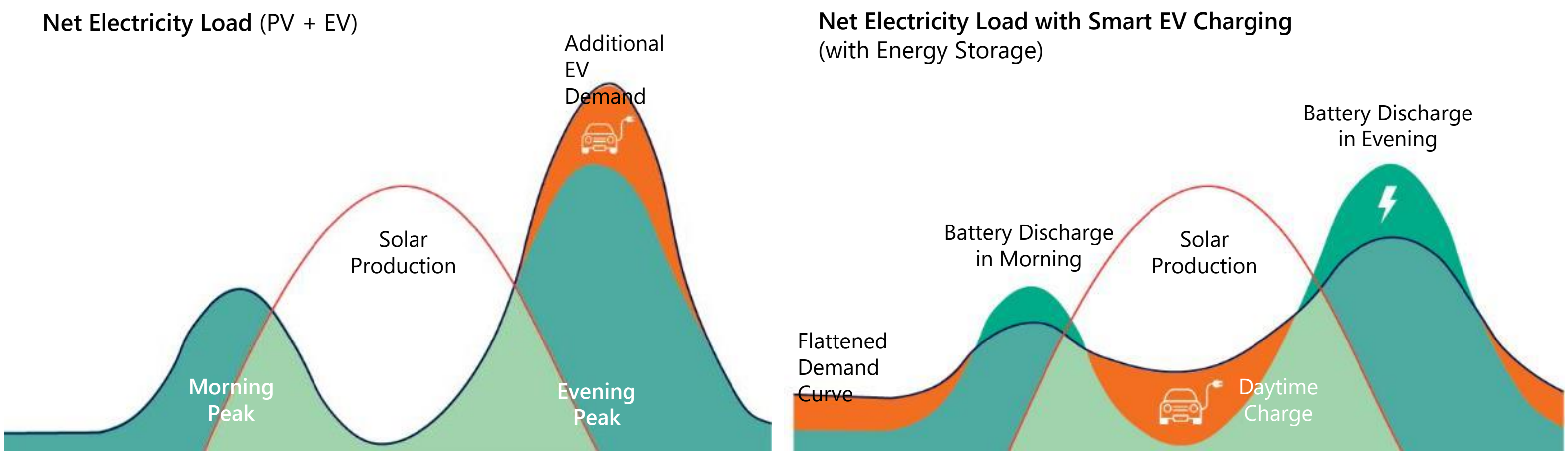
transportation
9.77¢
per kWh

 Source: EIA Short-Term Energy Outlook, EIA website

Opportunities

Overcoming Challenges

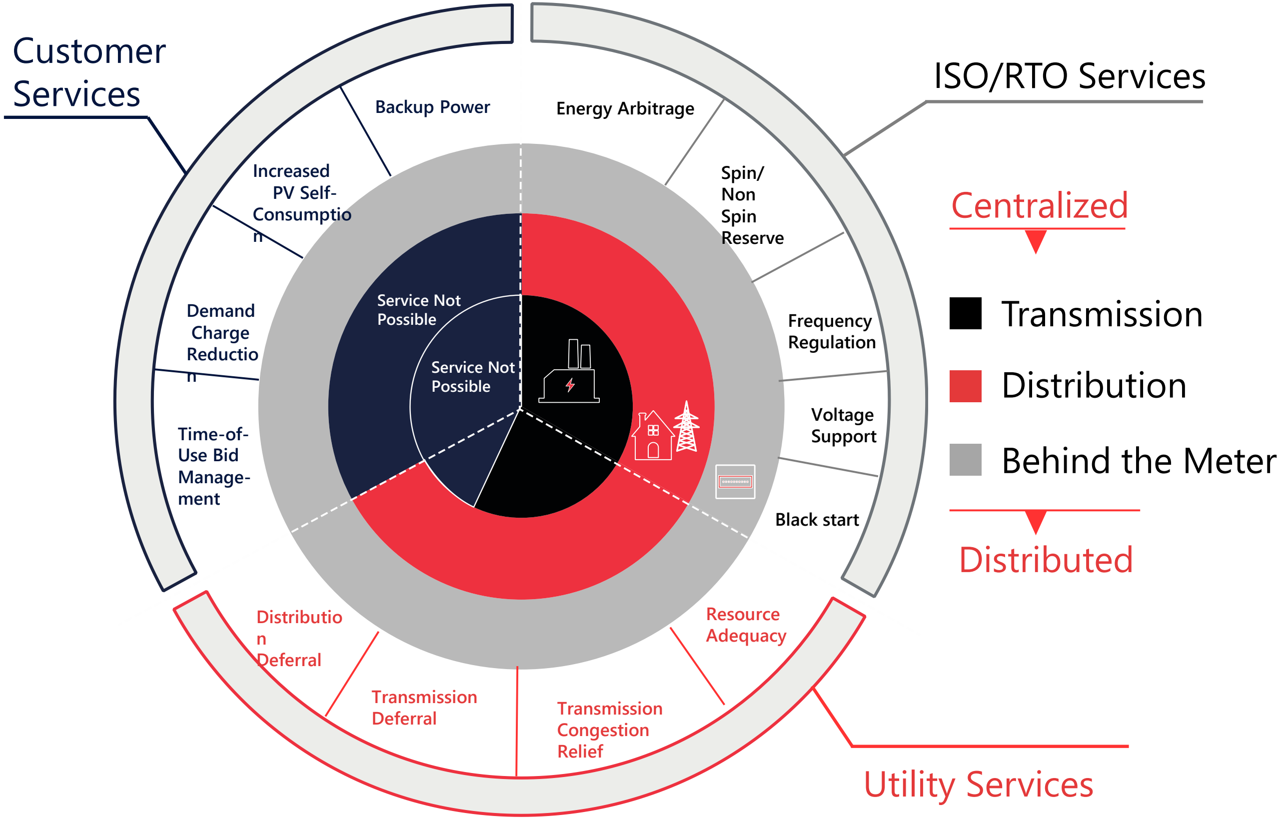
- Some of the problems can be used as part of the solution
  - Combining renewables, smart EV charging, and batteries can make the energy market more stable and cope with grid instability



 Source: Utrecht University: Analysis of the impact of controlled charging and vehicle to grid on growth of electric vehicle and photovoltaic systems: a case study in Amsterdam

Value Stacking

- Batteries can provide up to 13 services for 3 different stakeholders

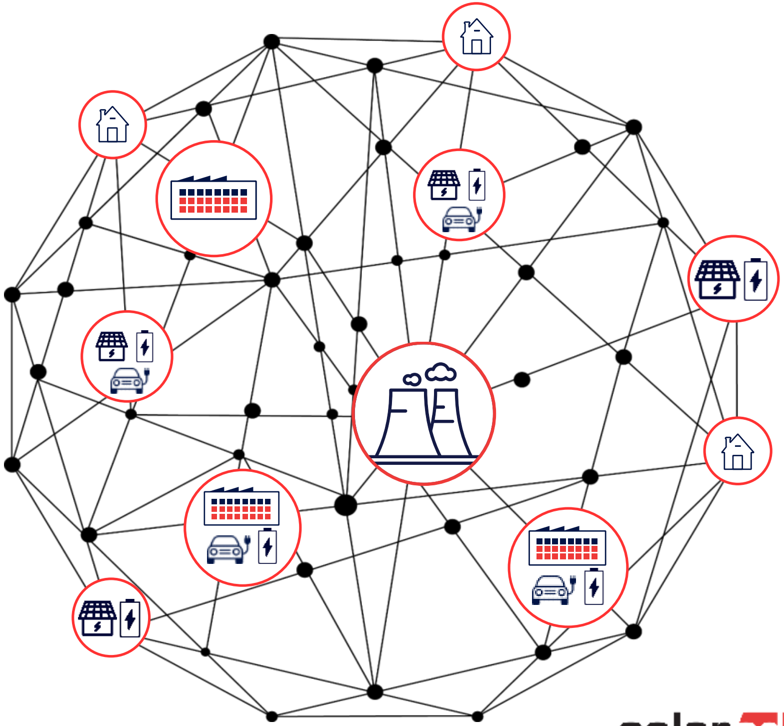


Source: *Rocky Mountain Institute*

C&I Opportunity

C&I may offer greater potential than residential for grid services

- Each site has a larger impact on the grid, but still distributed generation
  - Consume more energy
  - Produce more energy with larger roof space
- Larger variety of DERs that can be leveraged
- Specifically assist with duck curve ramp up - i.e. battery discharge in the evening
- Reduced acquisition costs per MW for grid services participation
- More value stacking opportunity
- Reduced communication costs per MW



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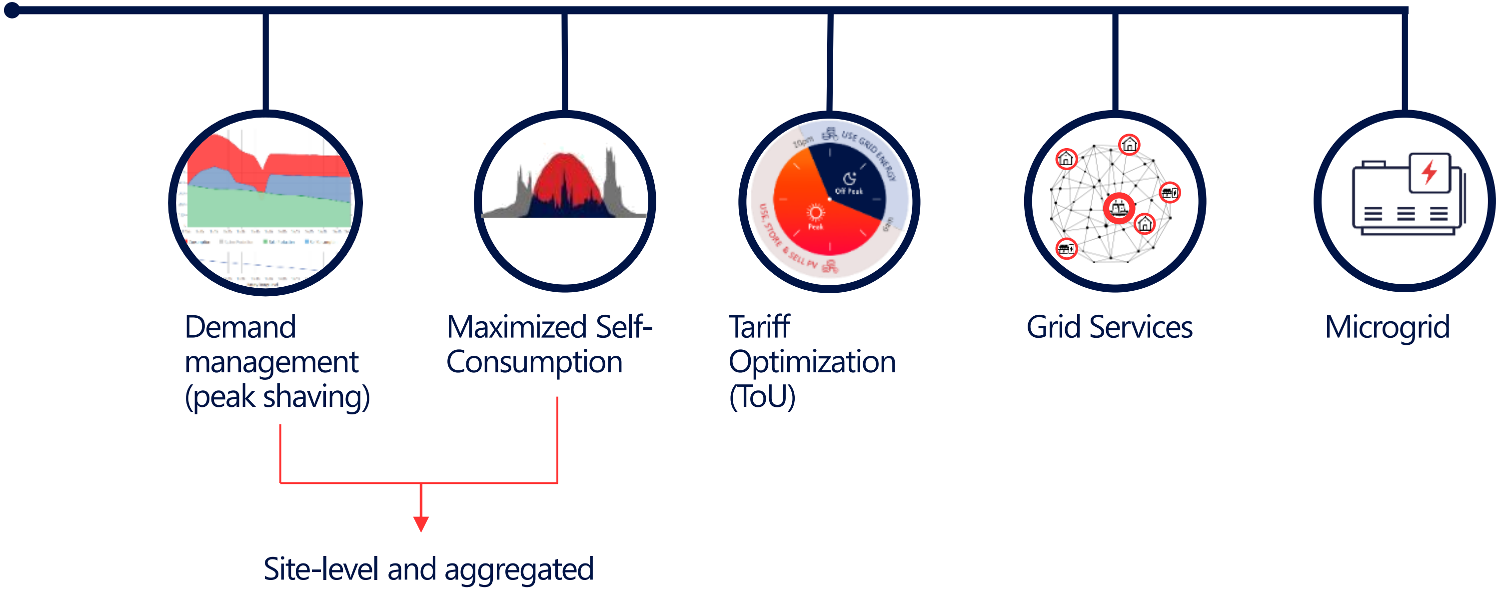
Stacked Value Energy Management

Improving the economics of distributed energy resources

Commercial StorEdge



Technology Requirements

Technology Requirements

- Smarter inverters: Fast communication/connectivity with high bandwidth, processing power, memory, interoperable
- Metering: Import/export, self-consumption, and grid sensing
- Predictive analytics, machine learning, and big data
- External interfaces: Pricing signal, weather information, etc.
- Batteries: Built to support high C rate, high energy throughput with unpredictable charging patterns, etc.
- Underlying DERs: Fast, accurate, fail safe, certified, interconnected (IoT), interoperable
- EV charging: Understanding usage patterns and interface with the driver to optimize charging times for driving needs in coordination with network needs

Thank You!

Booth 1601

Cautionary Note Regarding Market Data & Industry Forecasts

This power point presentation contains market data and industry forecasts from certain third-party sources. This information is based on industry surveys and the preparer's expertise in the industry and there can be no assurance that any such market data is accurate or that any such industry forecasts will be achieved. Although we have not independently verified the accuracy of such market data and industry forecasts, we believe that the market data is reliable and that the industry forecasts are reasonable.

Version #: V.1.0

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Panel discussion

Meeting grid needs with solar & inverters: examining how inverters can supply essential grid services such as frequency & voltage regulation, as the grid moves from large spinning masses to electronic controls, as well as how solar & storage behind the meter can serve as flexible demand

Peter Mathews

General Manager North America

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Mahesh Morjaria

Vice President, Systems Development

First Solar

Mark Ahlstrom

Vice President of Renewable Energy Policy

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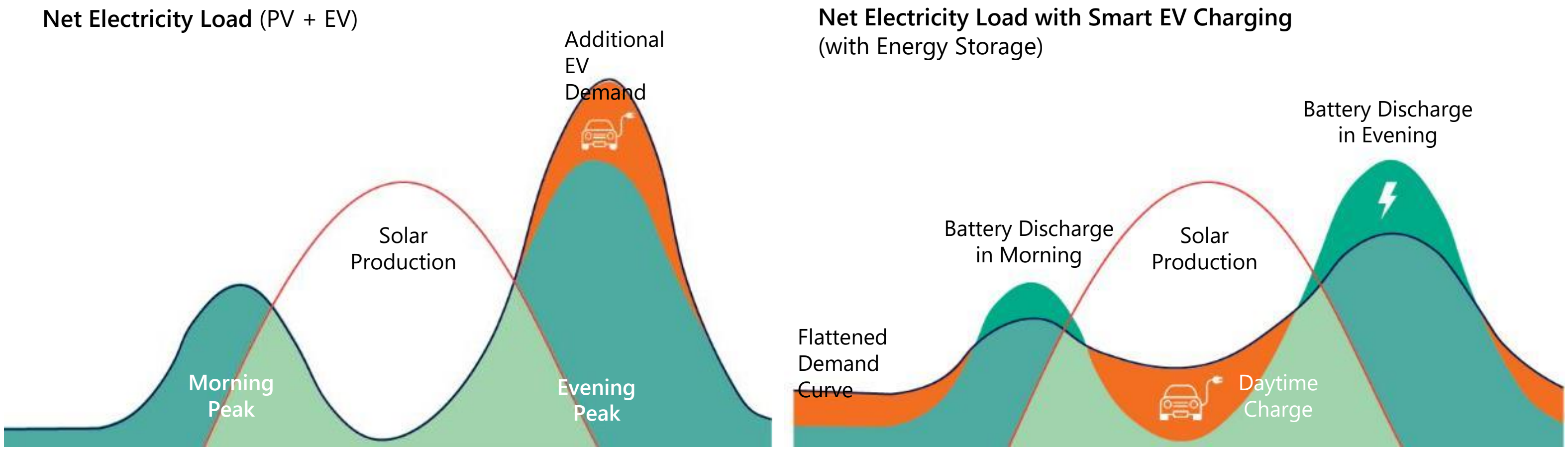
Combining PV, Storage and EV as a Grid Solution

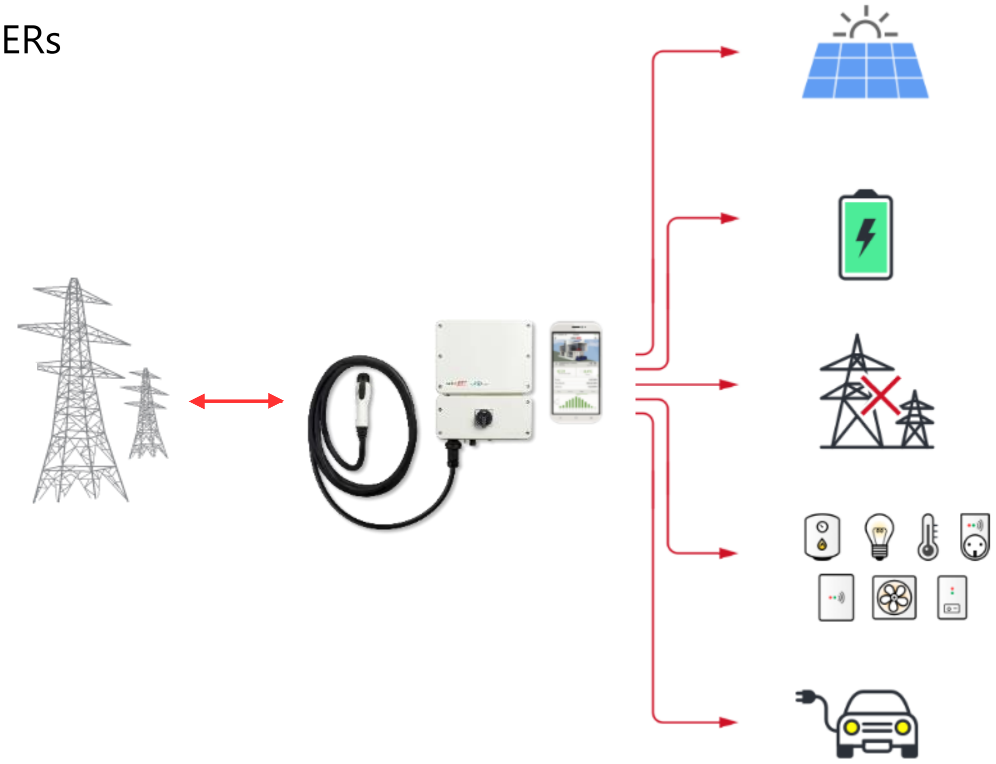
- EV charging causes even faster evening ramp up
- Smart charging and storage solutions can help to balance the effects of PV and EV penetration



 Source: Utrecht University: Analysis of the impact of controlled charging and vehicle to grid on growth of electric vehicle and photovoltaic systems: a case study in Amsterdam

Expanding Role of the Inverter

- Inverter manages multiple types of DERs
  - Storage
  - EV charging
  - Self-consumption
  - Home energy
- Manages and regulates smart grid
  - Takes aggregated commands and disaggregate them to underlying DERs



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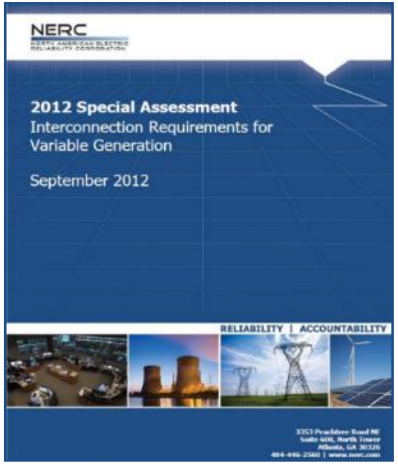
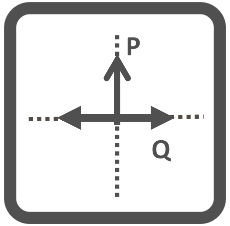
PV Solar Supports Grid Reliability & Stability



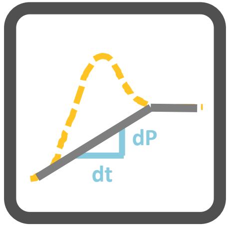
Features Required by NERC to be a Good Grid Citizen:

- Voltage regulation
- Active power control (ramping. Curtailment)
- Grid disturbance ride through (voltage and frequency excursions)
- Primary Frequency droop response
- Short circuit duty control

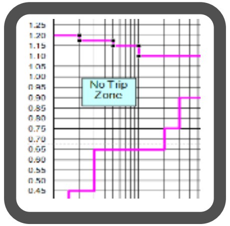
Voltage Support



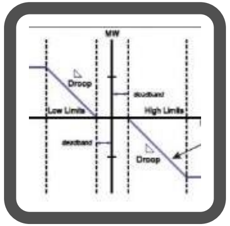
Power Control



Ride Through



Frequency Droop



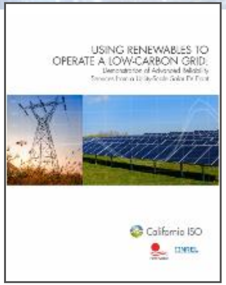
Base Capability

Sources: (1) NERC: 2012 Special Assessment Interconnection Requirements for Variable Generation
(2) M. Morjaria, D. Anichkov, V. Chadliev, and S. Soni. "A Grid-Friendly Plant." *IEEE Power and Energy Magazine* May/June (2014)

Solar Plant Provides Essential Reliability Services

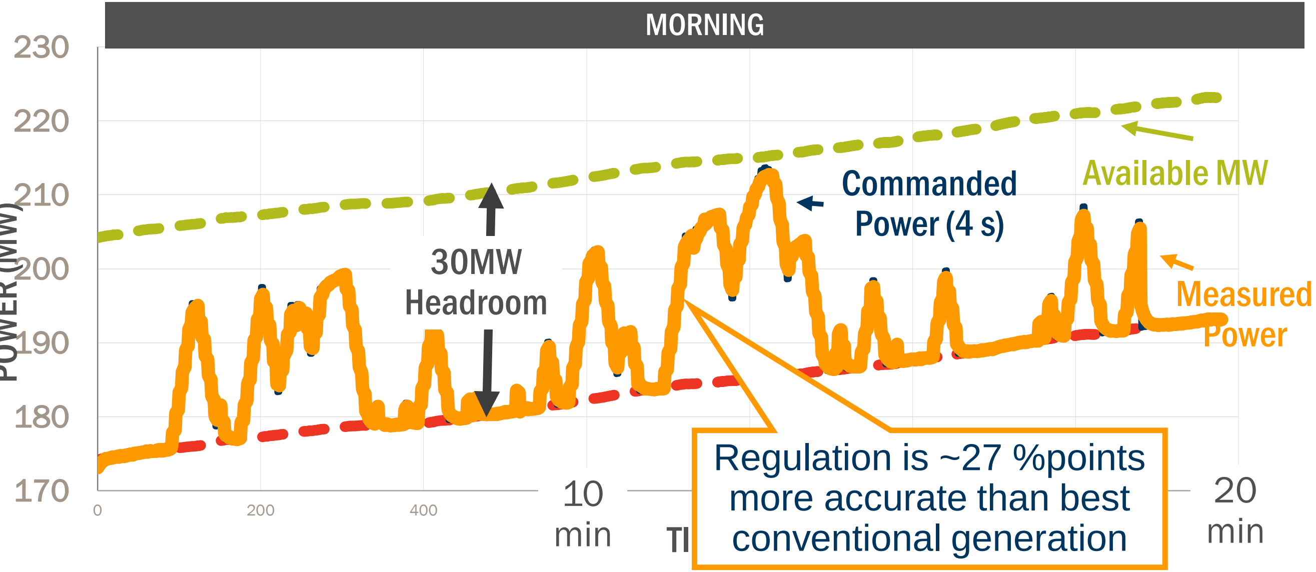
NERC: Essential reliability services

- Frequency Control
- Ramping capability or flexible capacity



Power Regulation

- AGC
- Up-Regulation
- Down-Regulation
- Frequency Regulation
- Flexibility



Grid Reliability Services

- Source: http://www.caiso.com/Documents/TestsShowRenewablePlantsCanBalanceLow-CarbonGrid.pdf.

AGC: Automated Generator Control

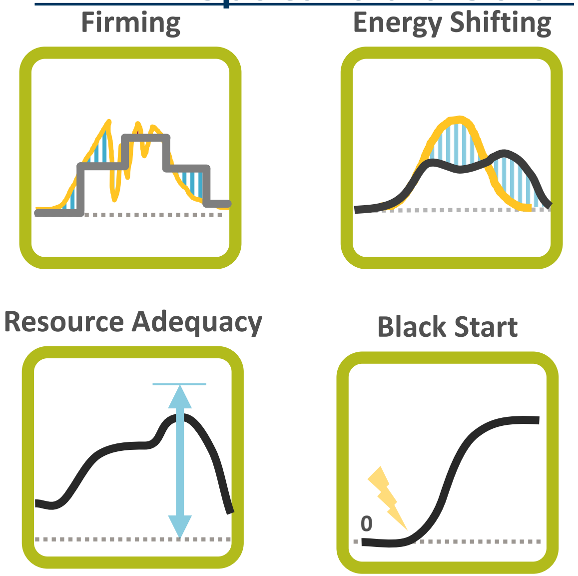
Firm Dispatchable Solar with Storage

+

Storage enhances Grid Flexible Solar to:

- Firm and/or shift solar energy delivery to the grid
- Meet resource adequacy requirements
- Potentially provide black start capabilities

Firm Dispatchable Solar



Solar+Storage designed to deliver firm capacity and enhanced grid services

Grid Capabilities Enhanced w Storage

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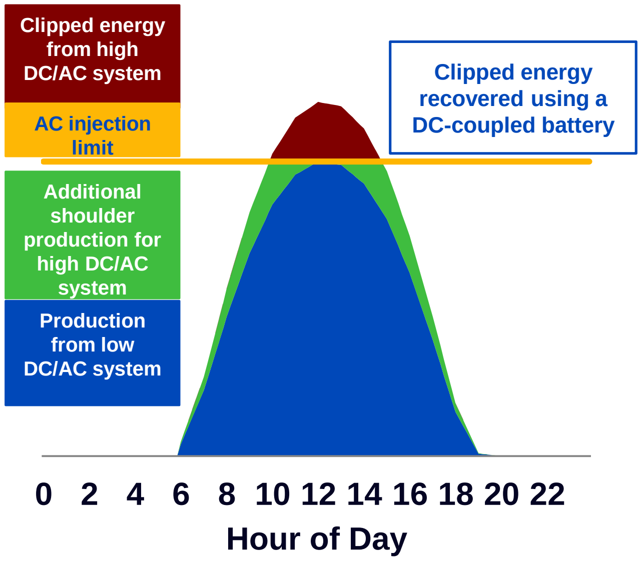
DC-coupled PV + Storage Hybrid Resources

Hybridizing changes plant design

- Leads to dramatic internal design changes and higher effective renewable capacity factors
- Variability is reduced by pushing much of it into clipped region and controlling battery charge rate
- Many options to optimize layout, orientation, bifacial PV panels, etc.
- Optimized use of interconnection



Important Example: Frequency Response to an Event

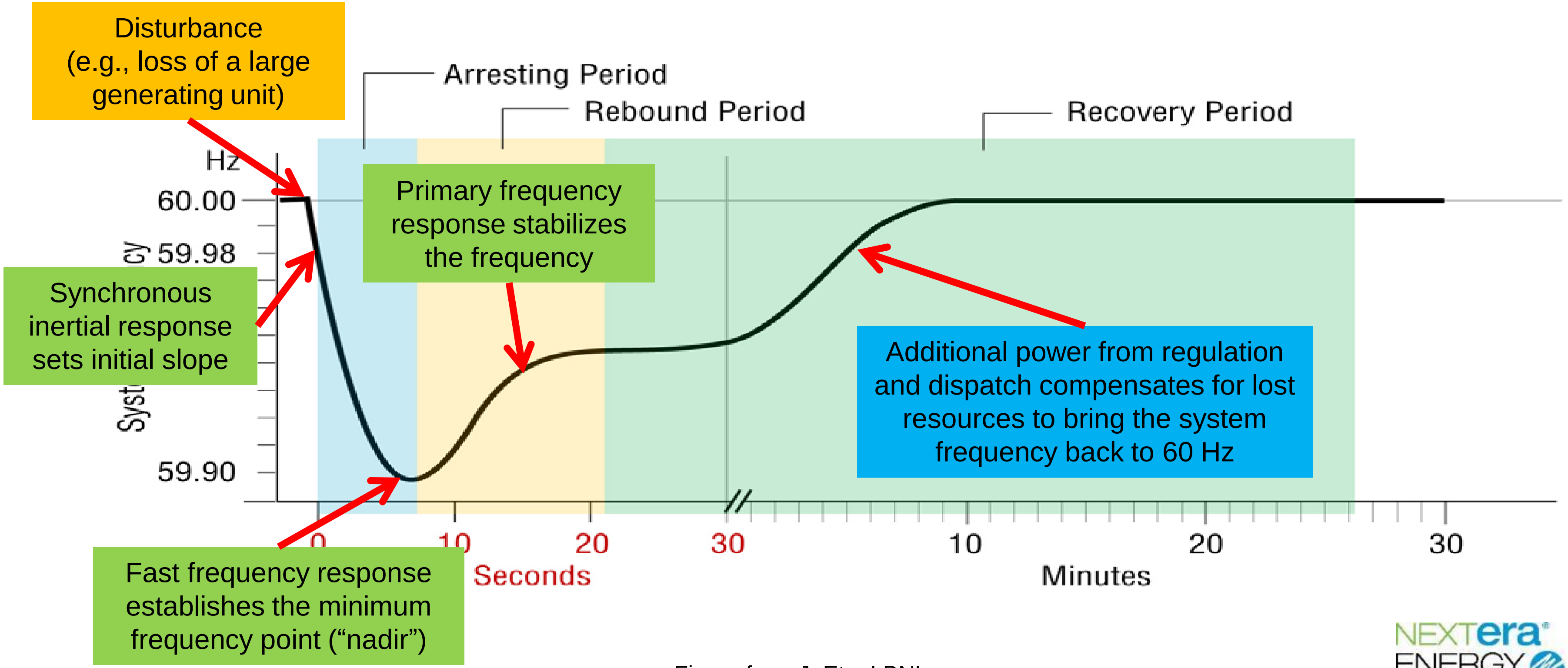


Figure from J. Eto, LBNL,
https://www.ferc.gov/industries/electric/indus-act/reliability/frequencyresponsemetrics-report.pdf

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Panel discussion

Explosion of cell & module technology: which designs can meet the challenges of mass production & stand the test of time?

Jenya Meydbray

CEO

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Alex Chen

Head of Sales and Marketing

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Kirsten Myers

R&D Director

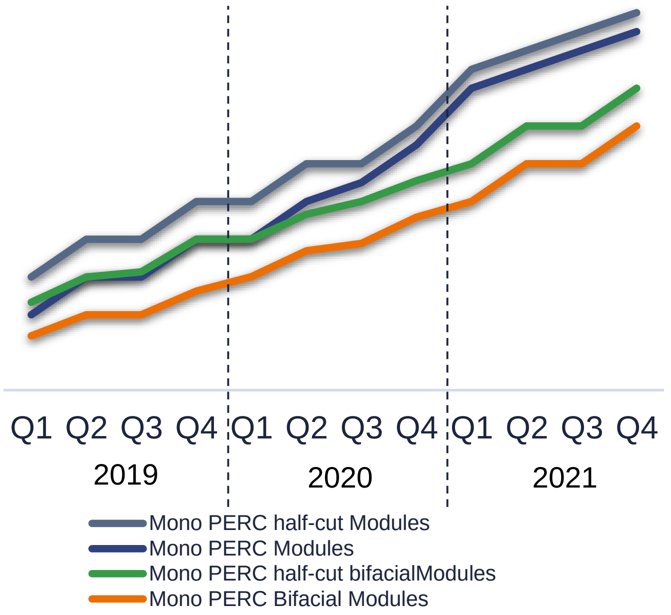
Heraeus

Module Power: Historical and Forecast

Historical

Source: Bloomberg NEF

Forecast

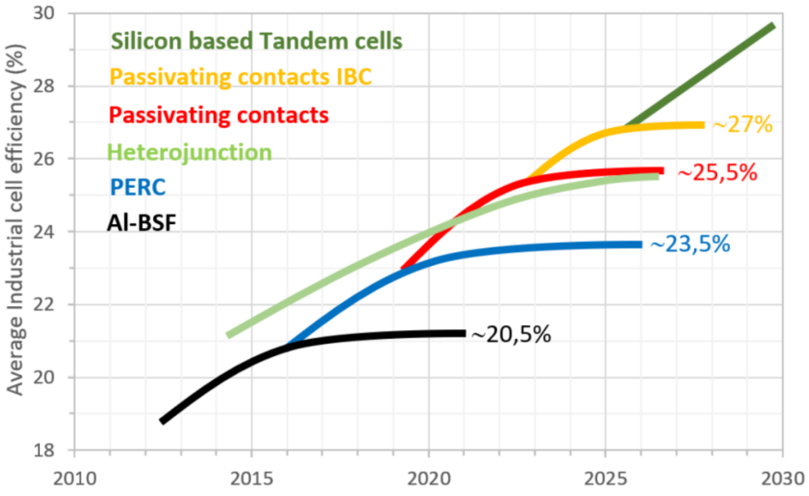


Source: PVEL

Which Technology Will Get Us There?

- The industry is now pursuing many promising technologies
- Modules are getting larger
- With all new technologies come new risks – Test, Test, Test!!

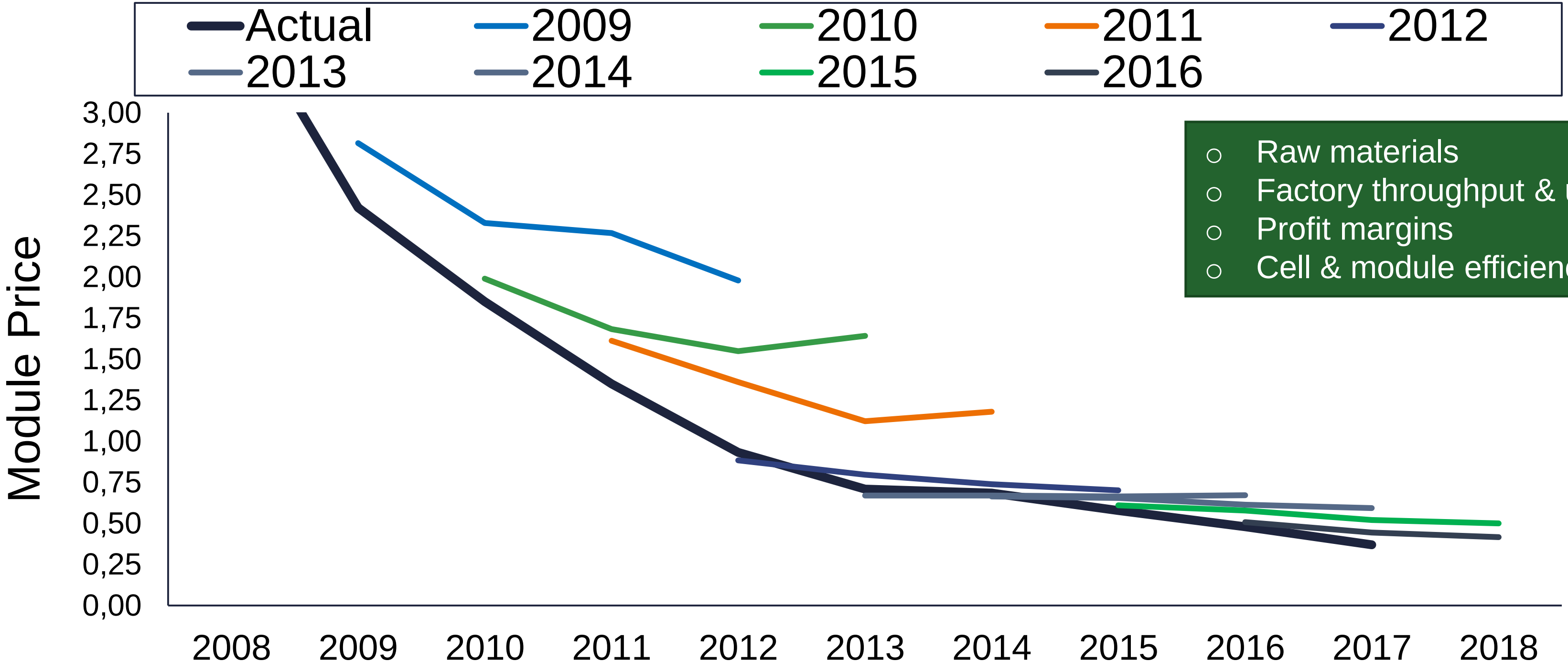
Larger Wafers	156.75 → 158.75 →161.7 → 166
Thinner Wafers	1.5 c / Wp per 10 um (0.01 mm)
Half-Cell	~5+ Wp at STC
Shingling	~10+ Wp at STC
Bifacial	3 – 20% yield gain
Tandem	30%+ efficiency



Source: Munnik, Semco, PV CellTech 2018

Forecast vs. Actual Module Price

From NREL study, based on 17 different market forecasts



- Raw materials
- Factory throughput & utilization
- Profit margins
- Cell & module efficiency

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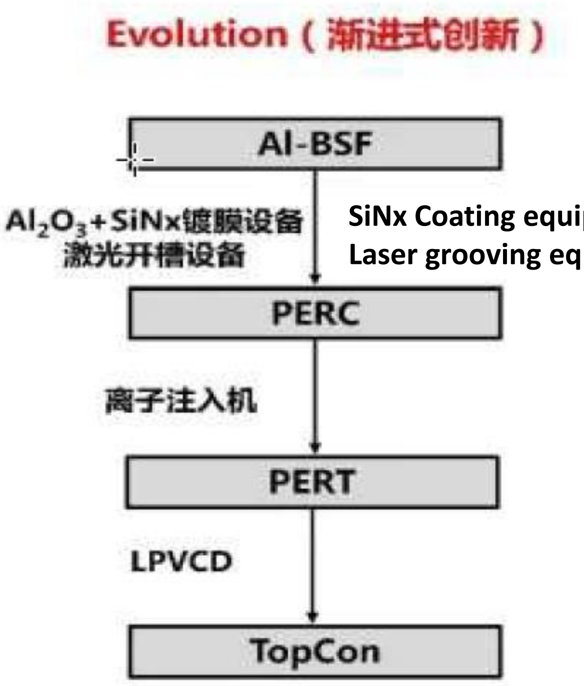
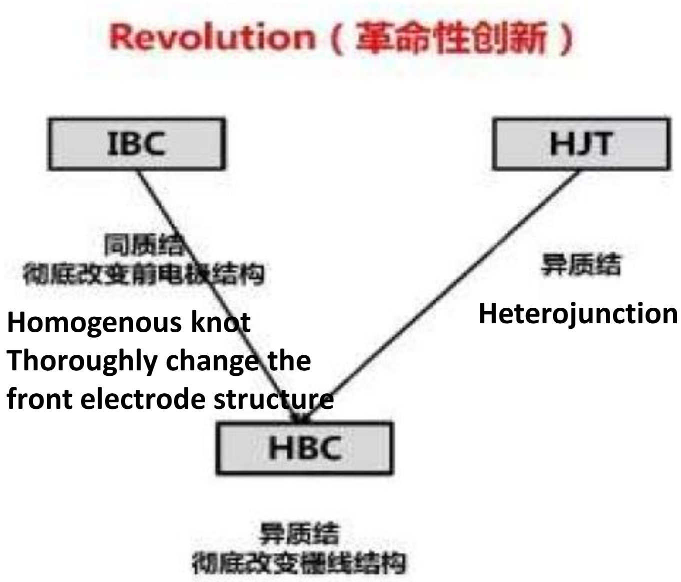
High Efficiency Cell Technology Route--Upgrade Route



SiNx Coating equipment
Laser grooving equipment



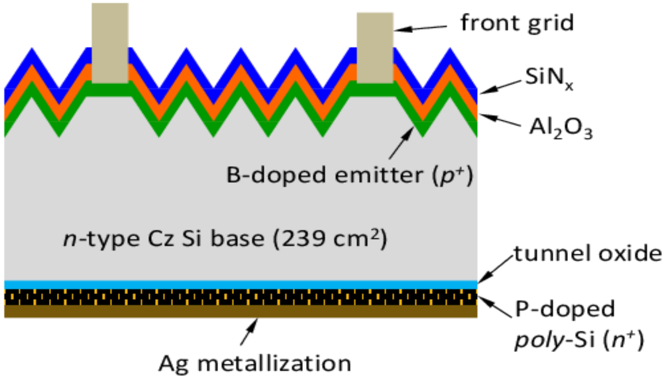
Homogenous knot
Thoroughly change the front electrode structure

Heterojunction

Heterojunction completely change the grid line structure

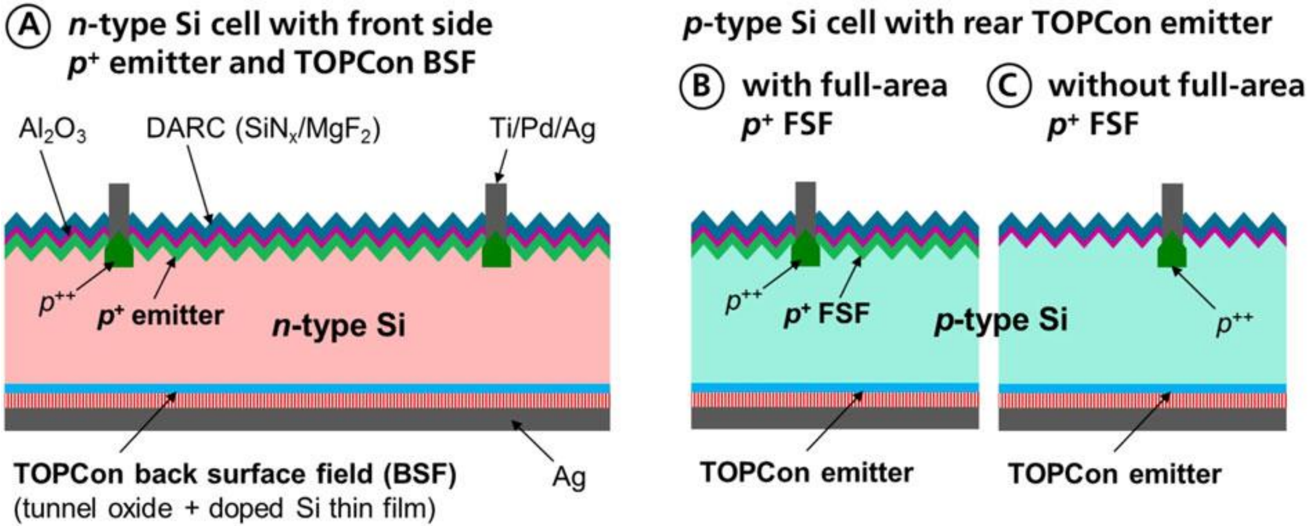
TOPCon Craft Route

TOPCon (Tunnel Oxside Passivated Contact) technology is to prepare an ultra-thin tunneling oxide layer and a highly doped polysilicon thin layer on the back side of the cell, which together form a passivation contact structure, as shown in the Figure. This structure provides good surface passivation for the back side of the silicon wafer, and the ultra-thin oxide layer can tunnel the multi-sub-electron into the polysilicon layer while blocking the minority sub-hole recombination, and the electrons are laterally transported and collected by the metal in the polysilicon layer, thereby greatly reduced contact recombination current, and the open circuit voltage and short circuit current of the cell are improved.



P-Type TOPCon and N-Type TOPCon

- In theory, TOPCon can be implemented on both P-type and N-type silicon wafers.



25.7%
(N-TOPCon)

24.3%
(P-TOPCon)

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PASSIVATED CONTACTS

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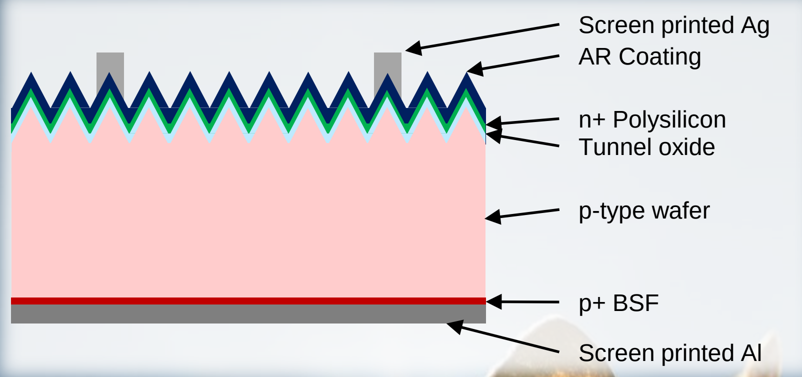
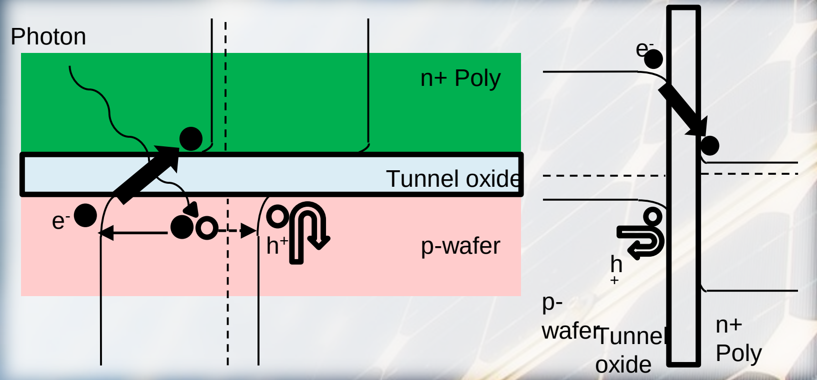




PROs:

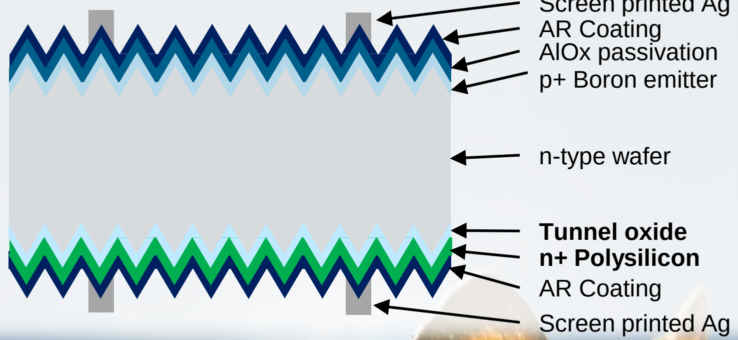
Low Recombination Current
High Voc
High Efficiency
Add-on to existing n- or p-type lines

Depending on who, and details of structure, also known as:

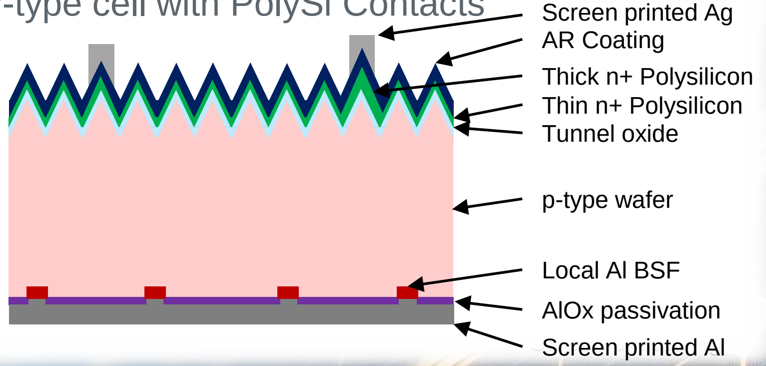
TOPCon™
MonoPoly™
POLO™
Poly Si

PASSIVATED CONTACTS - INDUSTRIAL

N-type cell with PolySi Contacts



P-type cell with PolySi Contacts



Champion: 24.58% by Trina
>23.0 % Ave Mass Pro (+Bifacial)

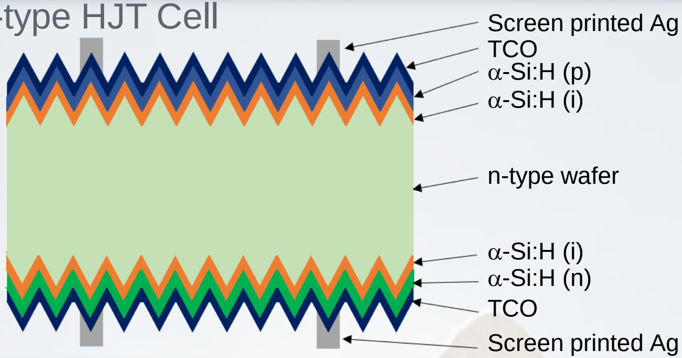
<u>Challenges:</u>
Cost: +10% wafer; 2X Ag
Add Vapor Deposition (SiO2 + PolySi)
Throughput – slow Poly growth
Metallization of thin poly layers (150 nm)

<u>Challenges:</u>
Optical Abs by Poly
Metallization of thin poly layers (<30 nm)
OR
"Structured" Poly only under contacts

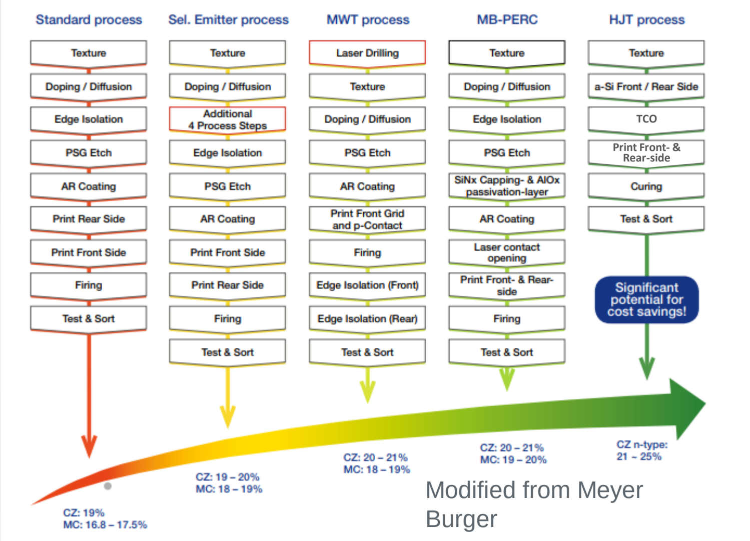
Heraeus

HETEROJUNCTION

N-type HJT Cell



Fewer Process Steps



Modified from Meyer Burger

Champion: 24.32% by Hanergy
Lowest LCOE, Bifacial, lower temp coeff.

Challenges:
High CapEx, 2X Ag
Unique Cell Line
Underdeveloped value chain

Options to Lower Cost:
Smartwire or MBB
Narrower FL (Challenge!)
Dual Printing
P-type wafer

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Networking session

Solving real problems with technology

Future PV Roundtable – Solar Power International 2019

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