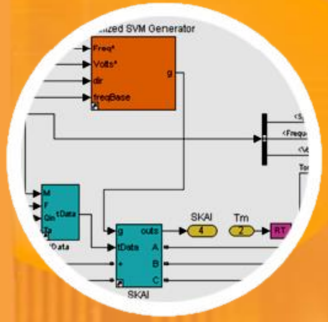
Evolution of the Electric Power Grid

IEEE LI Section
Power Electronics Symposium
Thursday, 2018 November 8

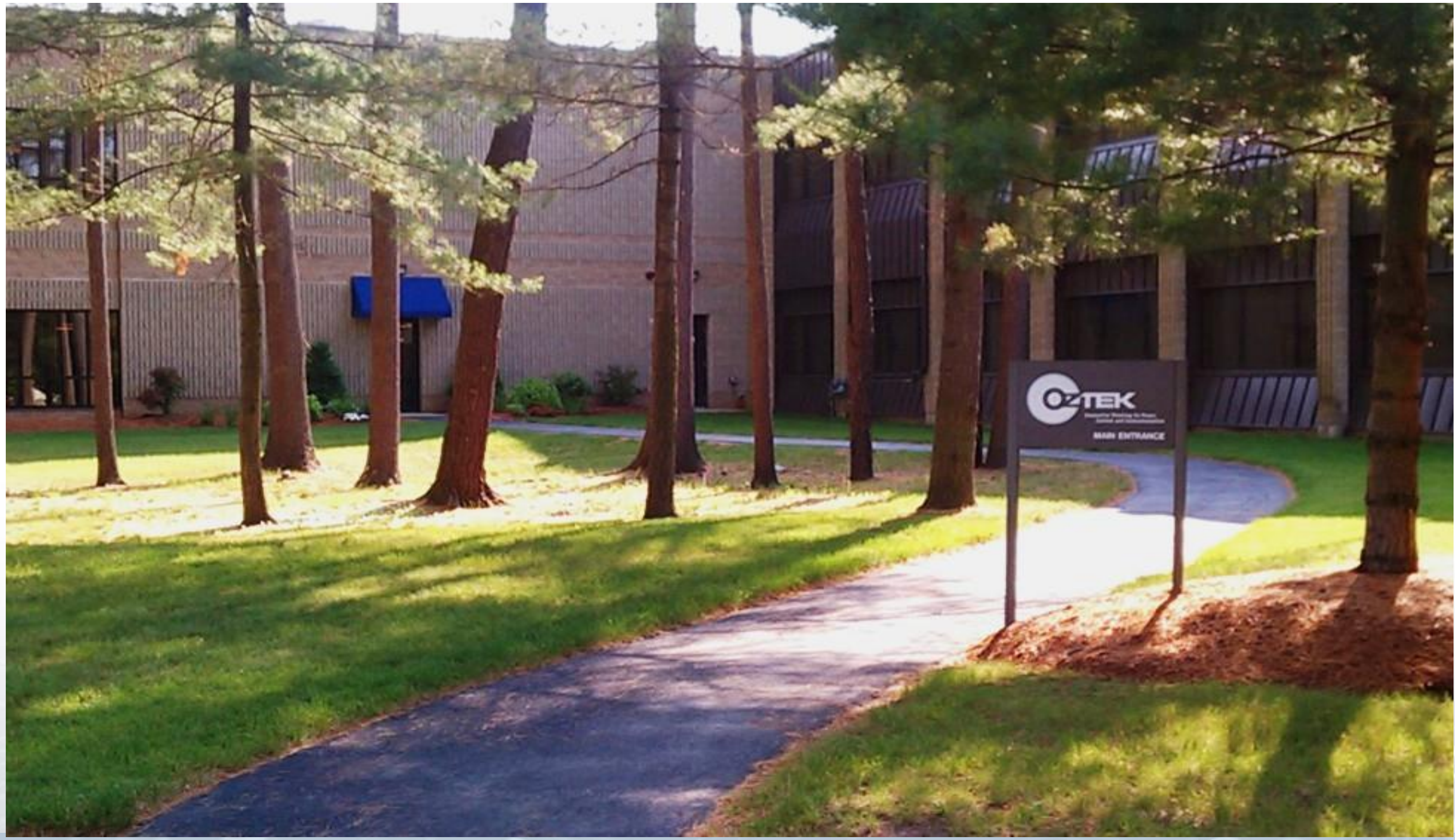


Greg Tremelling

About Oztek

- Founded in Merrimack, NH in 1997 by John O'Connor and Dave Zendzian

- Specialize in the design and manufacture of:
  - DC & AC Motor Drives
  - Power Inverters
  - DC/DC Converters



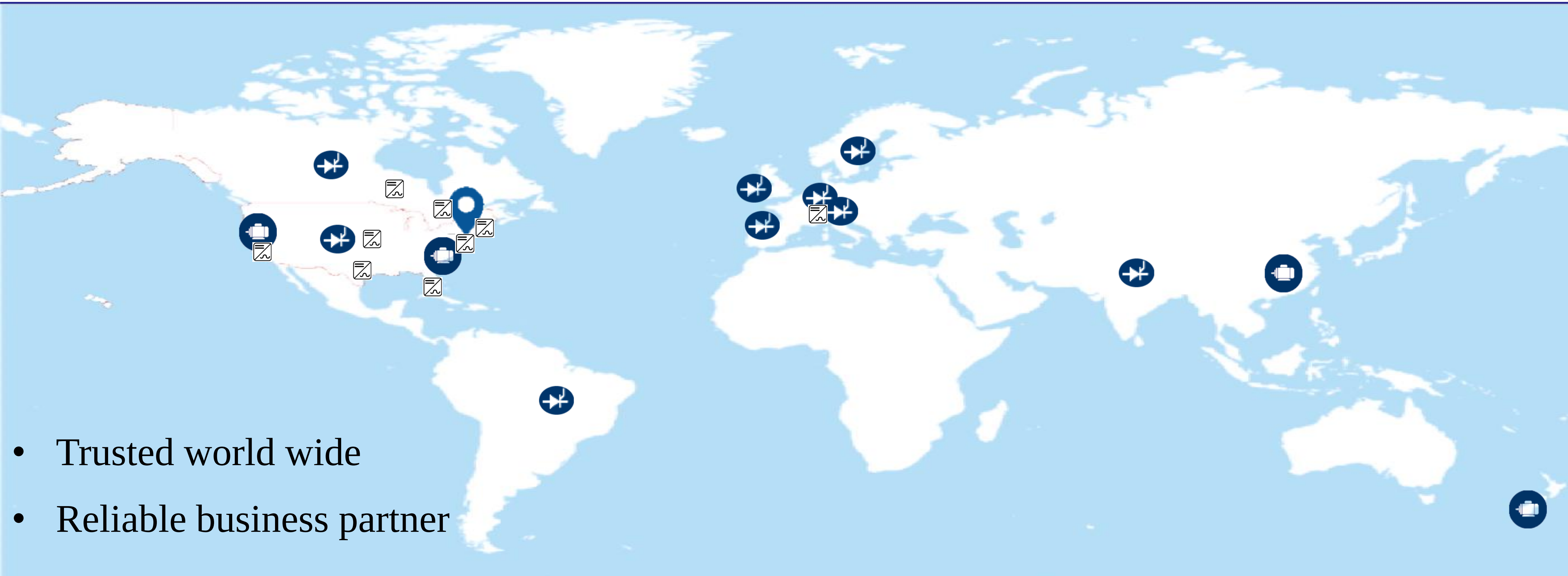
About Oztek

- Offering complete power electronics solutions - from concept to production
  - 24 employees
  - 12,000 sq ft facility in Merrimack, NH
  - In-house power / controls systems design engineering staff
  - Local Production & test geared towards low 1000's
  - China based manufacturing partner as needed
- Affiliate of Semikron International (www.semikron.com)
  - A global leader in power semiconductor assemblies and solutions

Key Customer List

DPG
ElectroMotive
NEC
epcpower excellence in power conversion
CAT
IBM
FlexGen
ELTEK A Delta Group Company
Momentum® Wireless Power
EDM
Beacon POWER
ETAGEN
Earl Energy
GLOBALFOUNDRIES

World Wide Customer Base



- Trusted world wide
- Reliable business partner

Head Quarters | SCR Boards | Motor Drives | PCS/Power Supply

Example Applications

- History of high reliability power conversion
- Legacy of serving high quality brand names
- Examples of the application of cutting edge technology

Grid Energy Storage

- Behind the meter
- Modular Grid Scale solutions
- DC to DC converters
- Grid Connected Flywheel Inverters

Mobile / Transportation

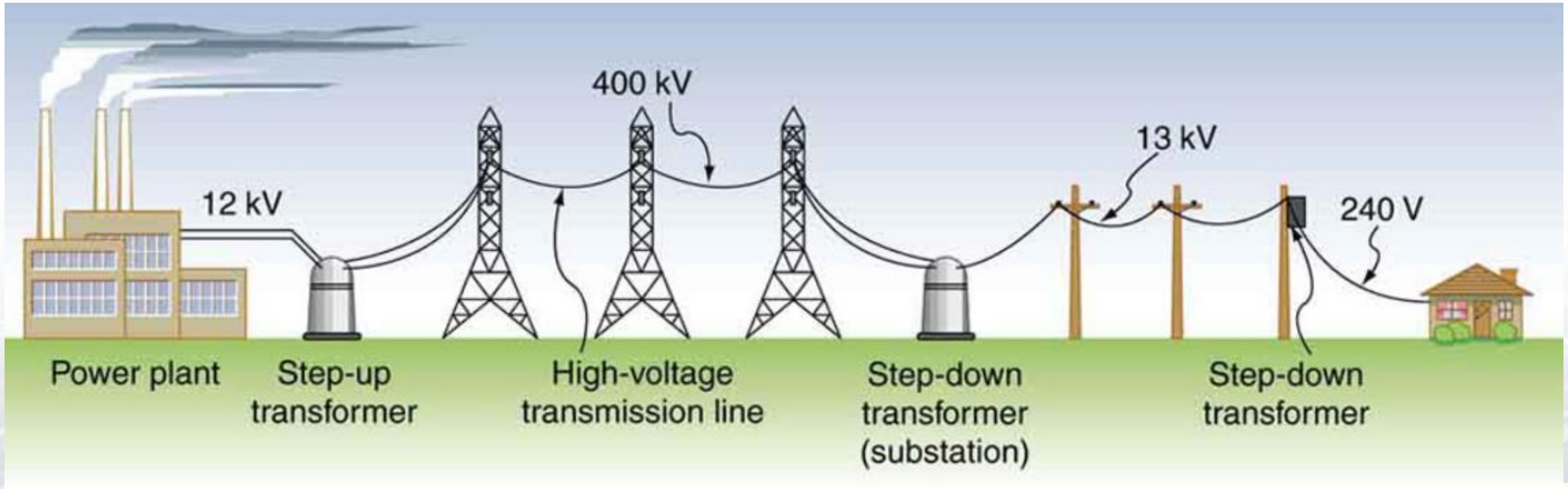
- EV Charging
- HVAC Compressor drives (Rail)
- Railway applications
- Heavy Truck

High Speed Drives

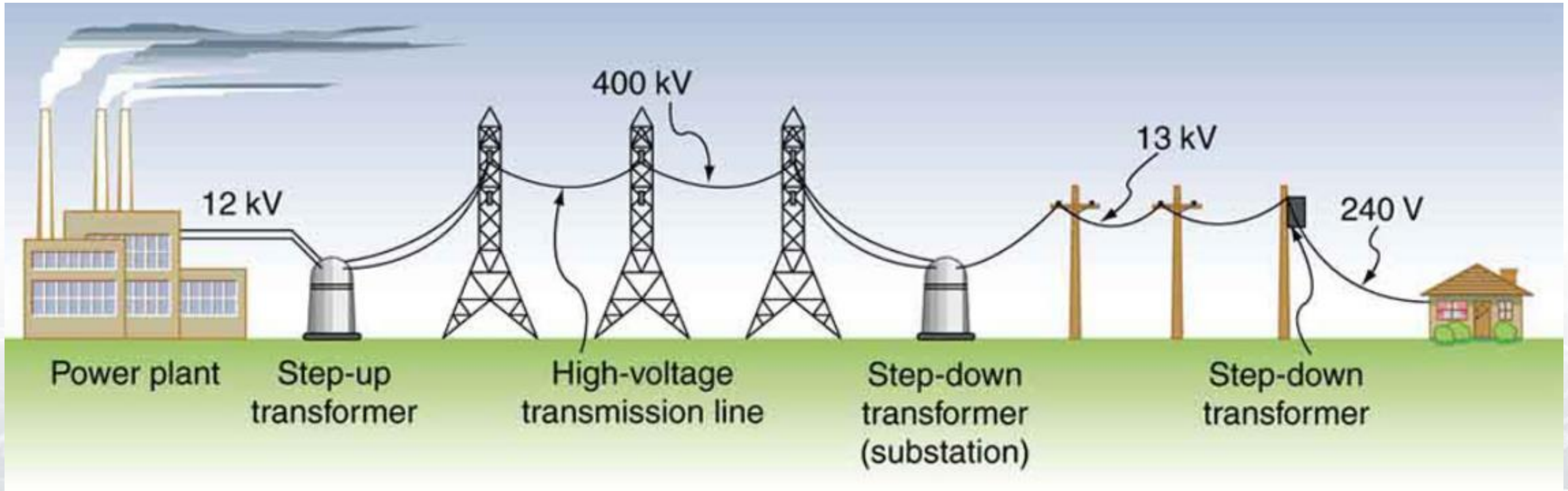
- Innovative micro turbine drives
- Multi stage generator technology
- High Speed Flywheel Electronics

- Central Generation depends on averaging loads over large geographical areas

  → Result is very heavily weighted average which <u>changes slowly</u>

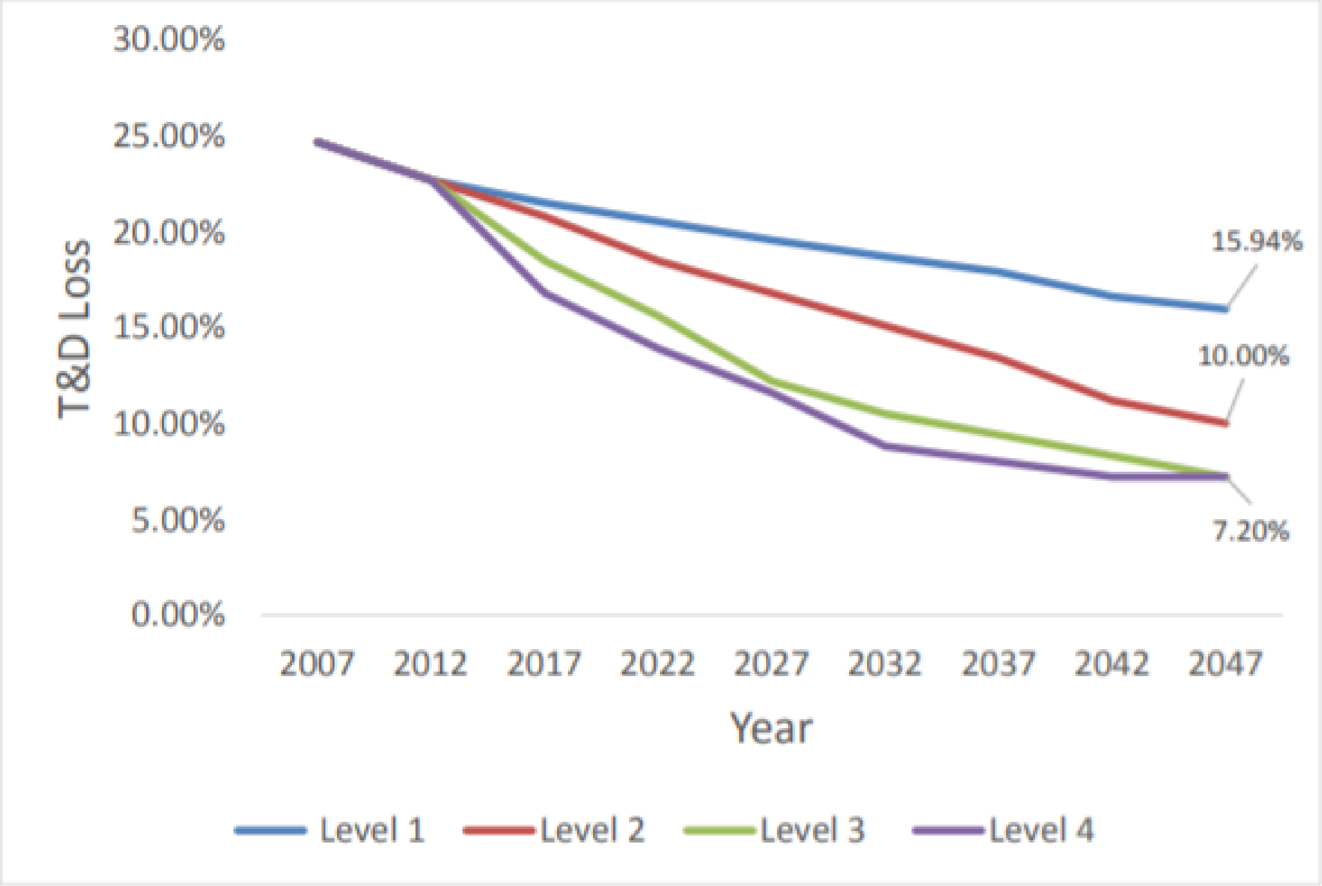


- Losses are substantial!!
- According to US Energy Information Administration (EIA) estimates that electricity transmission and distribution (T&D) losses average about 5% of the electricity that is transmitted and distributed annually in the United States.



- Other regions around the world suffer much higher losses than the USA
- India example
  - Currently ~20% lost in T and D

- Analysis shows that by application of DER
  - → 7% future loss target by 2042



Metering Of the past

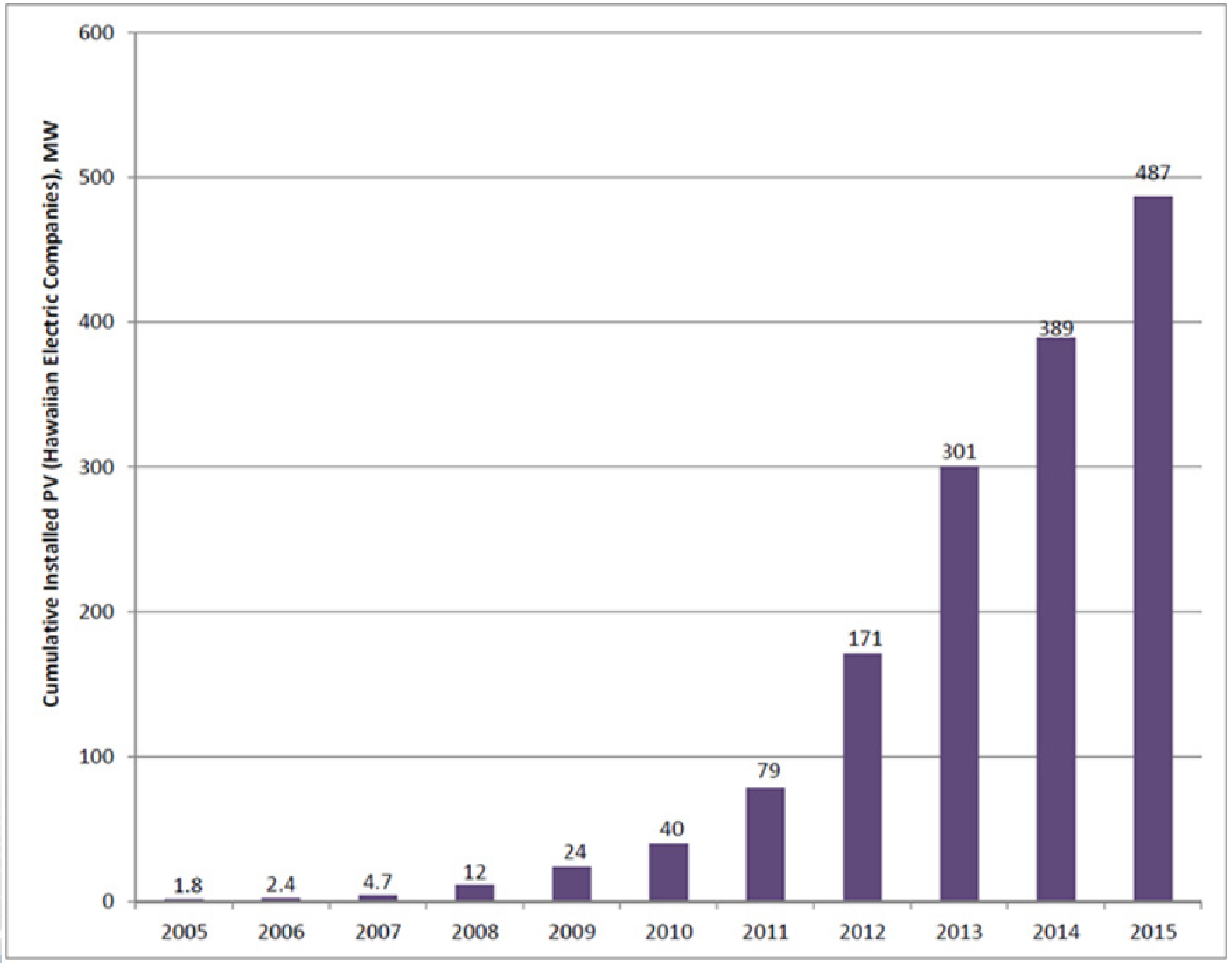
- Metering classes designed around types of consumers and size, time, and type of their **loads**
- Fundamentally does not comprehend accounting for Distributed Energy Resources around the grid
- In some ways early attempts to "bandaid" or update metering to account for DER have failed → Dec 2015 Nevada Example
  - https://www.greentechmedia.com/articles/read/nevada-regulators-eliminate-retail-rate-net-metering-for-new-and-existing-s#gs.1sk1oWc
- Metering policy will dominate adoption of Distributed Energy Resources

Hawaii

- "The Net Energy Metering Program Was A Huge Success"

  ……So much so that it has since been shut down

- 487MW of Solar installed across Hawaii utilities from 2001 until 2015
- Hawaii achieves 25% clean energy in 2016
- *As a direct result of renewable success/net metering was shut down and the model was changed to **"self consumption"***



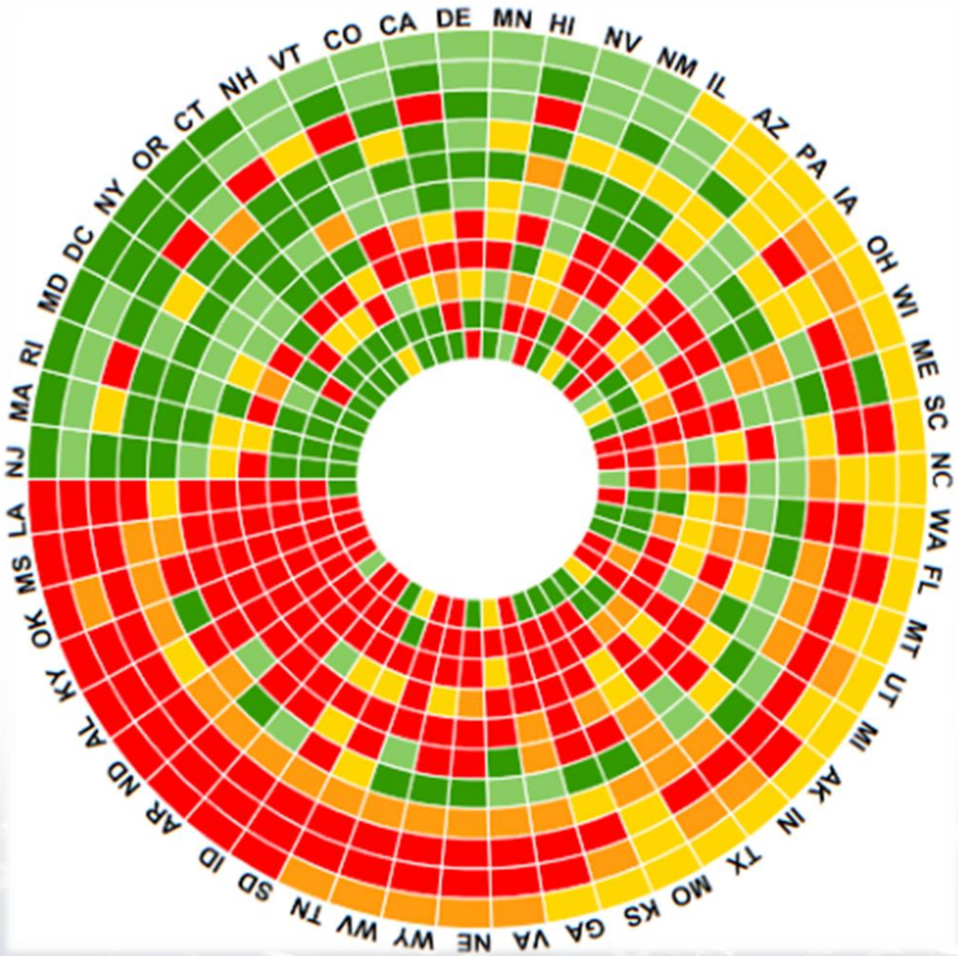
- 8 out of the 10 best solar states are clustered in New England area

Grading Scale:

A	B	C	D	F

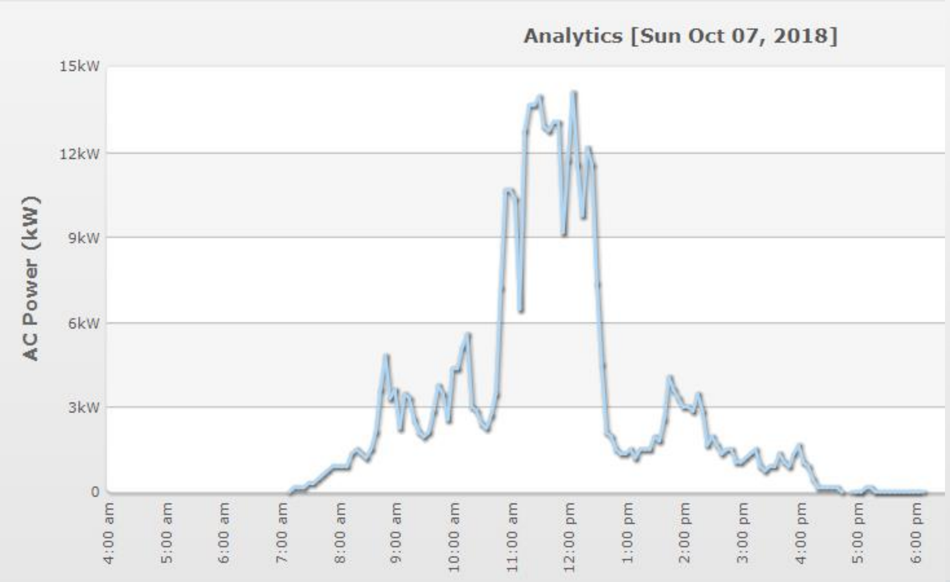
Factors:

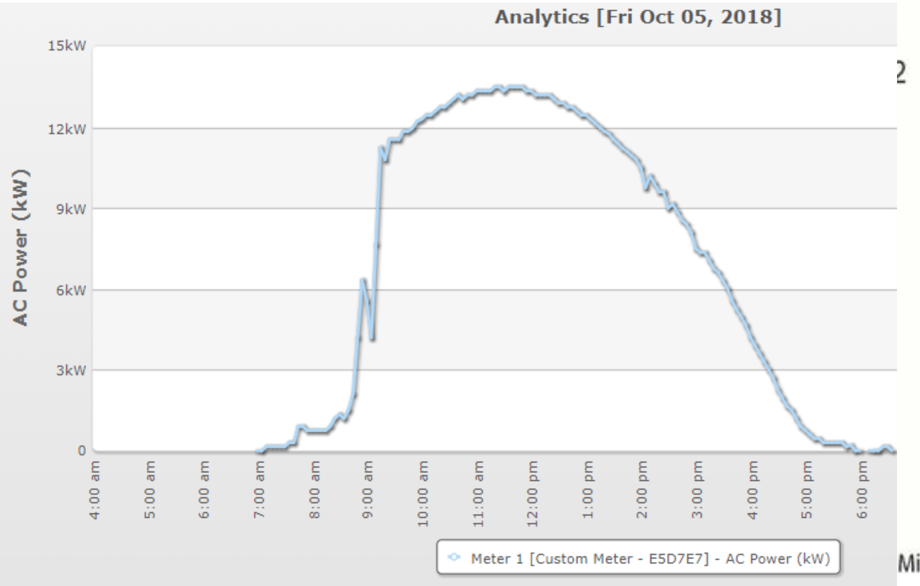
1) Overall Grade **(Outer ring)**
2) Renewable Portfolio Standard (RPS)
3) Solar Carve Out
4) Electricity Price
5) Net Metering
6) Interconnection
7) Solar Rebates
8) State Solar Tax Credits
9) Performance Payments
10) Sales Tax Exemption
11) Property Tax Exemption

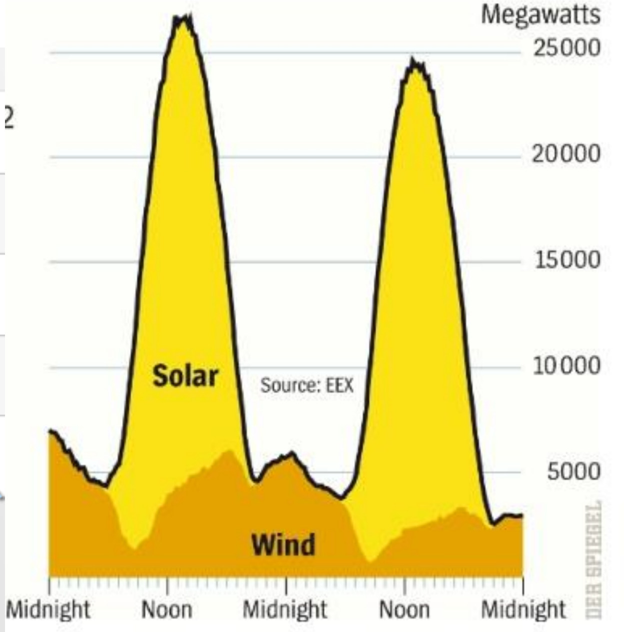


Challenges with Renewables

- Grid instability
- Abundance of power where / when its not needed (California/Duck; Germany/wind/solar transmission)
- Renewable plants more prone to injecting turbulence into grid network (~20% point of inflection)





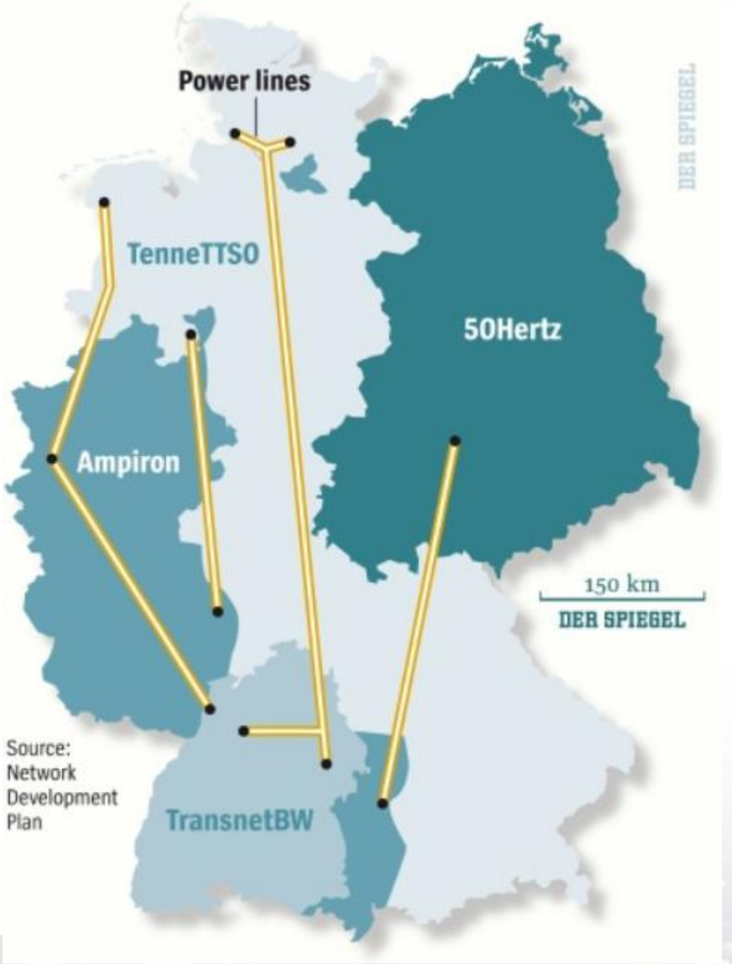


Challenges with Renewables

- ***(2013 headline..)*** "Germany's Green Energy Destabilizing Electric Grids"
  - Location of resources/ + 25 Billion transmission line upgrades

- Poland and the Czech Republic, are building a huge switch-off at their borders to block the import of green energy that is destabilizing their grids and causing potential blackouts in their countries.[v]

- This action by German's neighbors fragments the European electrical grid, turning Germany ***into an electrical island.***



Opposing Forces!

- Net metering puts burden on utility vs. consumer
- Lack of net metering hurts incentive to increase renewable penetration

- So… What is the correct answer then?

- 2017 Study by GE for Hawaii included application of storage

- GE study concluded that for Hawaii to operate efficiently, reliably, and securely new technologies like Energy storage would need to be deployed

ENERGY STORAGE APPLICATIONS

- GE study indicates majority of applications are between 15 min and 4 hours
  - Snicker…
- Many approaches to achieve grid stability and transactable financial models

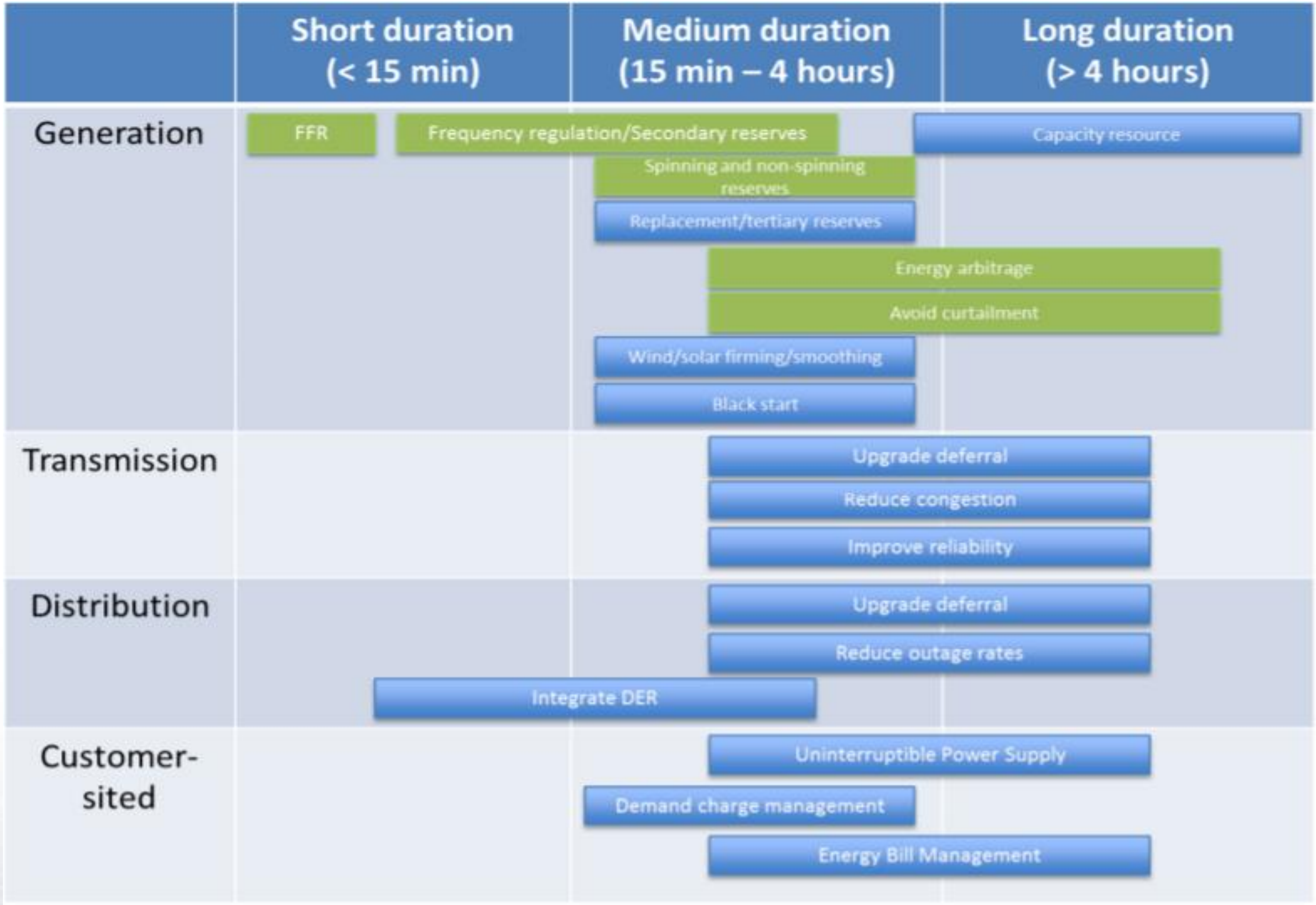
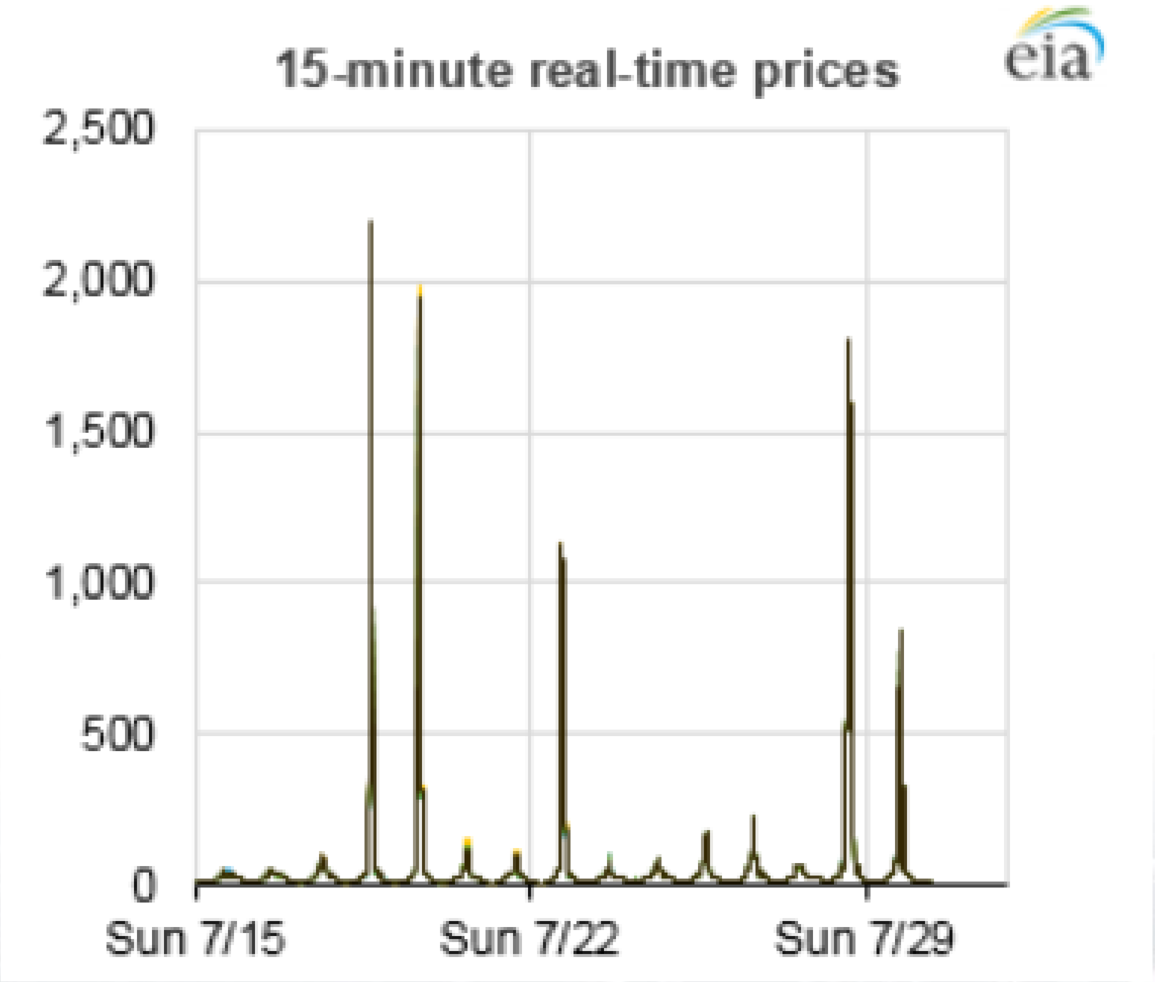


Figure 1: Various Applications of a Battery Energy Storage System

Energy Storage applications -Capacity

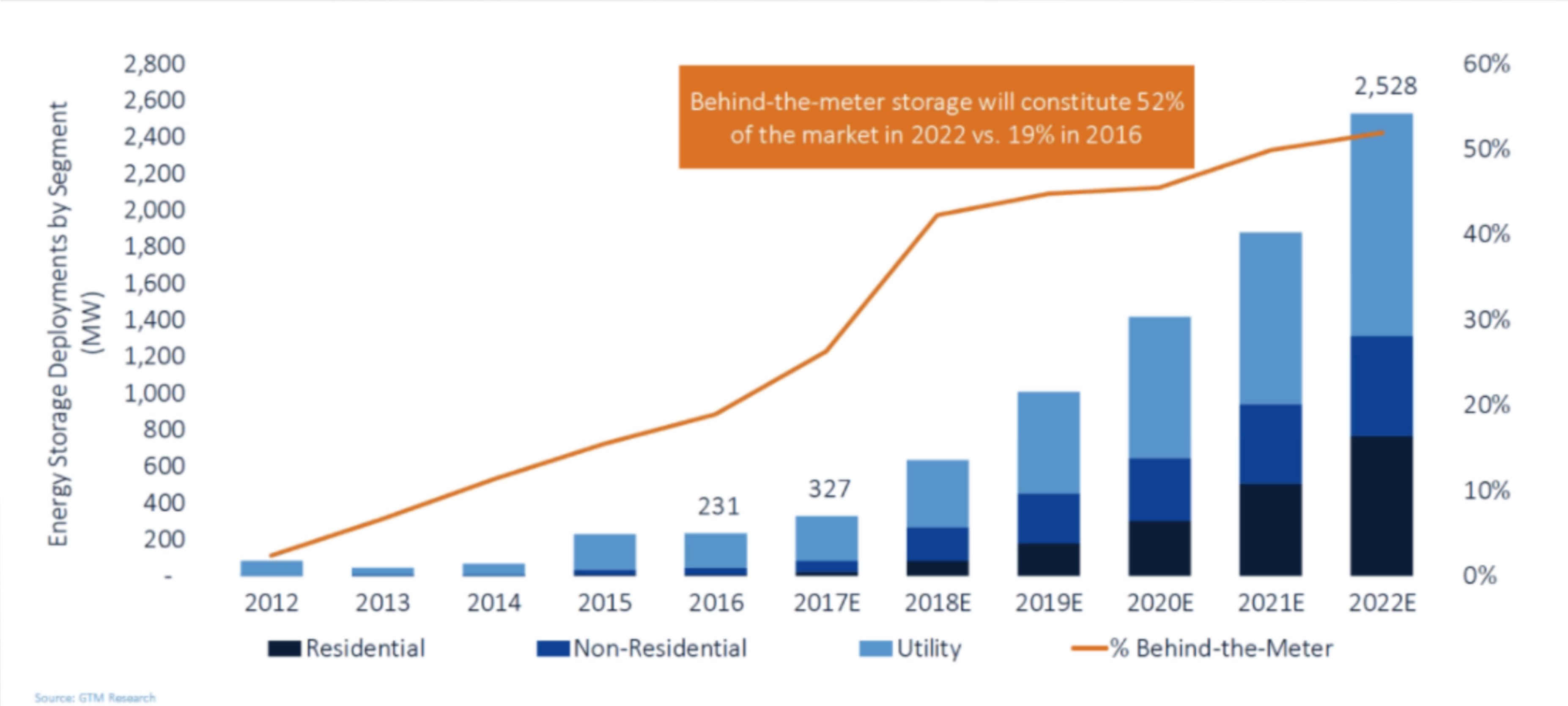
- ERCOT allows wholesale prices to rise relative to increases in demand, up to a price cap of $9,000 per megawatthour (MWh).
- $9,000MWh*(1MWh/1000Kwh) = 9$/KWh!
- Day-ahead wholesale prices in ERCOT reached close to $2,000/MWh on the days of record-high peak loads in July.



Energy Storage applications -Behind the meter

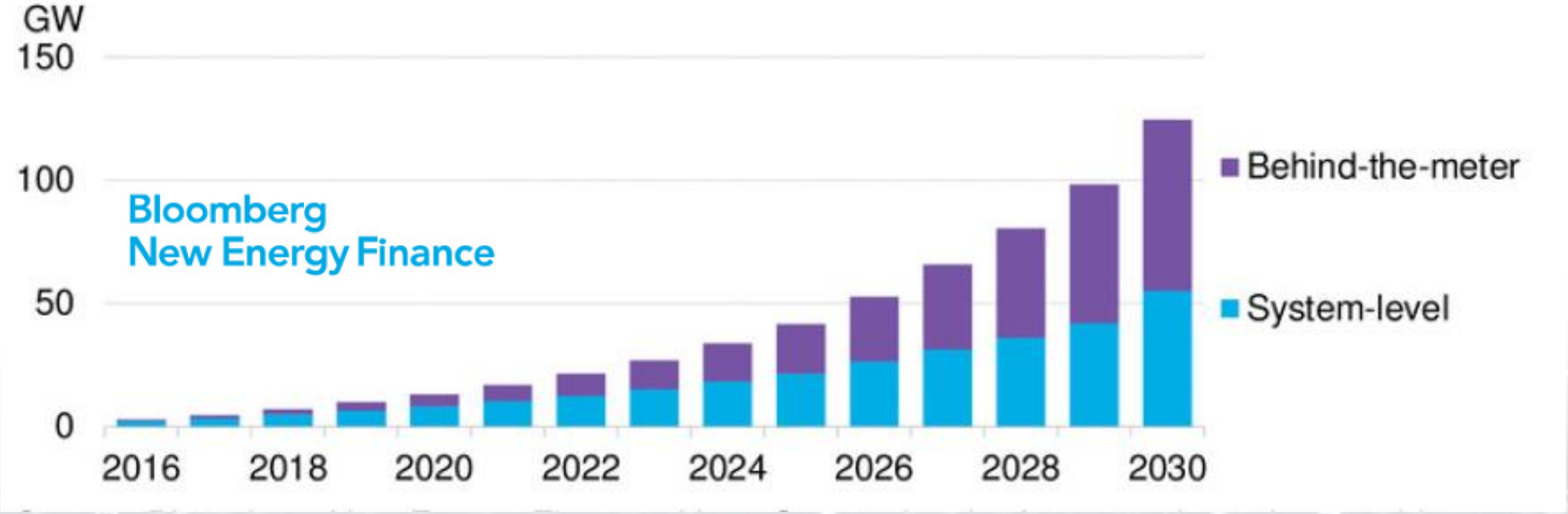
- 52% of the energy storage market will be behind the meter by 2022

Short Term forecast by GTM Research (2016 chart)



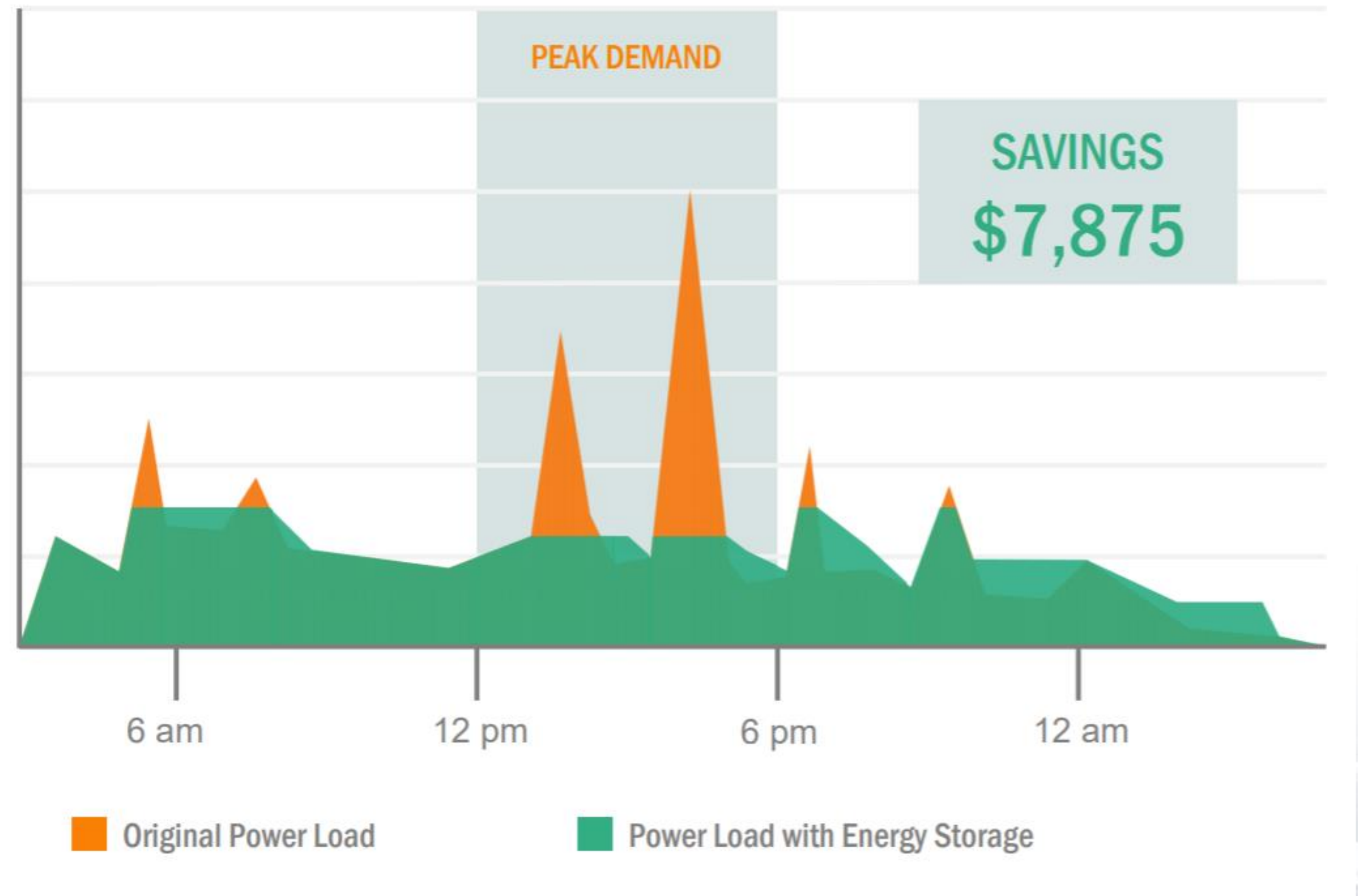
Energy Storage applications -Behind the meter

Behind the meter applications will represent ~50% of the market as the overall market grows according to BNEF



Demand Charge Management (DCM)

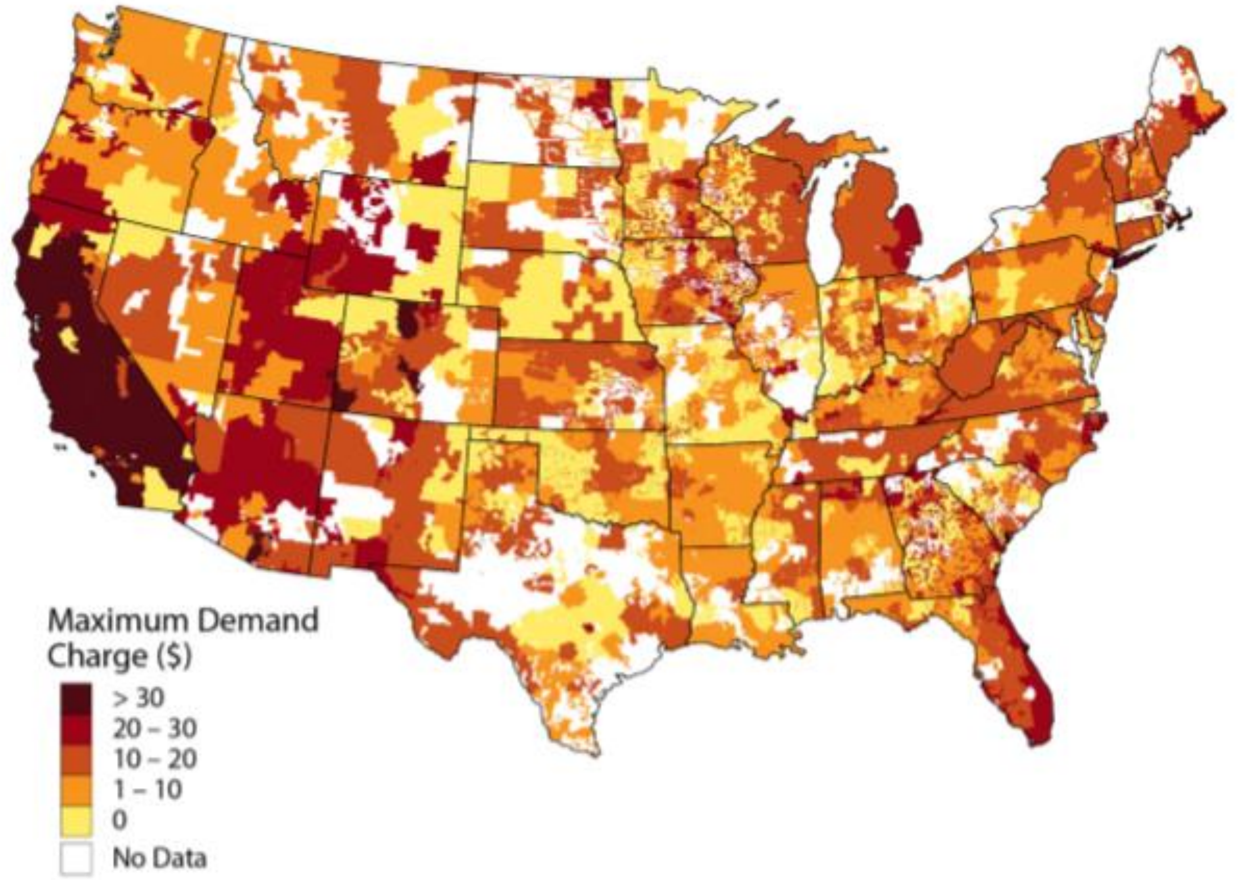
- Utilizes energy storage to “hide” peak power events from the utility to reduce electric bills
- Energy storage is discharged when power consumed from utility exceeds set threshold
- Utility charge is based on single highest 15 min average during the billing cycle



Energy Storage applications -Demand Charge Management

- Market for demand charge management exists when demand charge pricing is high
- Specific areas of the USA Market can be identified and targeted

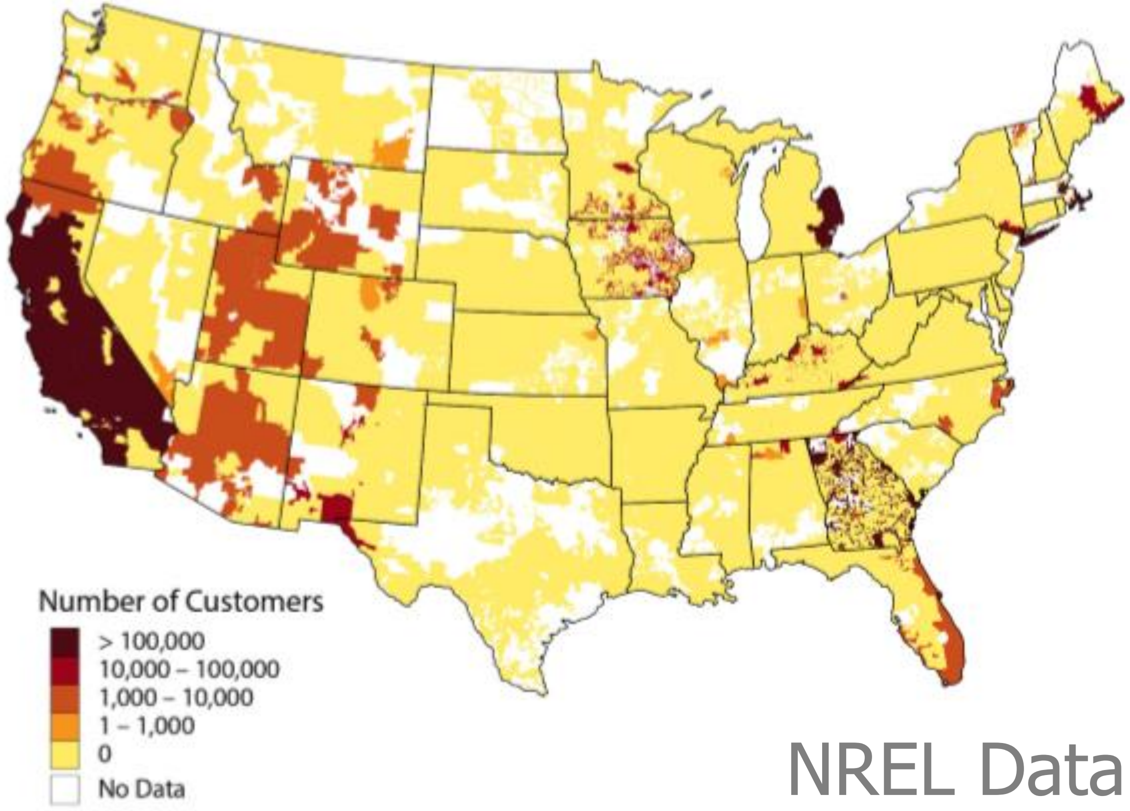
Maximum demand charges by utility territory



Energy Storage applications -Demand Charge Management

- Significant number of customers in the USA are eligible for demand charge rates as high as $20/KW
- Usage profile plays a large role in whether or not a business or facility can benefit from demand charge management

Number of Customers eligible for Demand Charge > $20



NREL Data

Emerging Applications

CA, HI, NY and PJM Account for the Bulk of Behind-the-Meter Storage Deployments to Date

California Market Drivers

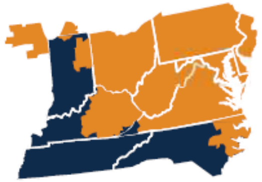
- SGIP Incentive Program
- Utility procurements including AB 2514 (1.3 GW of storage by 2020, portion must come from customer-sited resources), PRP and LCR
- Grid modernization activity via policies such as Demand Response Auction Mechanism
- High demand charges
- Residential TOU rates on the horizon for customers subscribing to net-energy metering

New York Market Drivers

- Insert teGrid modernization programs and pilot projects (e.g., NY Reforming the Energy Vision, Brooklyn-Queens Demand Management)
- Non-wires alternative RFPs from electric utilities offer opportunities for behind-the-meter storage participation
- High demand charges, particularly in New York City
- New York City's recently announced energy storage target of 100 MWh by 2020

Hawaii Market Drivers

- High electricity rates
- Revisions to net-energy metering rules: In October 2015, HECO ended traditional net metering, new customers must go on grid-supply (allows export at wholesale rate, has caps that self-supply, which encourages solar-plus-storage
- High solar PV penetration



PJM Market Drivers

- Resiliency programs (e.g., NJ Renewable Electric Storage program)
- Significant historical deployment of behind-the-meter solar PV
- Regional interest in microgrids

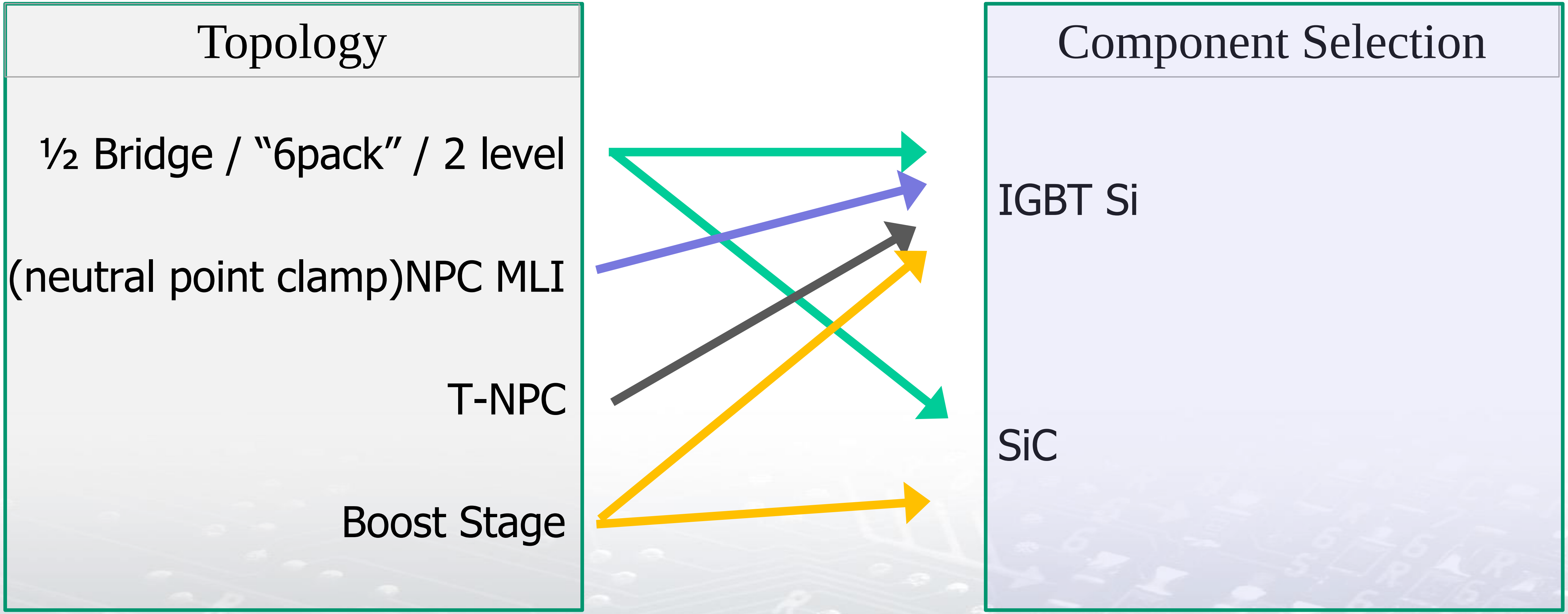
- **MASS SMART** program incentivizes adding storage to solar by applying a “bonus” adder for every KWh solar produces because storage is present

- **California** has mandated that 100% of homes build in 2020 and beyond have solar
  - Self-Generation Incentive Program (SGIP) has allocated more than 6x more money for energy storage systems >10Kw in size as compared to “small residential” energy storage systems
  - Distributed assets have the potential to more effectively manage the grid as opposed to central assets
  - VPP (Virtual Power Plant Concept)

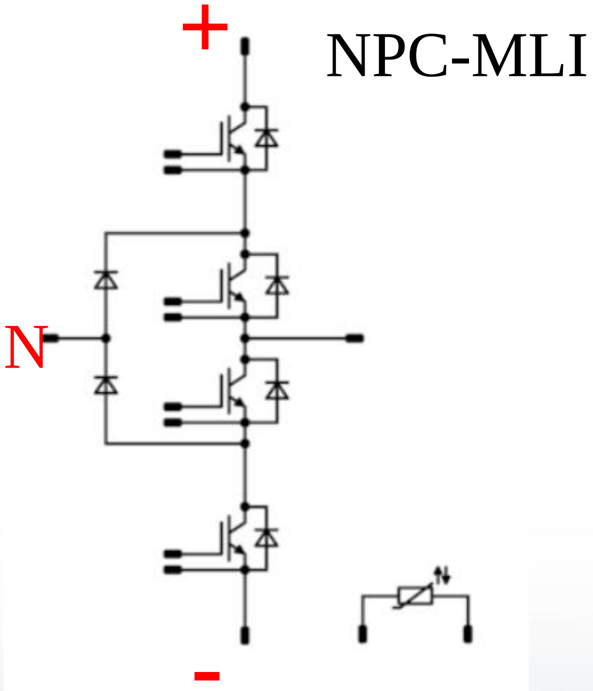
- **40KW** dual conversion in 19" 2.5U height!
- Air Cooled
- Flexible DC bus voltage/Auto sense AC output voltage

- "Ozip" Flexible **100KW** platform
  - Interleaved DC to DC
  - 3 phase grid tied
  - Motor drive

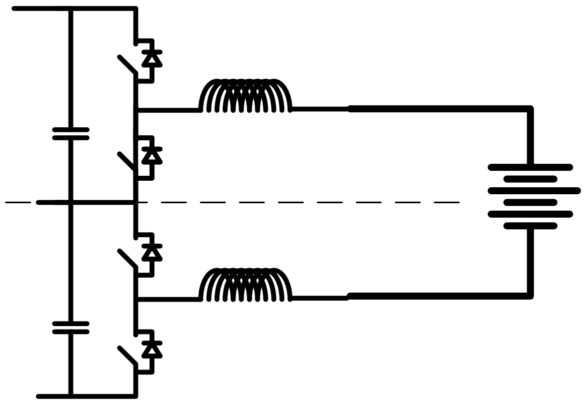
Topology and Component Selection



NPC (neutral point clamped)

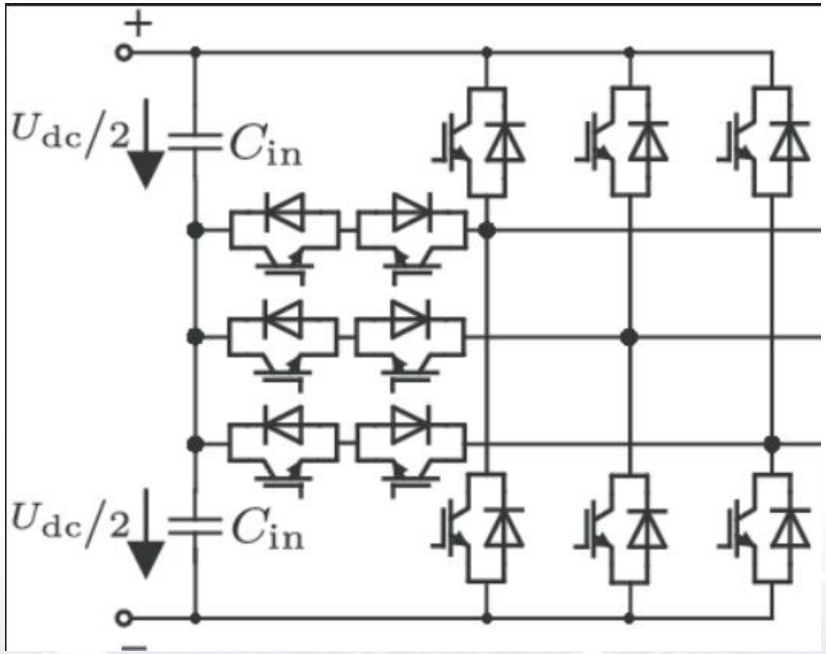


A-NPC variation also has its place (A=active)



3 level Bi Directional Boost Converter

T-Type NPC



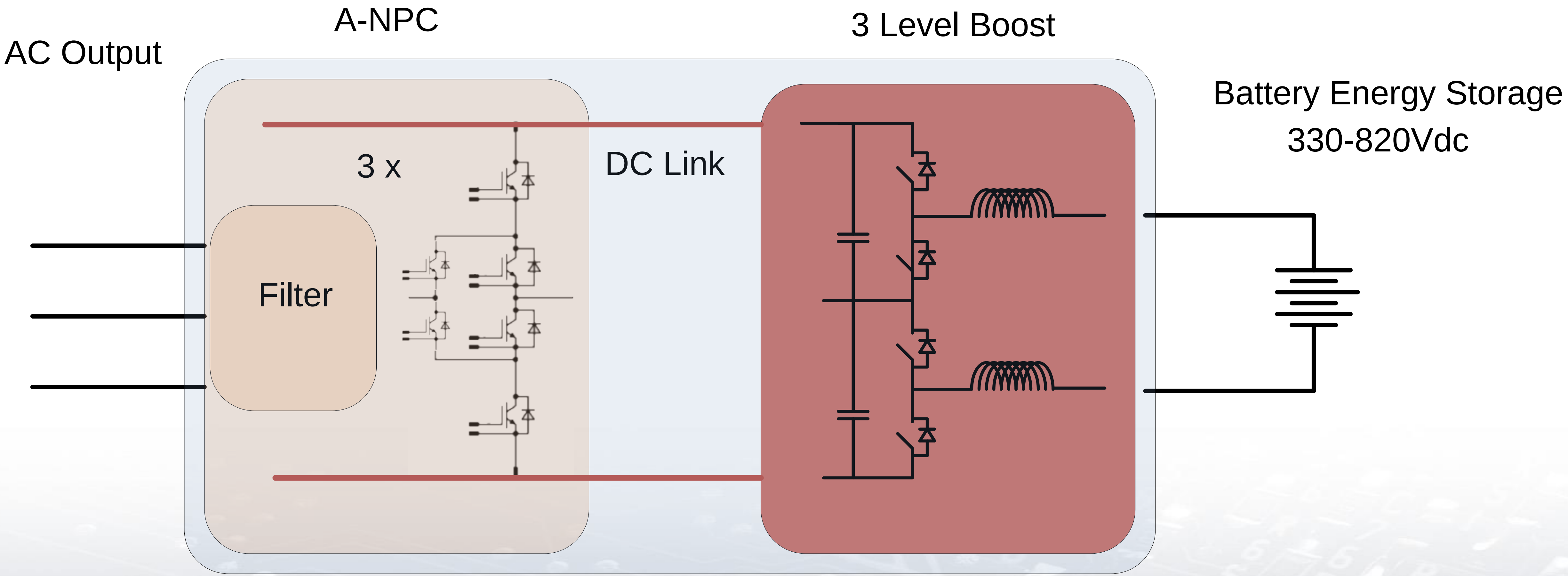
Topology Selection

Pout = 100kW, T=80C				Power loss (W)			Efficiency		
	Module / Device	Nominal VDC (V)	Fs (kHz)	Switch + Diode PF =0.95	Switch + Diode PF =-0.95	Filter (W)	Sourcing	Charging	Average
NPC	SKiM301MLI07E4	800	12	1390	1456	475	98.2%	98.1%	98.1%
	SKiM301MLI07E4	800	18	1604	1660	350	98.1%	98.0%	98.1%
	SKiM301MLI12E4	920	12	1825	1841	546	97.7%	97.7%	97.7%
	SKiM301MLI12E4	920	18	2261	2164	403	97.4%	97.5%	**97.5%**
TNPC	SKiM301TMLI12E4B	800	12	1127	1110	475	98.4%	98.4%	98.4%
		800	18	1393	1325	350	98.3%	98.4%	98.3%
3-level Boost	SKM600GB066D	800	20	778	1032	500	98.7%	98.5%	98.6%
TNPC Conbined			18/20						**97.0%**
SiC 2-Level	SKM350MB120SCH17	800	24	793	1038	475	98.7%	98.5%	98.6%
		800	36	952	1196	350	98.7%	98.5%	98.6%
		800	48	1111	1354	275	98.6%	98.4%	98.5%
SiC Conventional Boost	SKM350MB120SCH17	800	50	414	426	275	99.3%	99.3%	99.3%
SiC Combined			48/50						**97.8%**

Topology Selection

Topology & Conditions	Device Voltage	VDC (V)	Fs (kHz)	Efficiency	Normalized Cost
NPC	1200	920	18	97.5%	1.00
TNPC + 3-level Boost	1200/650	800	18/20	97.0%	1.44
SiC 2-Level + conventional Boost	1200	800	48/50	97.8%	2.01

- NPC MLI came out at the highest efficiency and lowest cost compared to other topologies


A-NPC
AC Output
3 Level Boost
Battery Energy Storage
330-820Vdc
3 x
DC Link
Filter

OZpcs-RS40 Specifications

DC Connection	
Operating Voltage Range	330 - 820 VDC
Full Power Voltage Range	550 - 820 VDC
Max DC Current	+/- 75 A
Max DC Power	40 kW
Wiring Configuration	2 Wire
AC Connection	
Max AC Power	40kVA @ 480 V_{RMS}
Max AC Current	50Arms
AC Line Voltage	208 - 480 V_{RMS}
AC Line Frequency	50 / 60 Hz
Power Factor	> 0.97 at rated power
Current Harmonics	IEEE 1547 Compliant, <3%THD
Typical Efficiency	97 %

- Designed for Behind The Meter (BTM) Energy storage applications
- Fully Scalable

- Bolt AC and DC sides together to build higher power solutions
- SunSpec Compliant
- Modular solution puts you in control of O and M costs