

An Integrated Grid Path for Solar

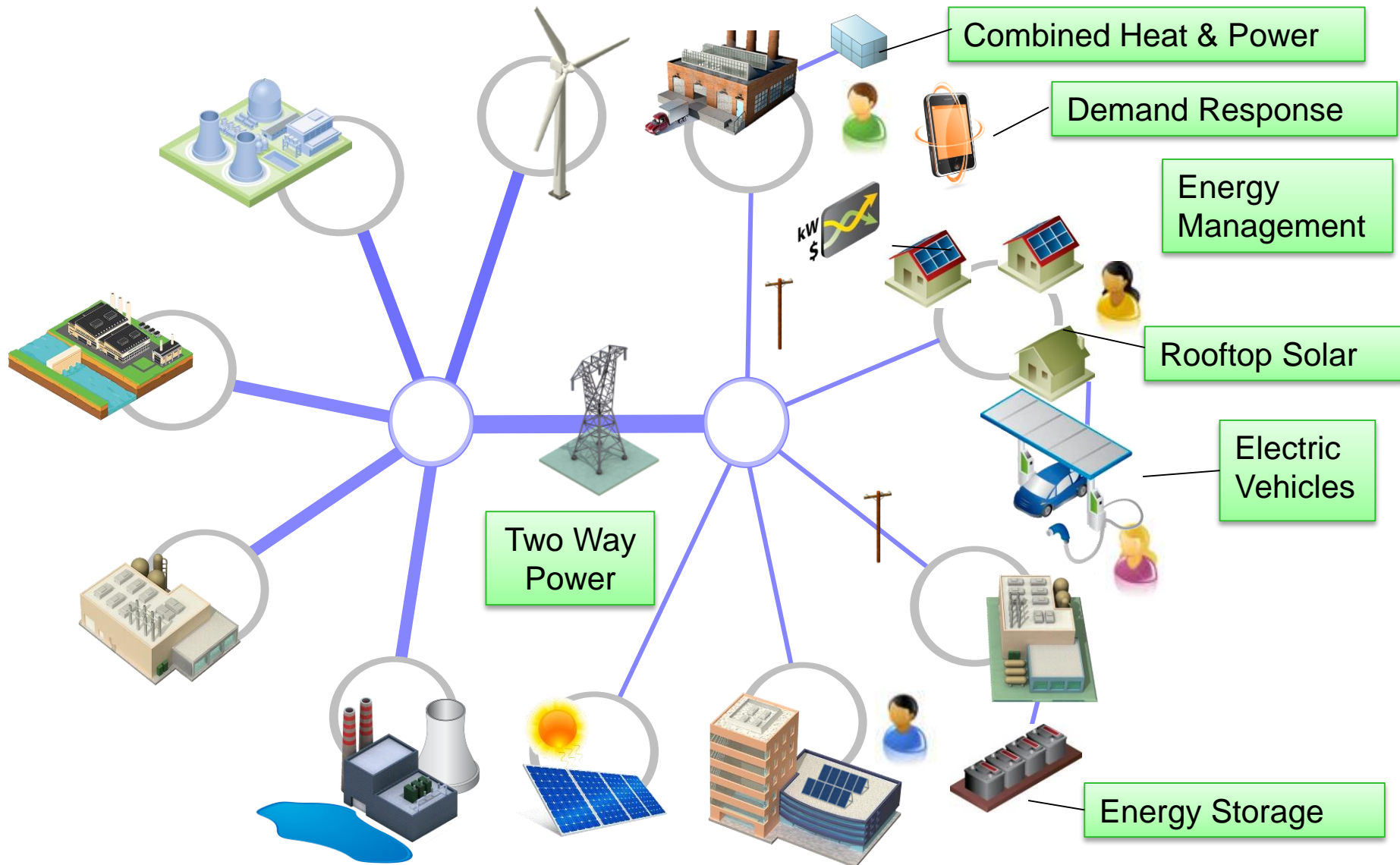
**Thomas Key, EPRI
Senior Technical Executive**

ISES Webinar

April 22, 2016



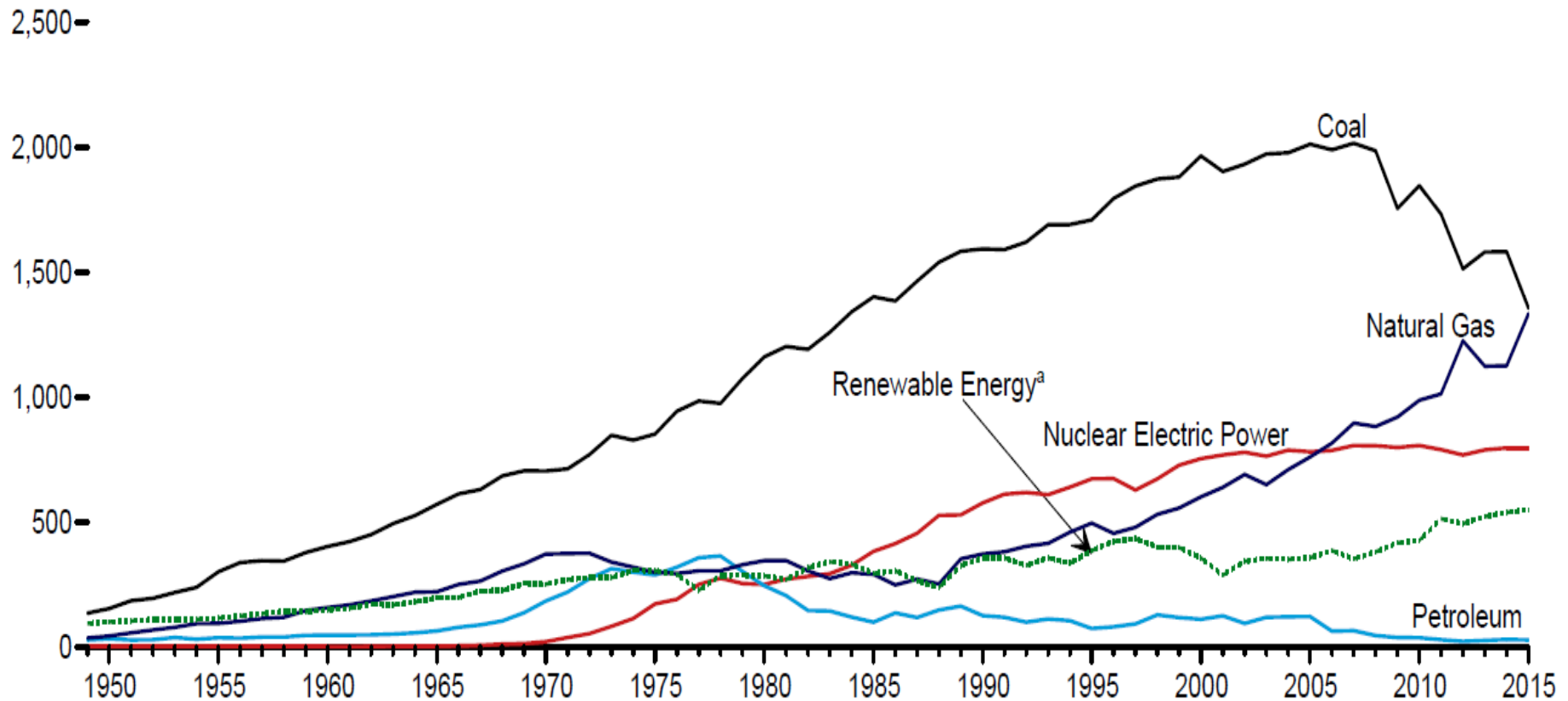
Changing Landscape: An Integrated Grid is a Better Grid



US, March 2016 Electricity Report

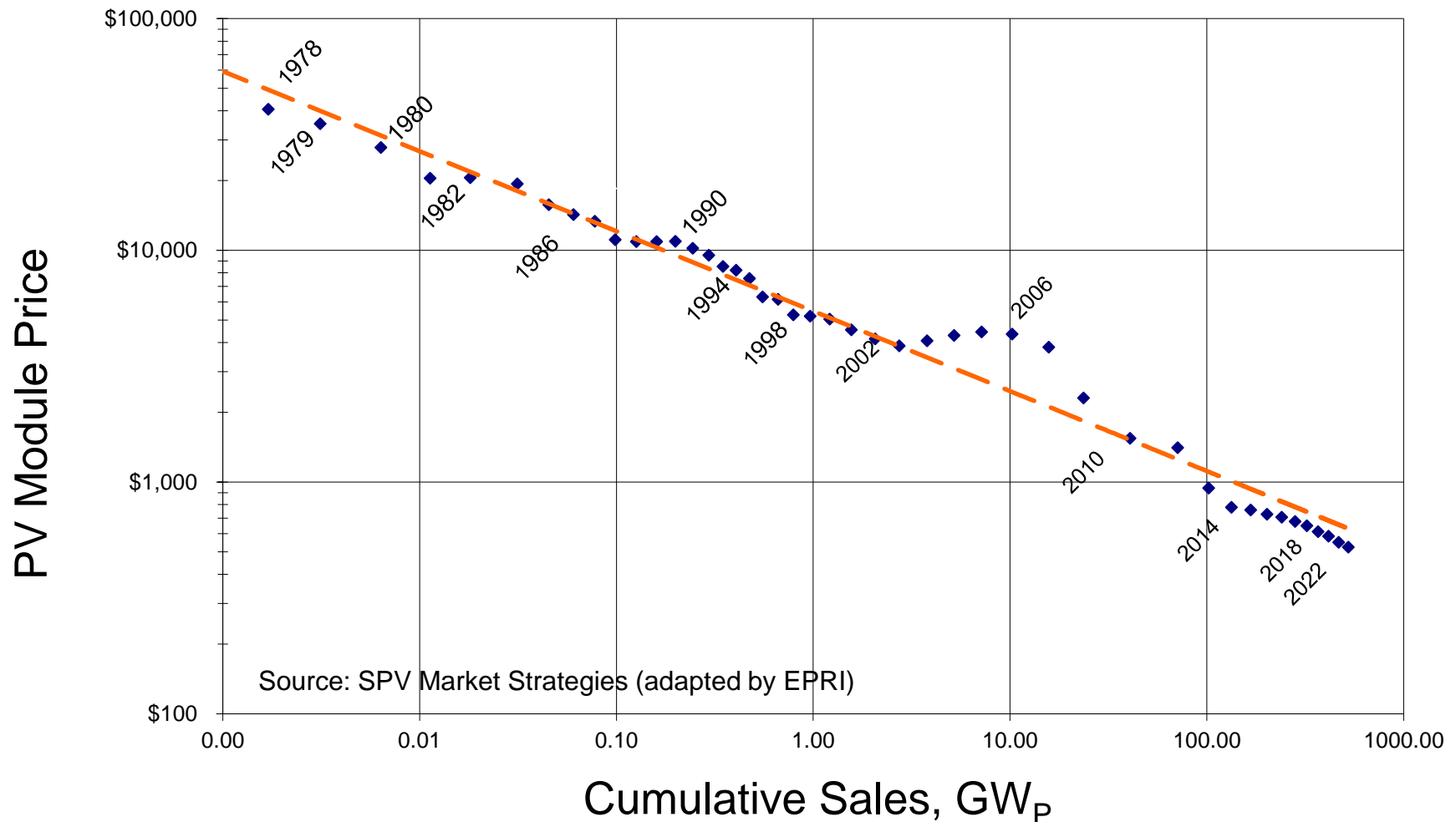
History of U.S. Net Generation (billion kWh)

Total (All Sectors), Major Sources, 1949–2015



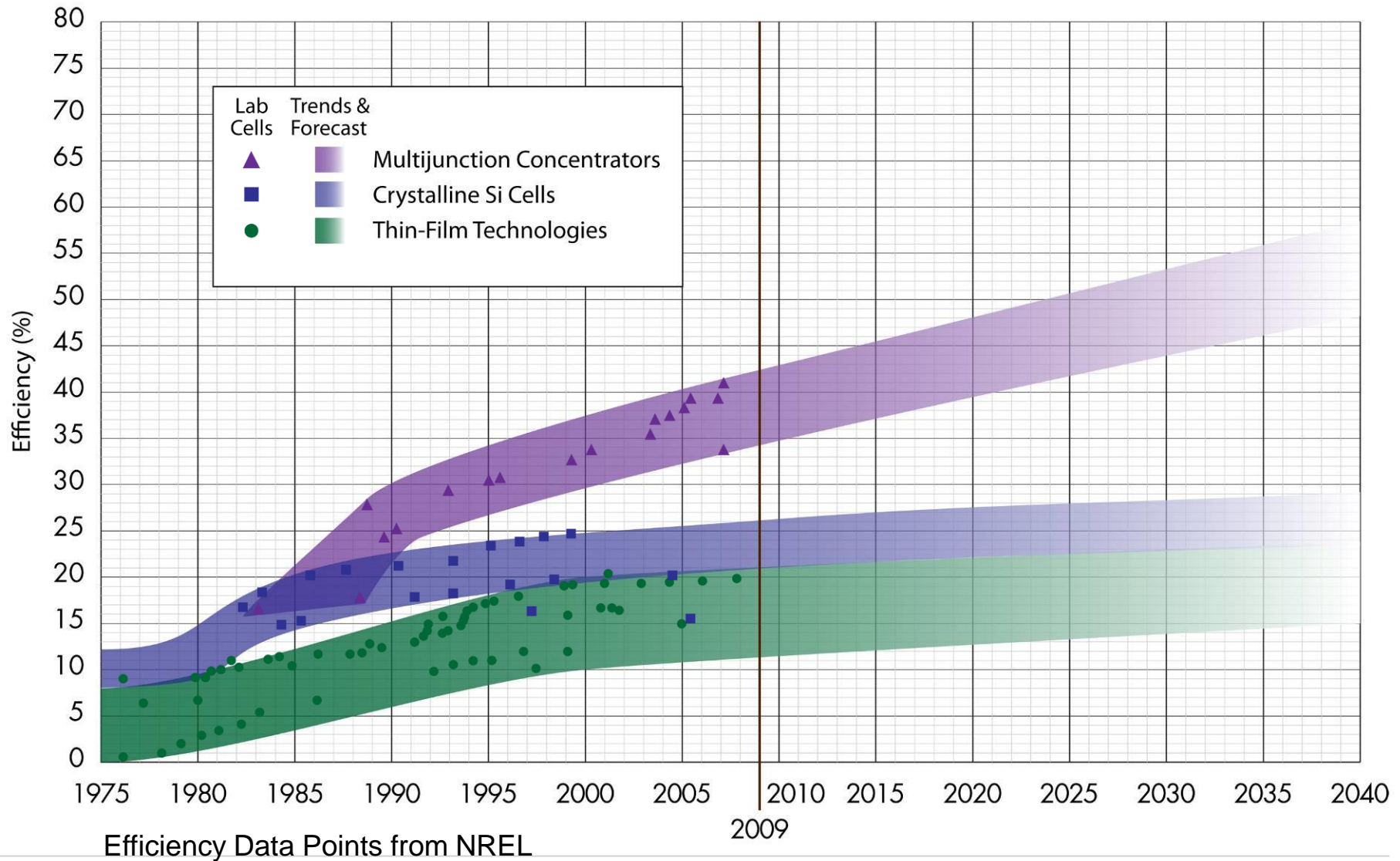
From EIA Database

Noting History... PV Module Price Trajectory



This illustrates how the historical average module selling price has declined by about 20% with each doubling of sales over several decades..

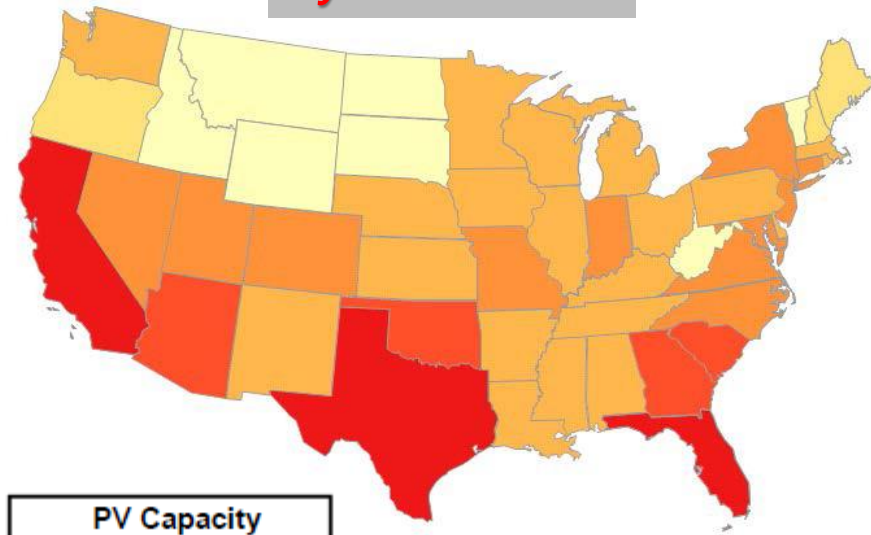
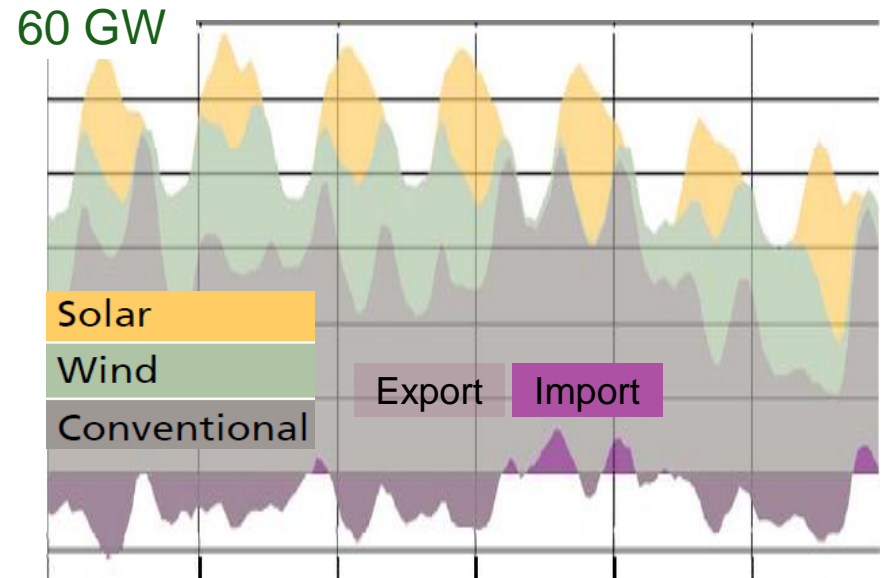
Noting History... Cell Efficiency Trajectory



Solar PV, a key driver of change

*US Future?
302 GW PV
by 2030*

*Germany Now – Power Demand
for one week in May 2015*



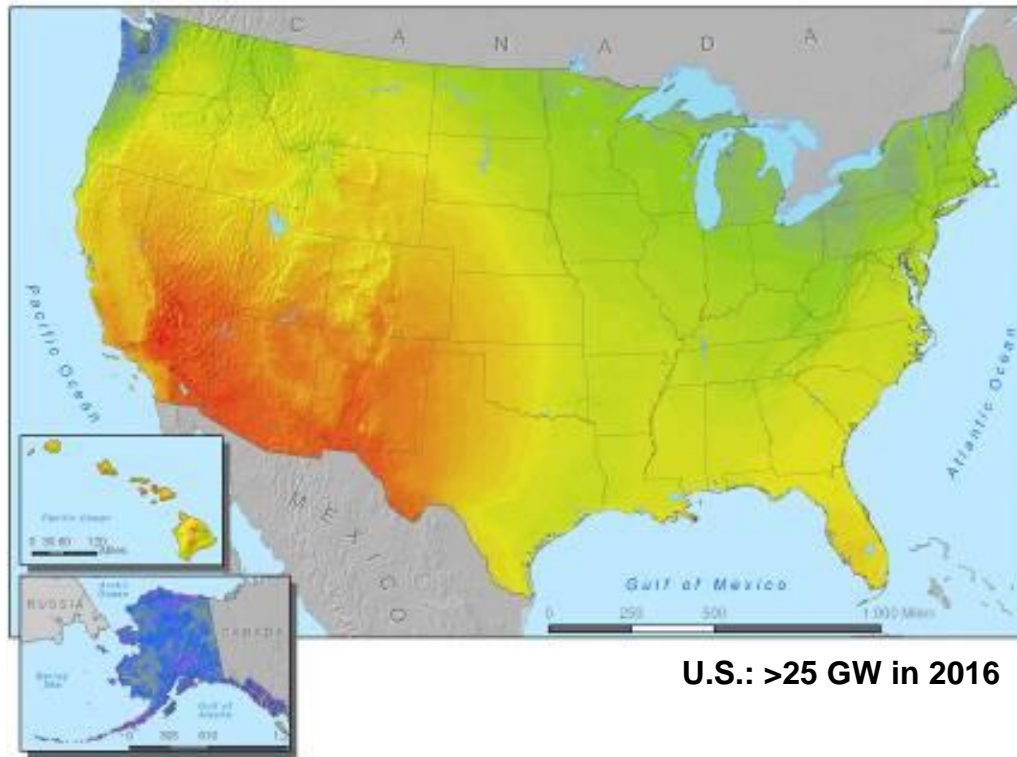
PV Capacity (GW)
< 0.5
0.5 - 1
1 - 5
5 - 10
10 - 30
30 - 50
> 50

**DOE “SunShot” Vision Study,
Released February 2012**

Is the grid ready for PV?

US Solar compared to Germany Solar

- **Fastest growing generation technology, ~200 GW worldwide**
- **U.S. total capacity ~25 GW at beginning of 2016**

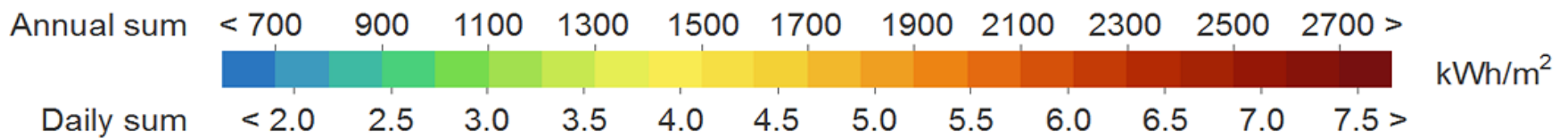
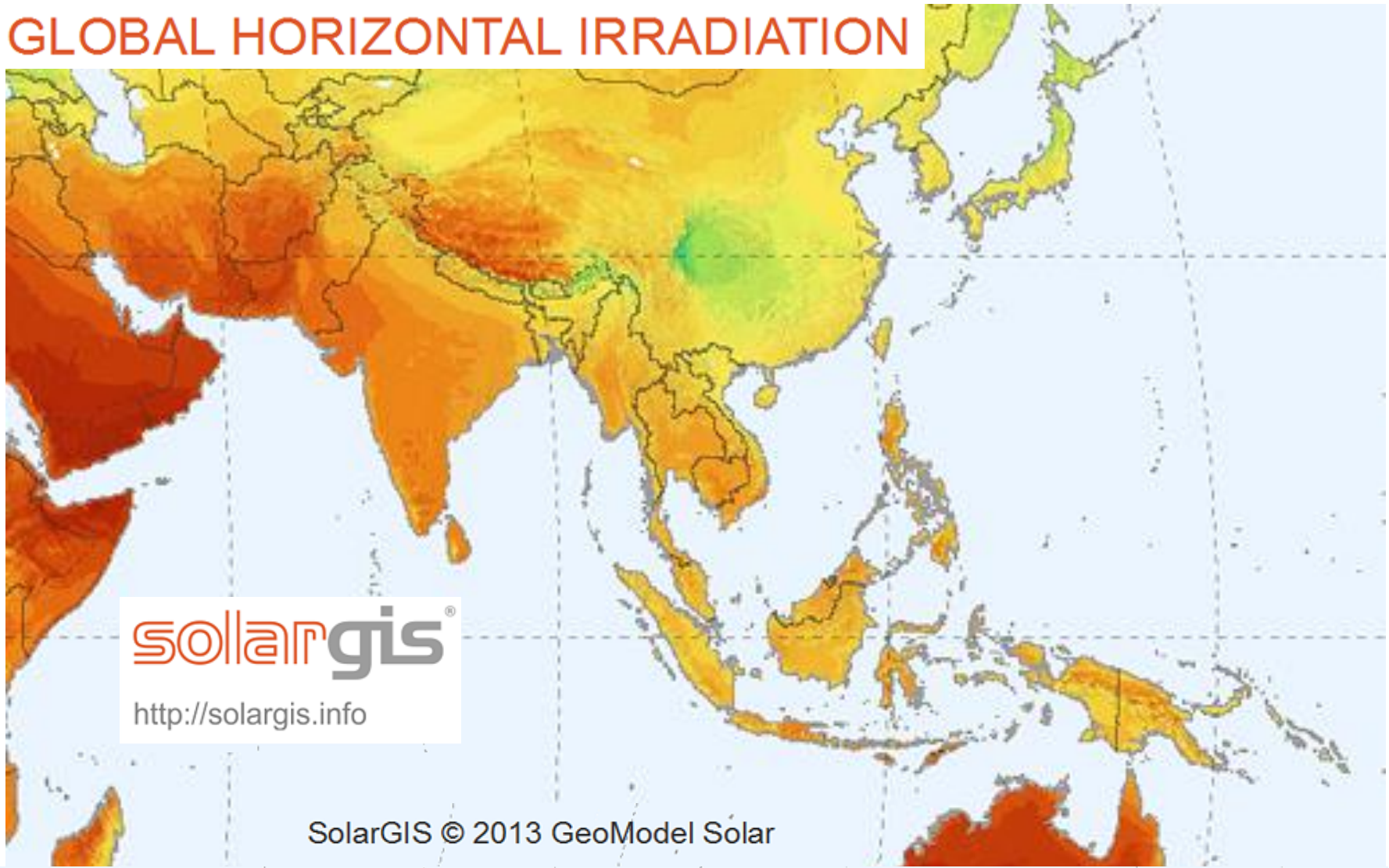


kWh/m²/Year



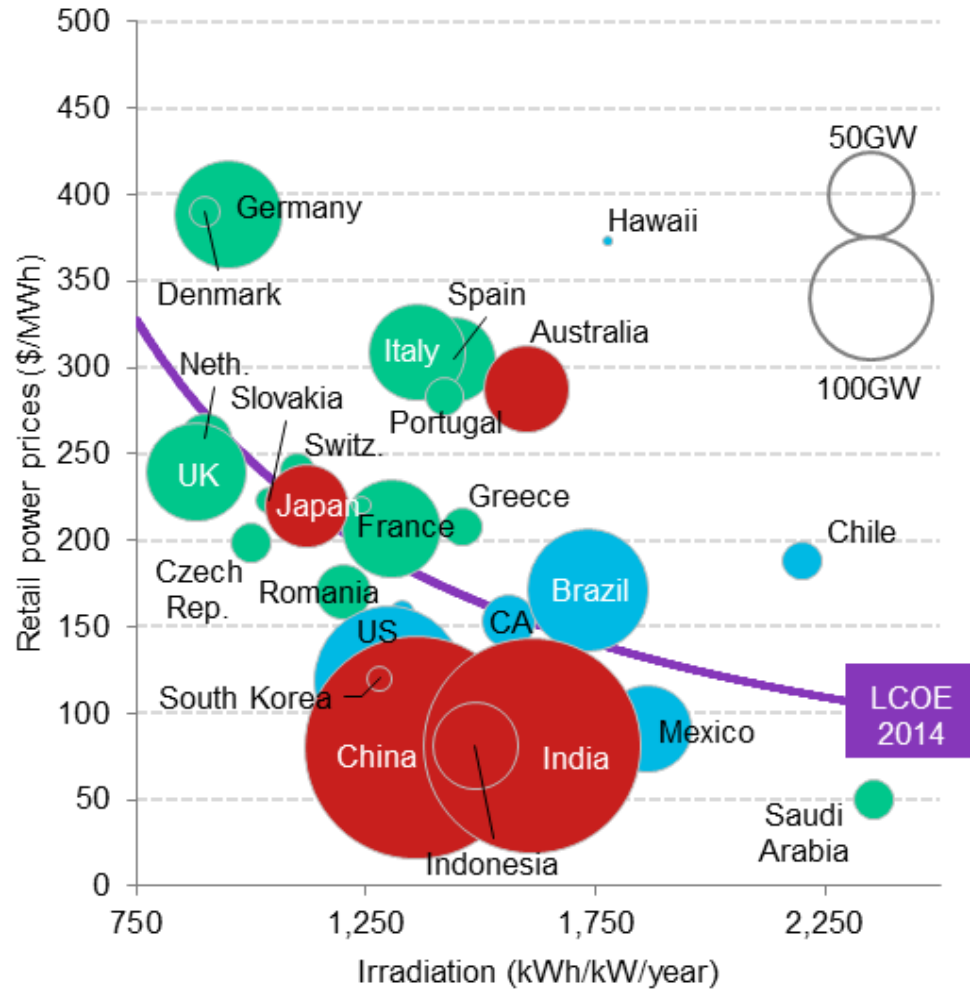
(Solar Resource Availability: NREL, PV Capacity Additions: SEPA)

GLOBAL HORIZONTAL IRRADIATION

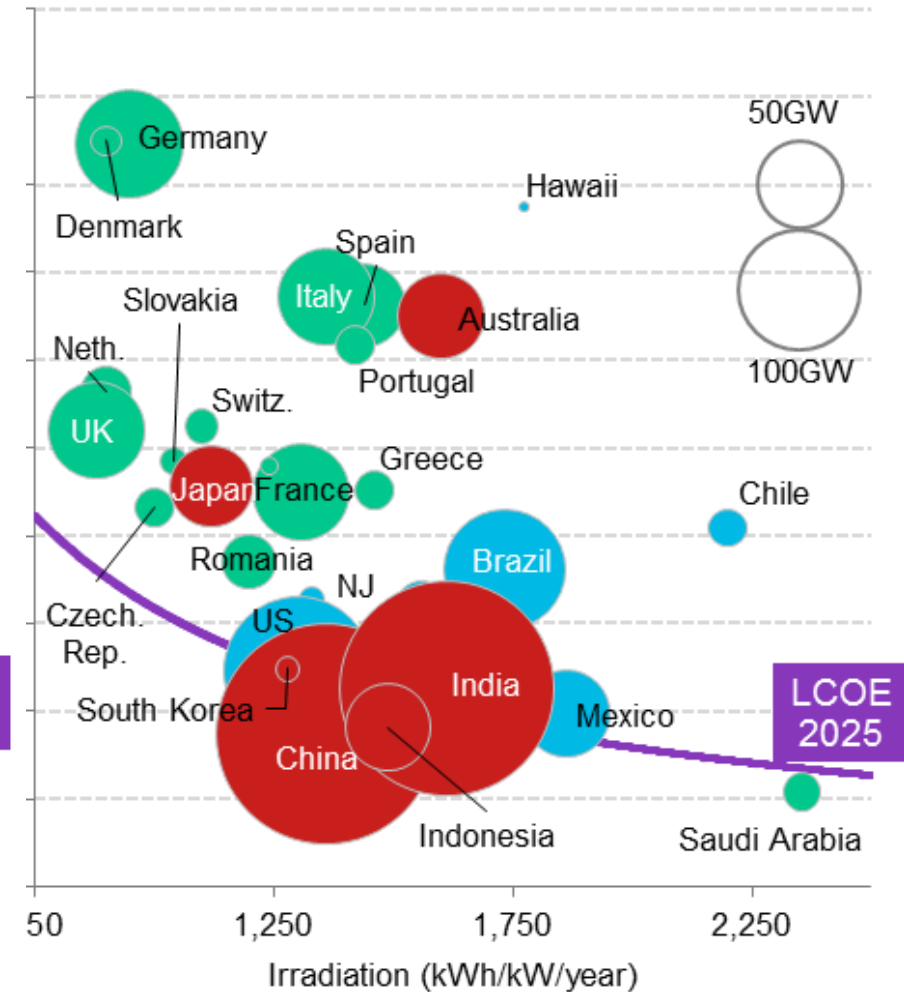


Solar Potential by country assuming residential PV Costs

2014



2025



Source: Bloomberg New Energy Finance

Interconnection Challenge: Solar output variability

Calendar based on irradiance, 1-min averages at 30° fixed tilt, Knoxville

April 2014

Sun

Mon

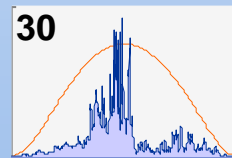
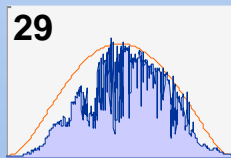
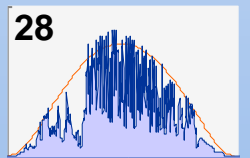
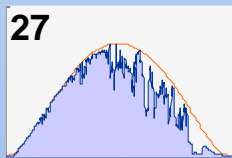
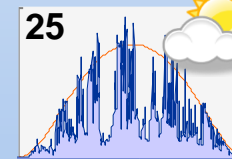
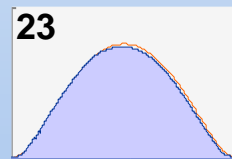
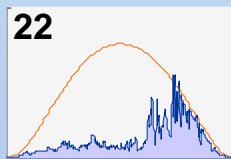
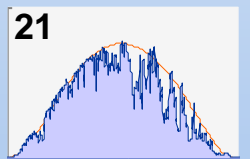
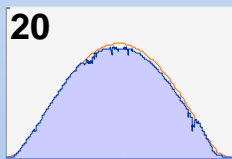
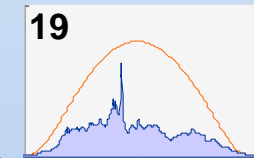
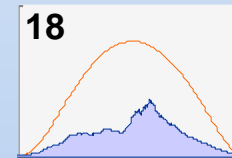
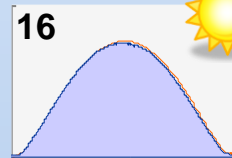
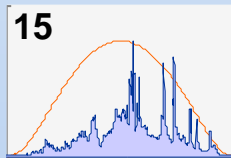
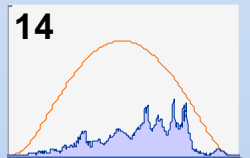
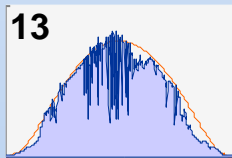
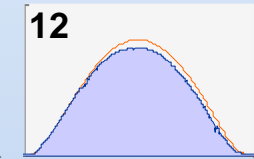
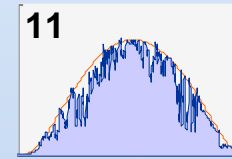
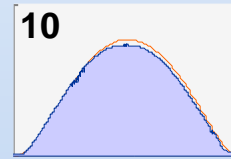
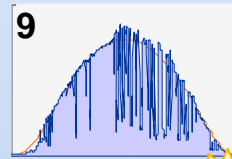
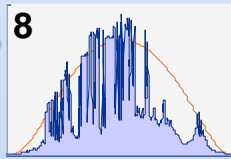
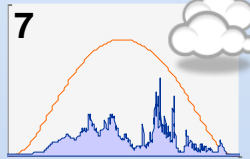
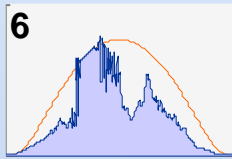
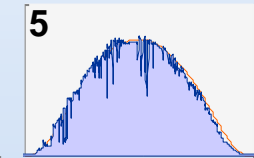
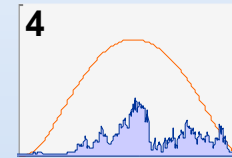
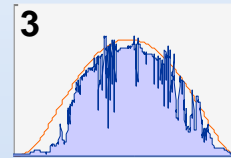
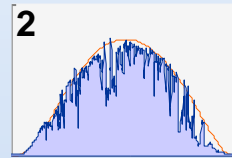
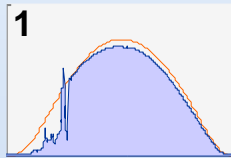
Tue

Wed

Thu

Fri

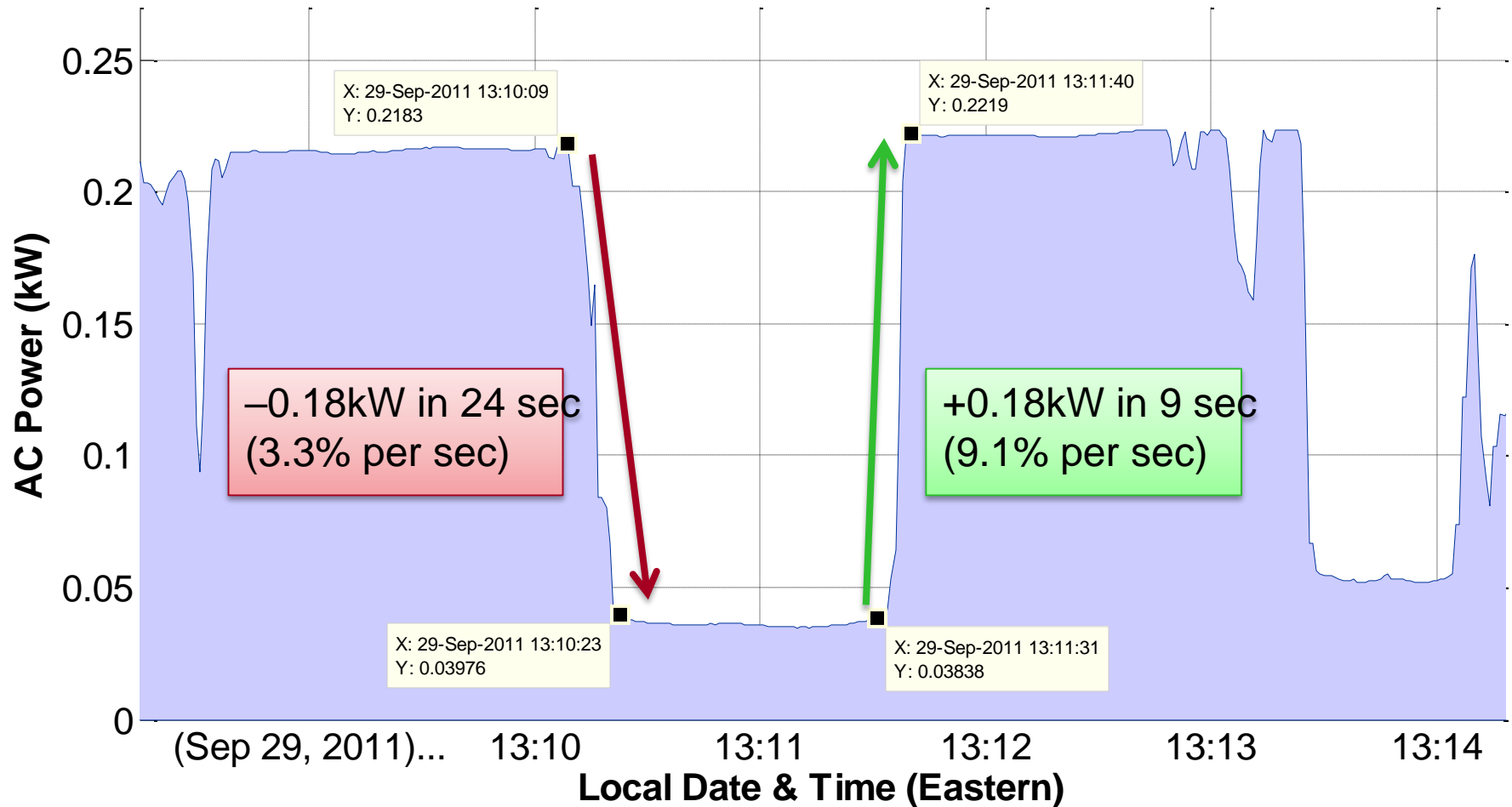
Sat



Single-Module Ramp Events on 1-MW Site in TN

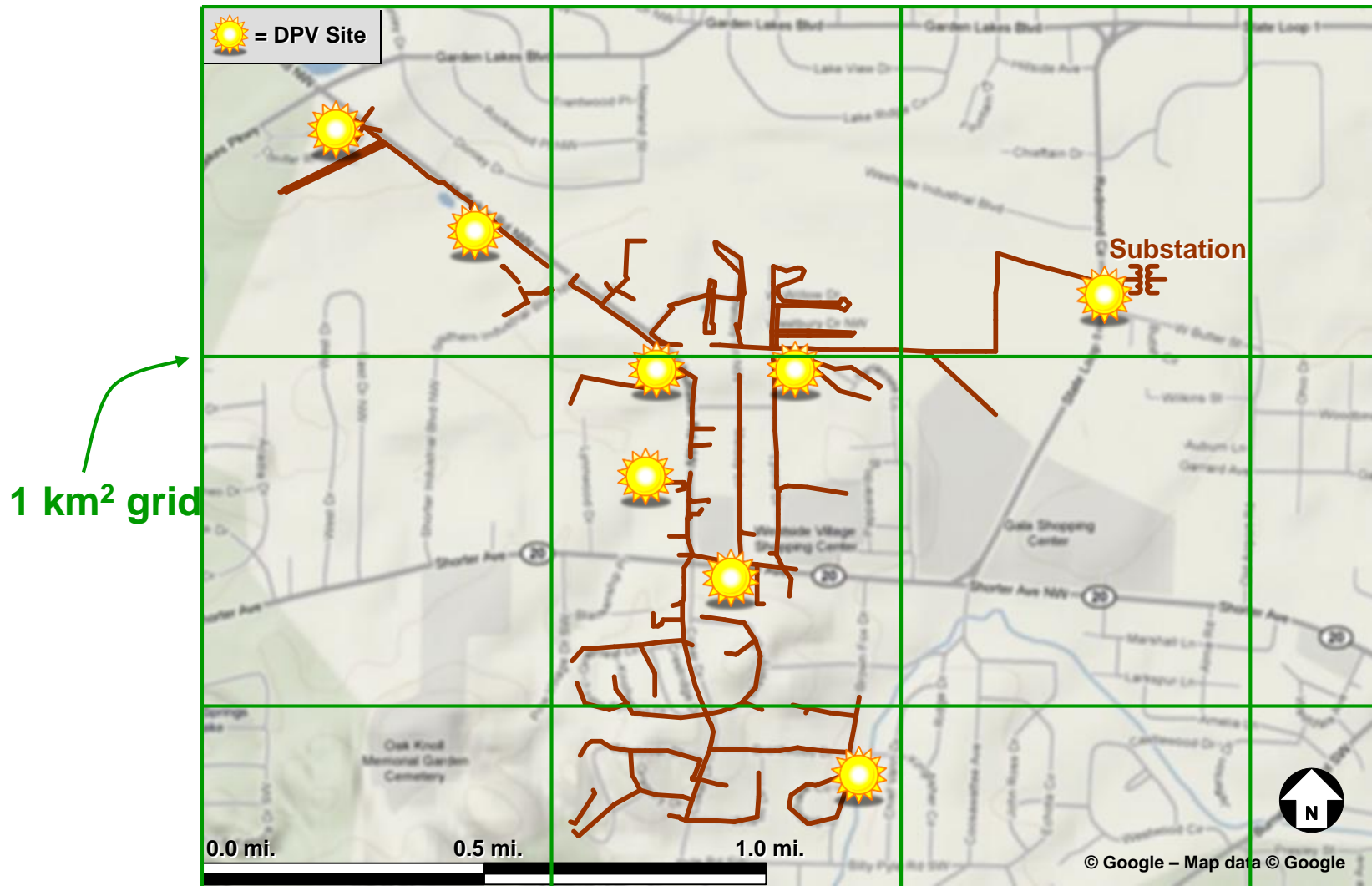
Measured 1-sec output from a 224-W module with micro-inverter

Single-Module PV System Power Production Profile



PV variable output on distribution feeder

Circuit map showing locations of pole-mount systems in Rome, GA

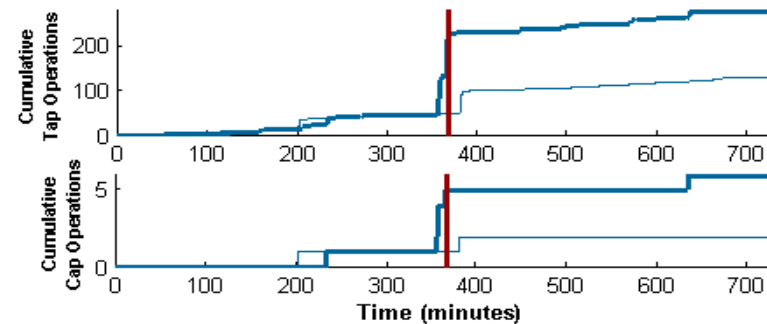
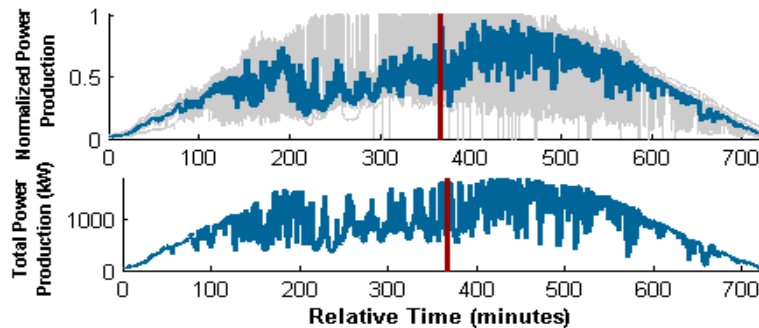
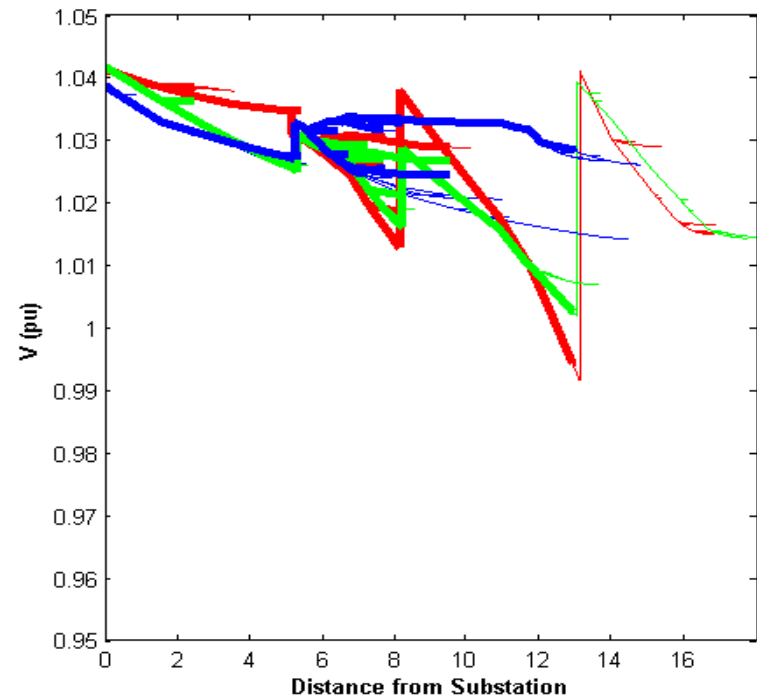
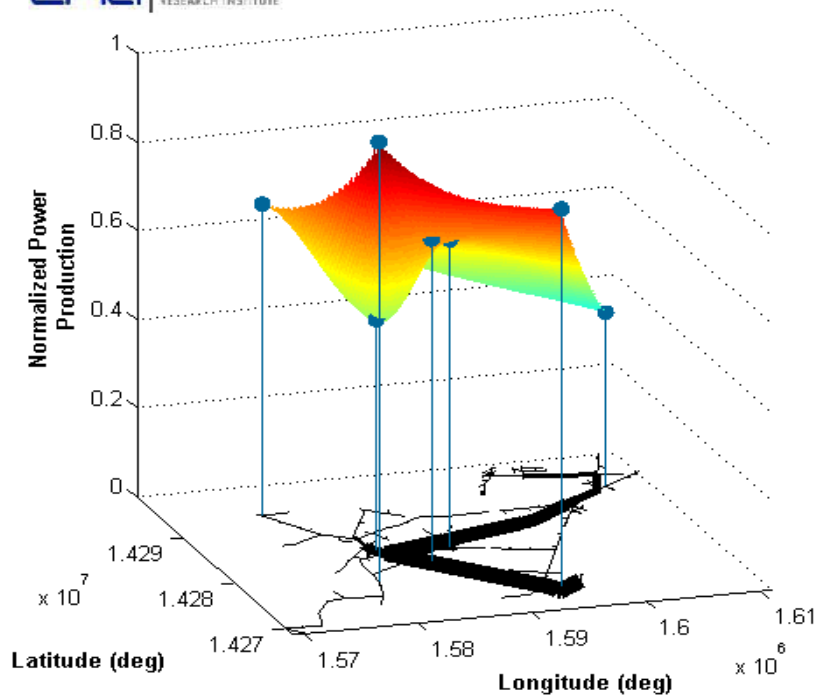


Spatial- and time-based PV-feeder demo

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366:42 min:sec



Search: "Youtube Epri Pv Penetration"

Potential Grid Issues with PV Variability

Voltage Control

- Overvoltage
- Voltage variations

Equipment Operation

- Feeder regulators,
- Load tap changers
- Switched capacitor banks

Demand/Energy

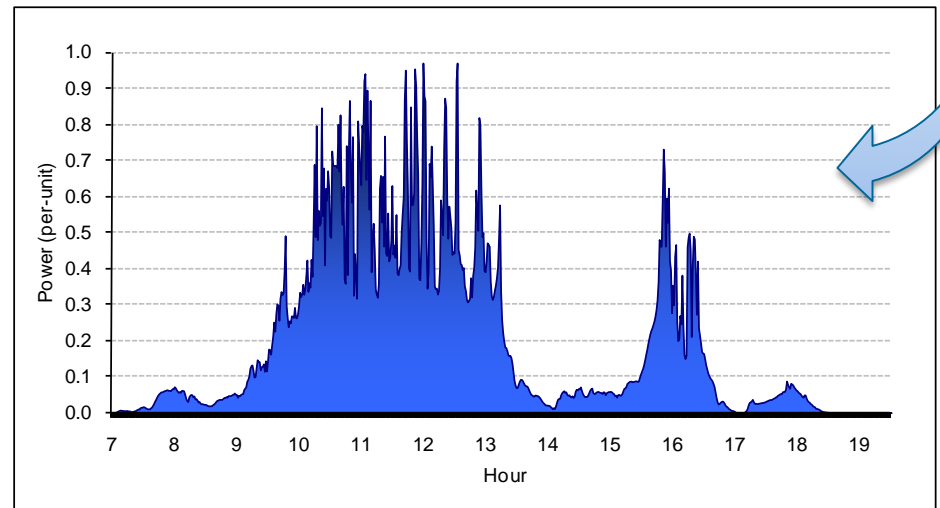
- “Masking” peak demand
- Unbalancing supply and demand

System Protection

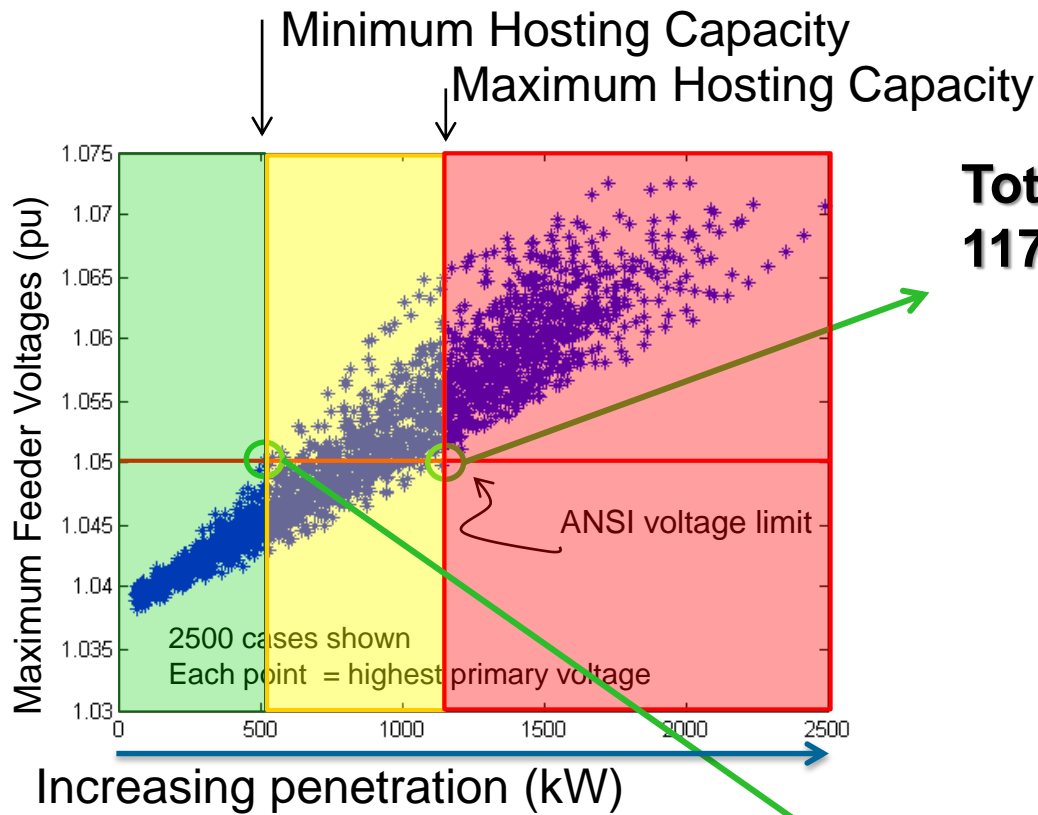
- Relay desensitization, networks
- Breaker reduction of reach
- Unintentional islanding

Power Quality

- Harmonic generation
- Flicker worries



Example: Overvoltage related hosting capacity

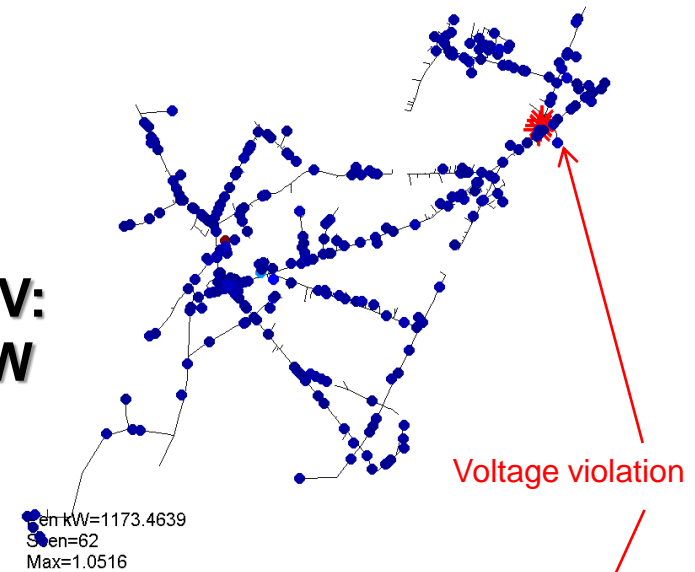


No observable violations regardless of size/location

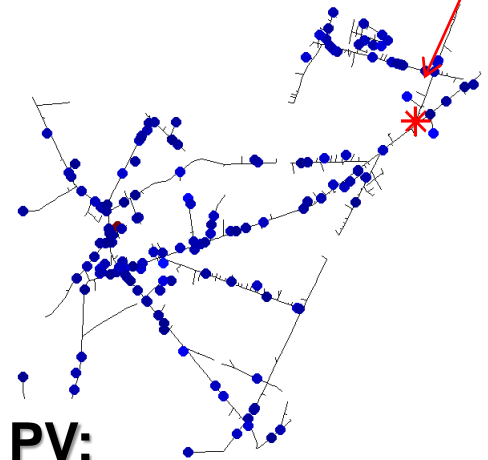
Possible violations based upon size/location

Observable violations occur regardless of size/location

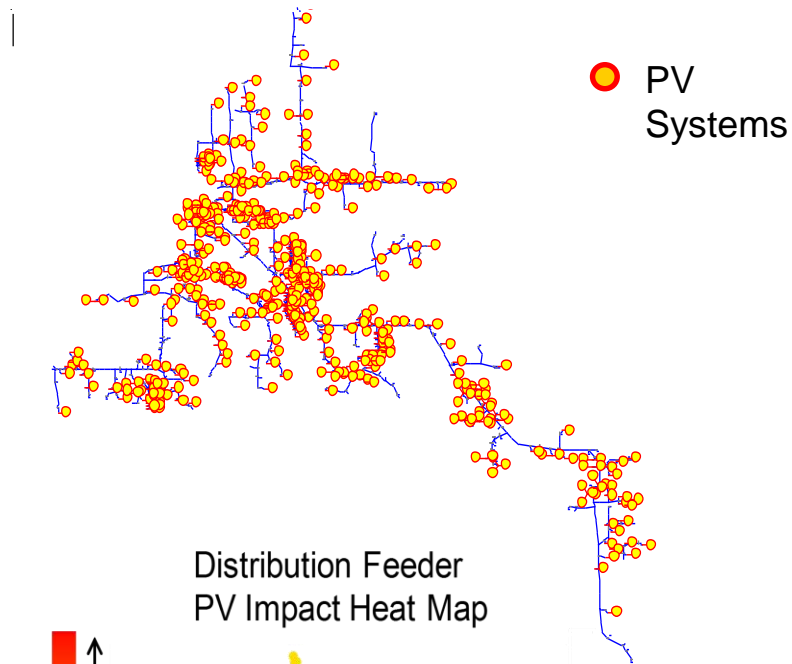
**Total PV:
1173 kW**



**Total PV:
540 kW**



Individual feeder PV “Hosting Capacity” is important



Baseline – No PV

PV Penetration 1

PV Penetration 2

PV Penetration 3

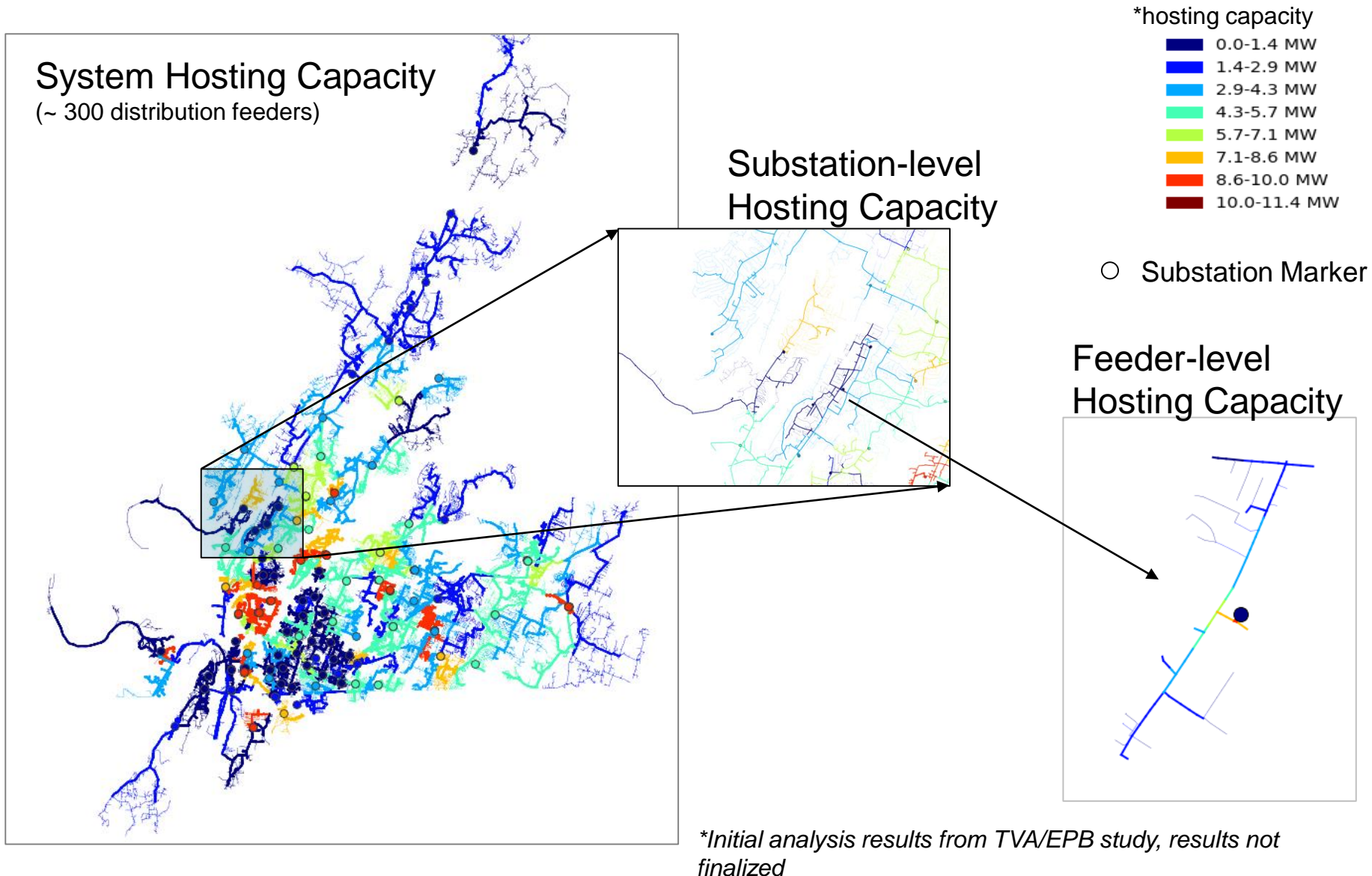
Beyond...

Process is repeated 100's of times to capture many possible scenarios

Increase Penetration Levels Until Violations Occur

- voltage
- protection
- power quality
- thermal

Mapping Feeder Hosting Sample Chattanooga, TN, USA



Inverter – Role in PV Plants

PV inverter converts DC energy from solar modules in to AC energy and interface the PV system with electricity grid



Traditional Inverter

- Matching PV output with grid voltage and frequency
- Providing safety by providing unintentional islanding protection
- Disconnect from grid based on over/under voltage/frequency

Smart Inverter Functionality

- Voltage Support
- Frequency Support
- Fault Ride Through (FRT)
- Communication with grid

Planning with DER - Mitigation

Analytics

- Screening
- Hosting Capacity
- Reliability
- DER/Grid Modeling

Tools

- Advancing commercial tools
- Open-source (OpenDSS)

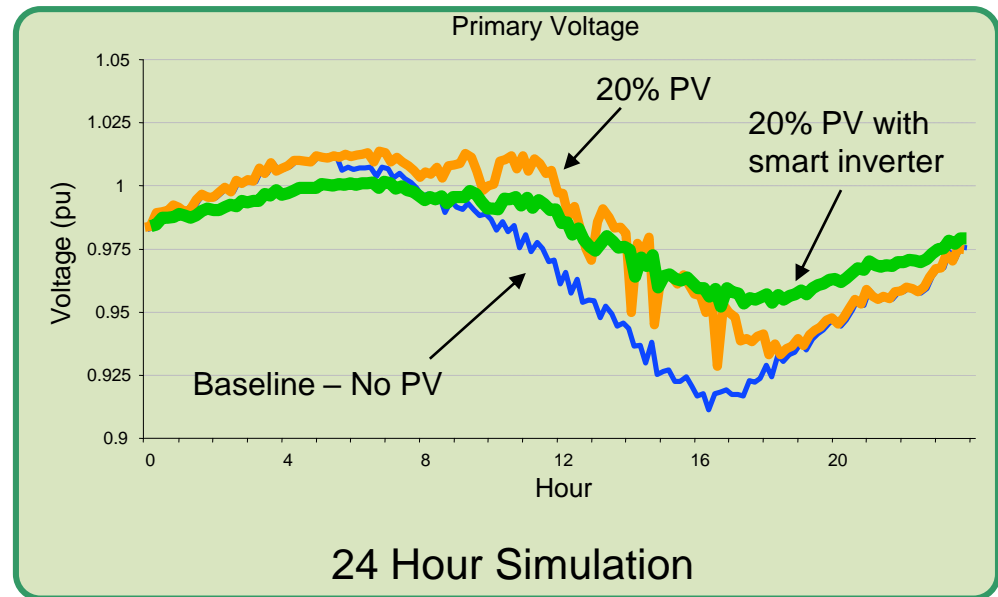
Mitigation

- Smart inverters
- Grid-side enhancements

Training

- Engineering Guidelines
- Planning with DG

Improved
Integration with



- Often least-cost solution
- Increased hosting capacity

Advanced Inverters Have Significant Upside

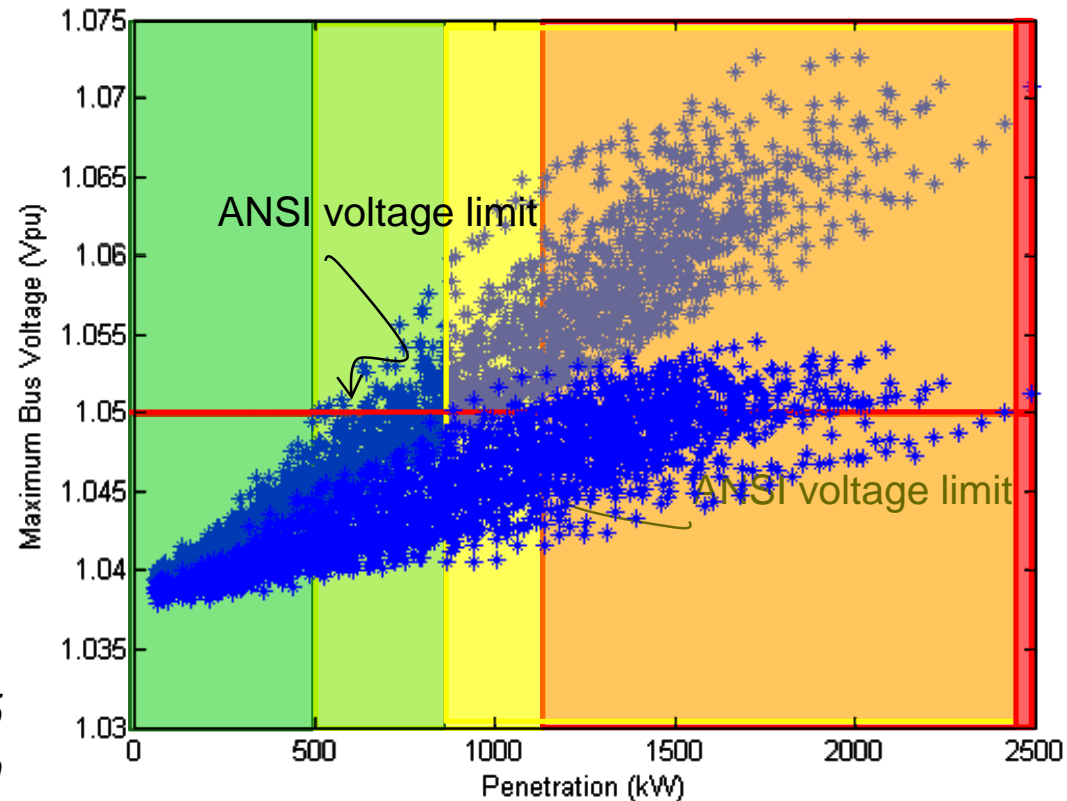
Distribution Feeder Hosting Capacity:
What Matters When Planning for DER?

April 2015



EPRI White Paper summarizing ~ 5 years of research on the Integration of DER.

Search “**EPRI and 3002004777**”



Conclusions: Key Takeaways

- *Variable PV works better with the grid*
- *We need to leverage our existing grid, cultivate “**hosting capacity**”*
- *Grid upgrades and reinforcements increase hosting, **see PVGrid***
- *Future DG to provide grid support with **Smart Inverters***
- *An **integrated grid approach** will help to transform the power system*



Integrated

*The Whole is Greater
than the Sum of its
Parts*

Transforming the Power System will be a *Journey* not a Destination

Questions?

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www.epri.com

*Together...Shaping the Future
of Electricity*

The Integrated Grid Online Community
<http://integratedgrid.epri.com>

