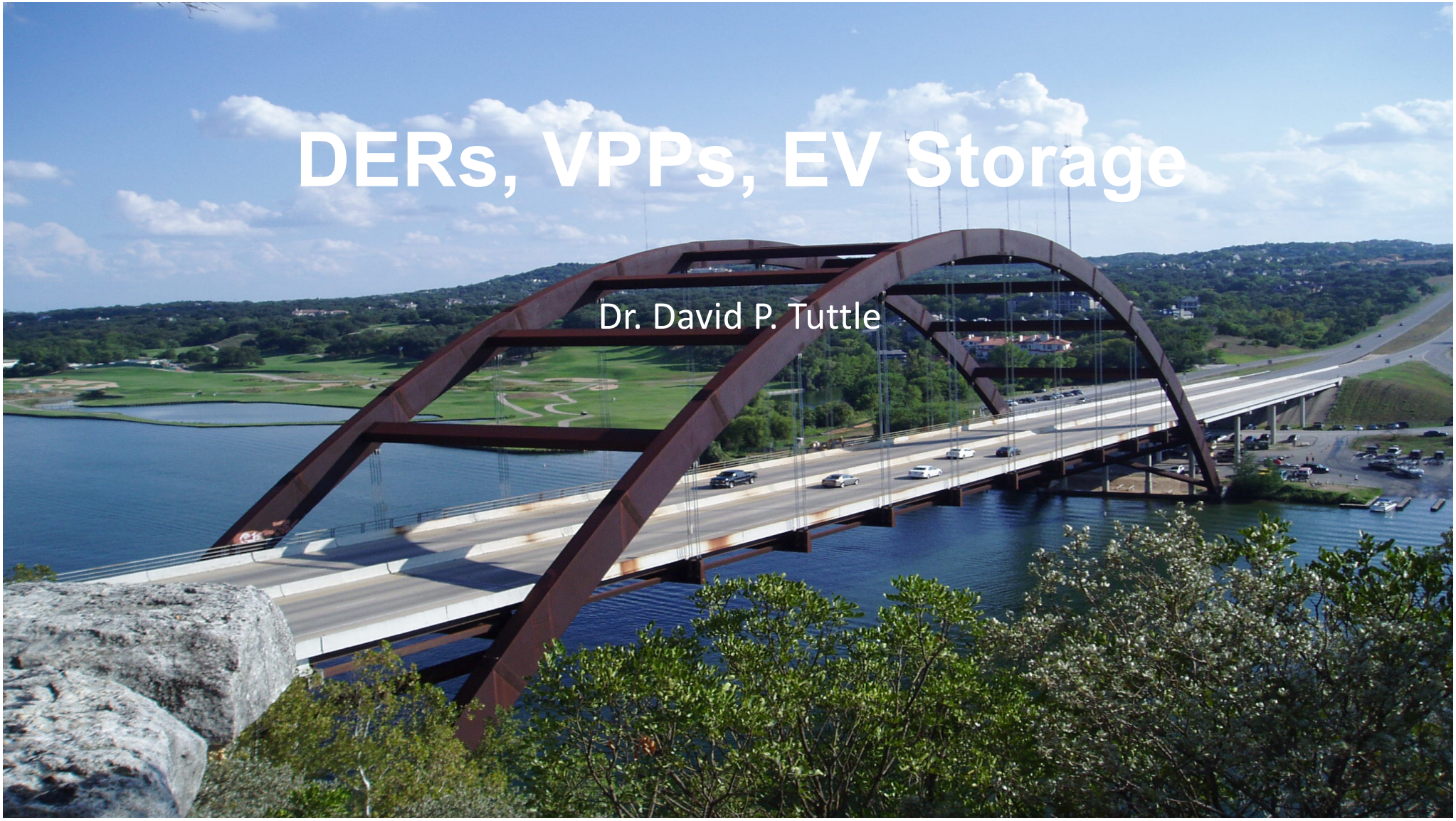
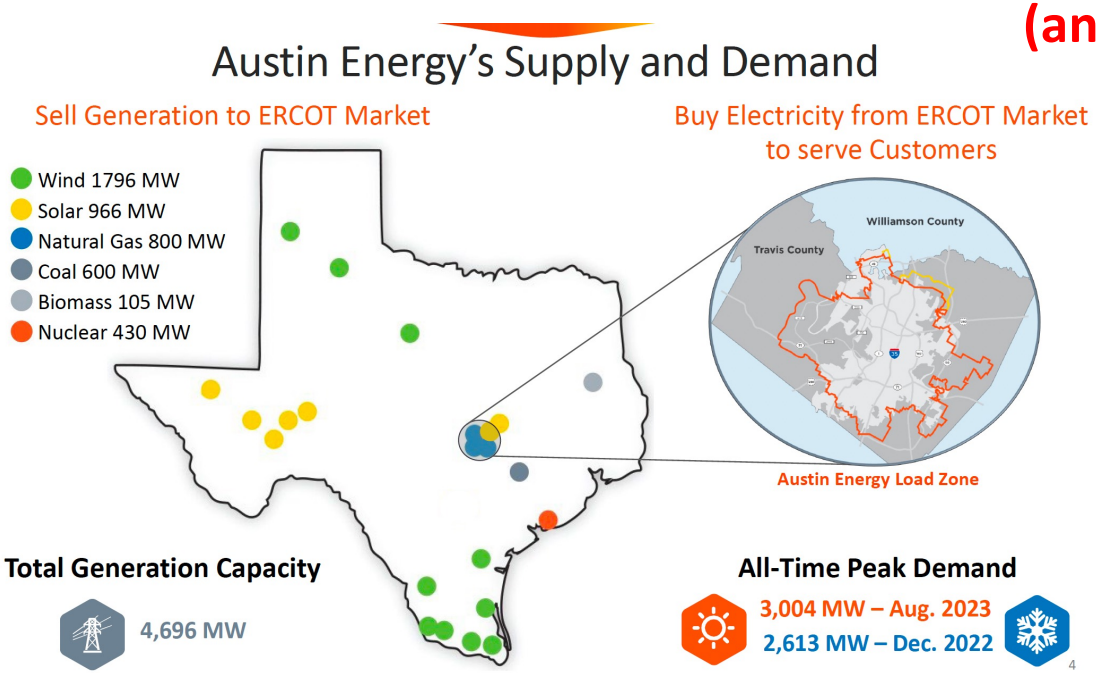

DERs, VPPs, EV Storage
Dr. David P. Tuttle

- **Distributed Energy Resources (DERs):**
  - **Flexible demand such as EVs, HVAC, Water Heaters, Pool Pumps**
  - **DG: Local Solar PV, Behind the meter storage, bidirectional EVs**
- **Virtual Power Plants (VPPs)**
- **Electric Vehicles (EVs) as flexible loads & distributed storage**
- **Deployment**

Utility Scale Renewables limited by Transmission

Need to increase Local PV & Storage (and Transmission)



Utility Scale Wind/Solar

Advantages:

- ***Lowest Cost***
- ***Fastest deployment at large scale***
- ***Better alignment w/Load for PV***
- ***Can be managed by ISO to not harm grid stability***

Disadvantages:

- ***Limited by transmission constraints***
- ***Inability to use PV+Storage for resilience***

Note: 7% loss from T&D likely offset by better Solar resource in Western Texas, optimized site, single-axis tracking vs fixed PV

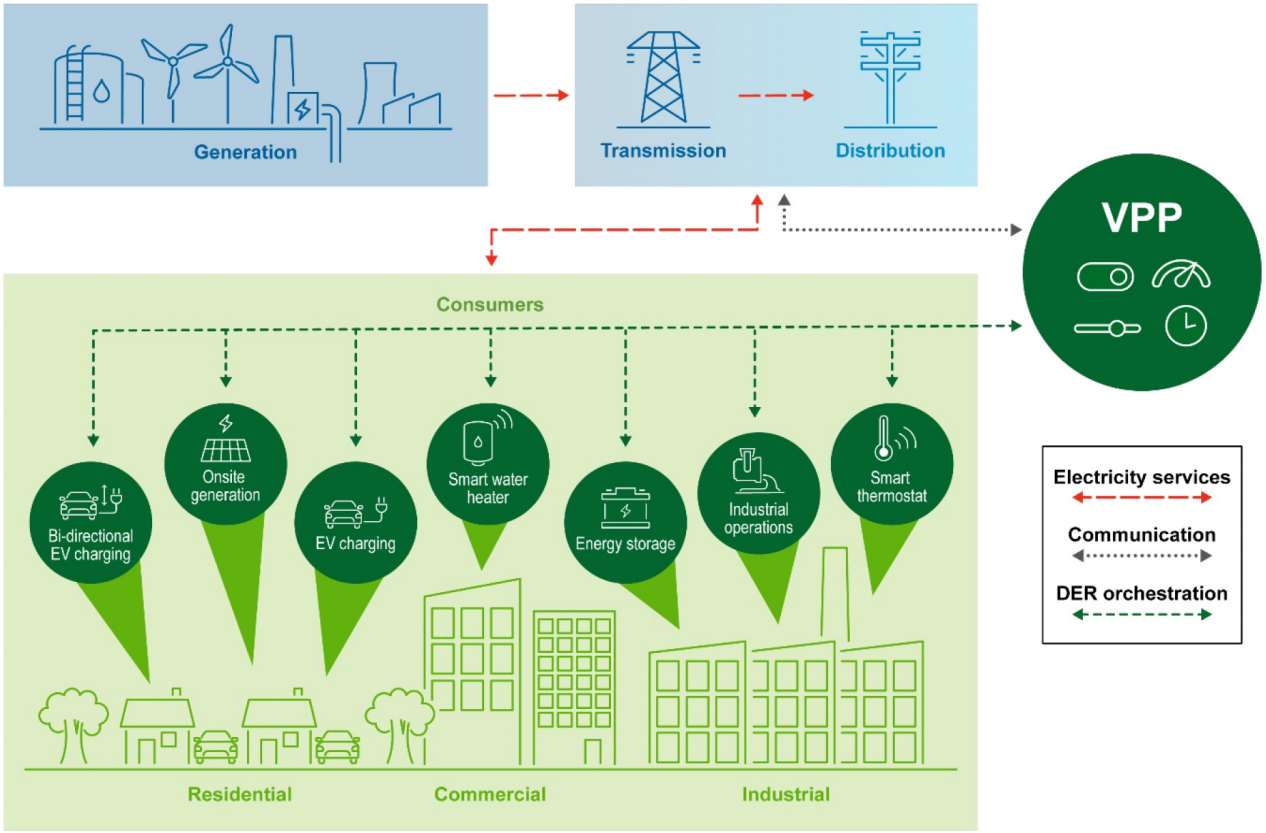
PV ⟶ Load

Earth's rotation leads to a better alignment of PV with Western PV & Eastern Load

Source: https://services.austintexas.gov/edims/document.cfm?id=415009

Virtual Power Plants (VPPs)

Virtual power plant **Tie together Distributed Energy Resources (DERs) to create VPPs**

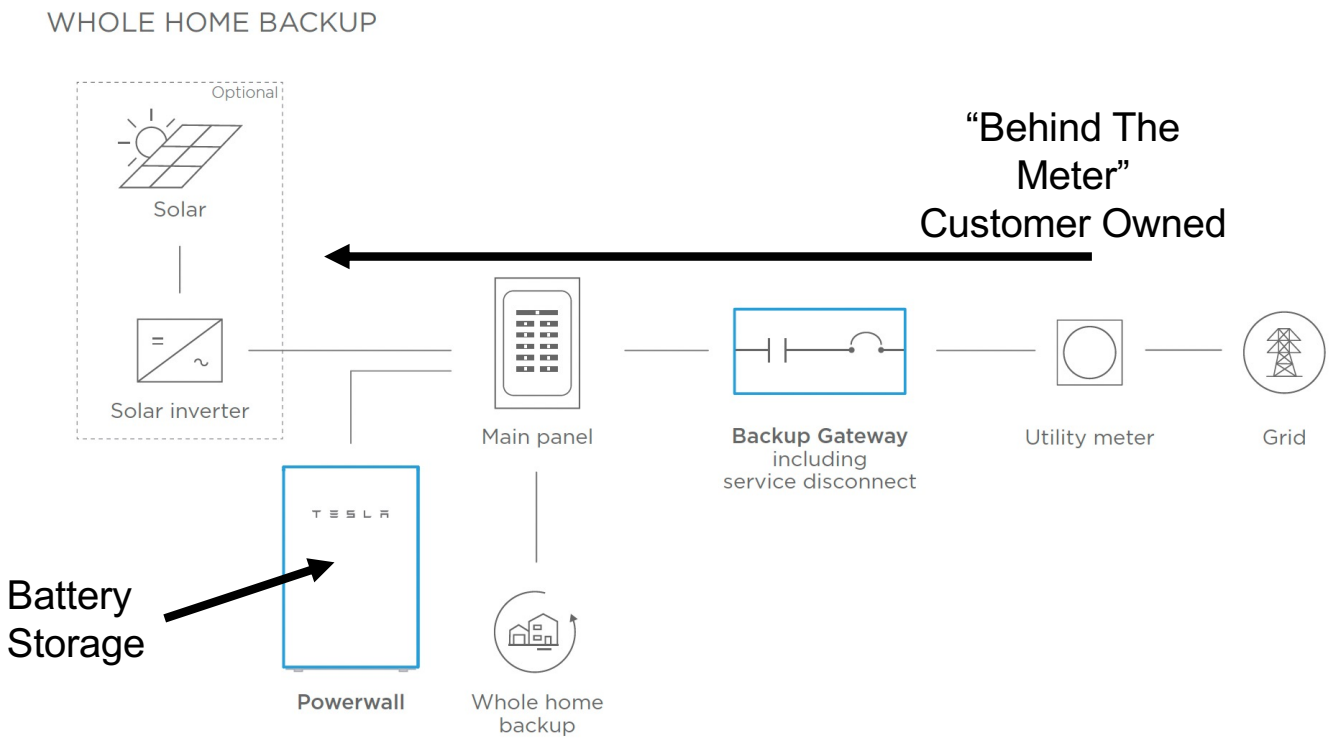


Source: Department of Energy

https://liftoff.energy.gov/wp-content/uploads/2023/09/20230911-Pathways-to-Commercial-Liftoff-Virtual-Power-Plants_update.pdf

Behind the Meter ("BTM") Storage

Can be used for Resilience as well as VPPs

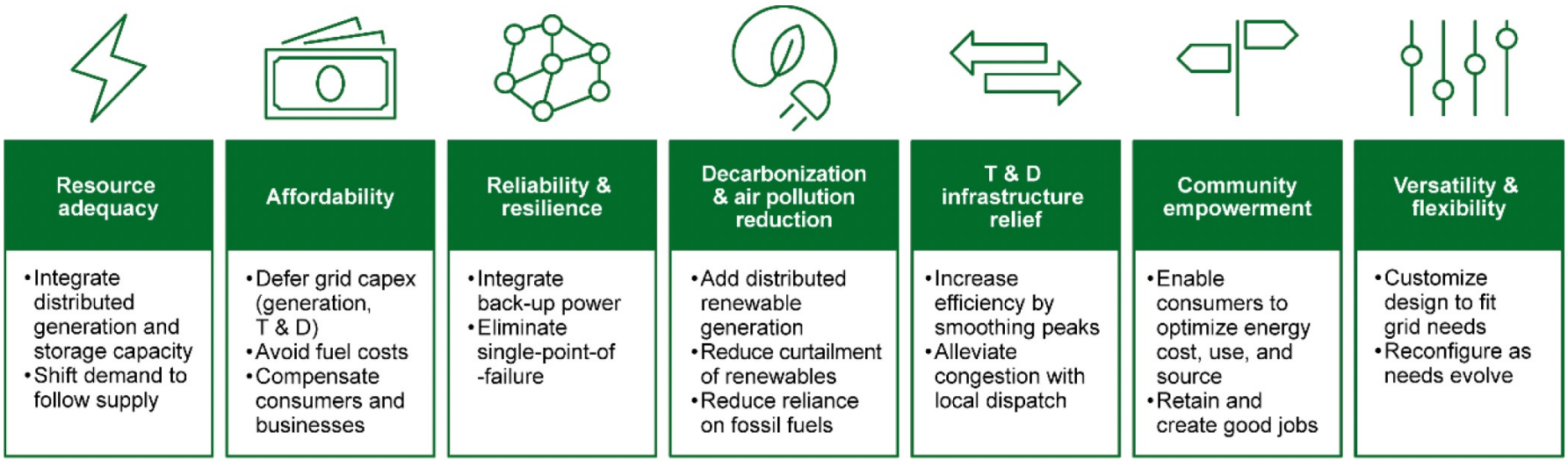


Source: Tesla

https://digitalassets.tesla.com/tesla-contents/image/upload/powerwall-2-ac-datasheet-en-na_001

Virtual Power Plants (VPPs)

VPP value proposition



Source: Department of Energy

https://liftoff.energy.gov/wp-content/uploads/2023/09/20230911-Pathways-to-Commercial-Liftoff-Virtual-Power-Plants_update.pdf

EV-Grid Synergy & EVs Exporting Power

***Vehicle-Grid-Integration (VGI)*: most importantly "V1G" and then V2G**

- *V1G*: *<u>one-way power flow</u>* to the EV, with varying levels of sophistication

- **Highest priority/greatest short-term payback for utilities/zero battery impact**
- **Needed to avoid aggravating grid stress, lowering the cost to charge, improving grid economics**

- *V2G*: *<u>two-way power flow</u>* charging into the vehicle + power export from the EV

- Great potential… but it is the most sophisticated Vehicle-Grid Interaction

Vehicle-Power Export (VPE)

- Exporting power from the EV to an *<u>isolated microgrid</u>*:

- V2L: Vehicle to Load

- V2H: Vehicle to Home

- V2B/V2P: Vehicle to Building or Premise: EVs coupled to power a larger premise

Compelling Opportunities for EVs

For Every 1M EVs on the road, ~60-75GWh of storage (AE Load ~3GW max)

- Huge, growing resource

<u>Grid connected</u> V1G/V2G applications as a DER (Distributed Energy Resource):

- Energy Arbitrage: Buy low & then sell high
- Ancillary Services: essential services that keep the grid working
- Ramp rate mitigation: When the sun sets at the end of the day in the "Duck Curve"
- Renewables firming: Filling the gaps when wind or PV output declines
- Commercial & Industrial (C&I) customer Demand Charge reduction

<u>Off-grid applications</u> for resilience or to support microgrids:

- V2L
- V2H
- V2B/V2P

"V1G" = Vehicle (one-way) Intelligent Charging

EV charging synergistically w/Grid

Avoid Aggravating Peak, charge when grid load is low
- Reduces new CAPEX, improves economics for all grid customers

Charge during periods of low grid stress, emissions, or wholesale price

Lowering the cost to charge

Charge when have an abundant low-emissions generation

Charge when possible to mitigate ramp rates (e.g. California Duck Curve)
- To help further enable greater renewable generation integration

AE already pursuing V1G by extending Power Partner Smart Thermostat Program
- No technological breakthroughs are required

V2G = Vehicle to Grid (Power to & from EV)

When Homes & EVs are grid connected and the grid is operational
- By either AC or DC EVSE (EV Supply Equipment) connection
- Could leverage onboard AC-Level2 charger or V2H enabled bidirectional hardware
    - Bidirectional AC pilots ~20 years ago, SAE J3072 & UL-1741SC under development
    - Bidirectional DC hardware meeting UL-1741SA/IEEE-1547 available today
        - Buses, Fermata w/CHAdeMO DC 2020, Sunrun-Ford V2H w/CCS DC 2022
        - SAE J3271 Megawatt Charging Standard (MCS) will support bidirectional charging

EV acts as DER (Distributed Energy Resource)
- Perhaps in conjunction w/other home DERs
- Considerable Interaction with the Utility, Retailer, Aggregator, OEM, ISO
    - Retail DR/DER market participation
    - Wholesale market participation w/aggregation (100kW minimum)

EV synergistically interacts with Grid

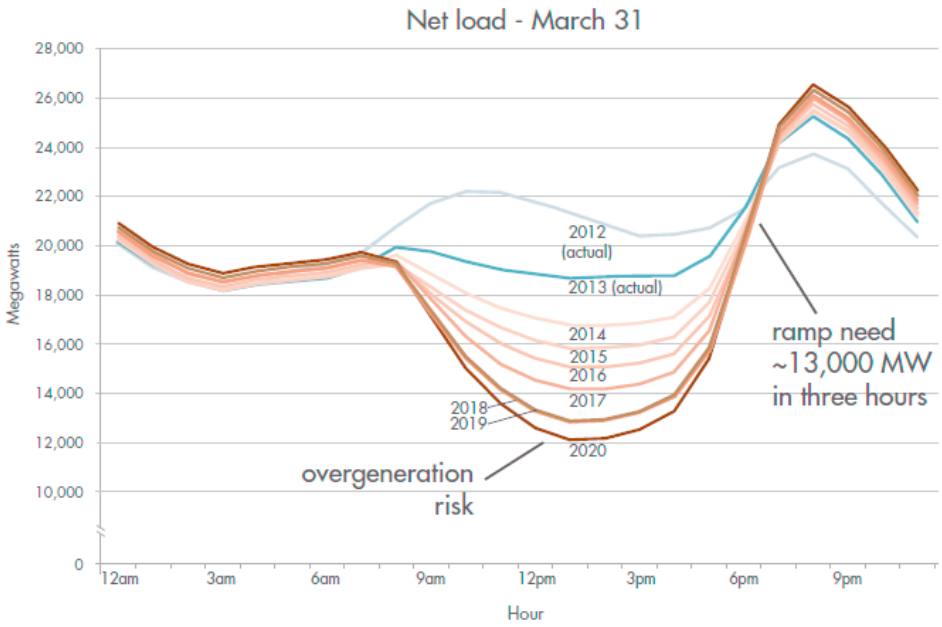
The Duck Curve

Created from ever more amounts of Solar PV

Grid must deal with ”Net Load”
- Net Load = Actual Load minus PV output

When sun sets, PV output declines precipitously
- Grid operator (e.g. ERCOT) must rapidly increase other generation output to balance the grid
- The magnitude of this end-of-day ramping is a serious technical problem

Figure 2: The duck curve shows steep ramping needs and overgeneration risk

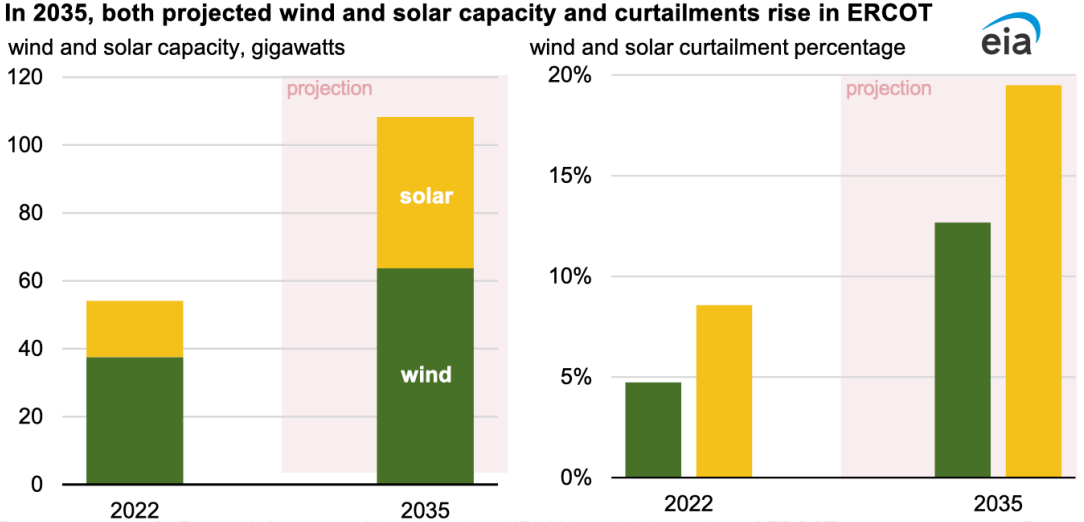


Future ERCOT Challenges

JULY 13, 2023

As Texas wind and solar capacity increase, energy curtailments are also likely to rise

In 2035, both projected wind and solar capacity and curtailments rise in ERCOT



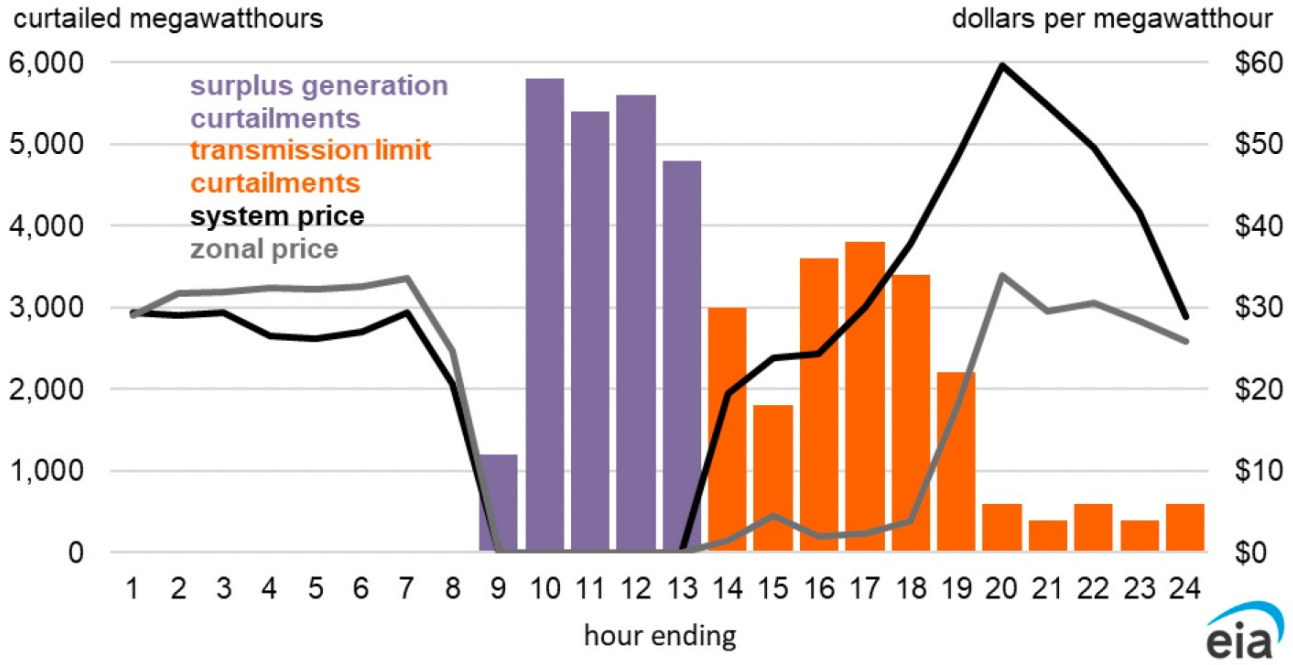
Data source: U.S. Energy Information Administration, UPLAN model simulation of ERCOT power market, and Potomac Economics, *State of the Market Report for the ERCOT Electricity Market*, May 2023

We project combined wind and solar generating capacity in Texas's power market will double by 2035, fueling a growing renewable share of total generation. However, without upgrades to the state's transmission system, wind and solar generation will increasingly be curtailed, according to our recent analysis, *A Case Study of Transmission Limits on Renewables Growth in Texas*.

Source:https://www.eia.gov/todayinenergy/detail.php?id=57100

Future ERCOT Challenges

Figure 5. Two types of curtailments: surplus generation versus transmission capacity limits (projected 2035 scenario, LZ_South region, a June day in 2035)



Data source: U.S. Energy Information Administration, UPLAN model simulation of ERCOT power market

Source: https://www.eia.gov/electricity/markets/quarterly/archive/2023/transmission_limits_07_2023.pdf

V2L = Vehicle to Load

200-400 Watt Integrated Inverter

Source: Ford (ProPower Onboard 7.2kW)

Intelligent Backup Power Overview

Extended Range Vehicle (Dual Onboard Chargers 19.2kW capable)	Included	Included (Install w/ Sunrun[3])	Purchase & Install w/ Sunrun[3]
Standard Range Vehicle (Single Onboard Charger 11.3kW capable)	Paid Activation @ Ford	Purchase @ Ford (Install w/ Sunrun[3])	Purchase & Install w/ Sunrun[3]
		(3-year Ford Warranty)[2]	(10-year Sunrun Warranty)[2]

Deployment

EV batteries are a compelling resource,
- But safely and economically connecting and controlling them is not free

- Likely to see progressively more sophisticated Vehicle-Grid or Vehicle Power Export deployments over time
  - *Compelling applications like V2H will help drive adoption*

- Need *low-cost bi-directional* charging equipment
  - Either with V2G-AC or V2G-DC interfaces
    - V2G-AC likely to have lower infrastructure costs
    - Today's V2G-DC hardware is $3895 + installation (Ford F150 Lightning EV Home Integration System)

- Interoperability Standards are critically needed

- Auto Manufacturers' experience and comfort with battery cycling wear implications and profit model for V2G
  - Vehicle manufacturers are comfortable with V2H home backup w.r.t. battery wear and warranty
    - Will learn the risks of V2G with more field data

- Compensation: Utility tariff structures, market rules

- *Utility SCADA and Billing Systems*

- Business & profit models given the different actors

- Secure & Reliable Communication/Cybersecurity

V2G Deployment

Many pilots in past and now underway to test the technology

- 2002-Brooks/AC-Propulsion CARB
- 2008-Kempton et al PJM-Ancillary Services
- 2013-Univ of Delaware/KU Leuven: Mini-E + eBox to PJM
- 2014-ERCOT/SWRI/CCET/Frito-Lay V2G FFRS pilot (DOE Award# DE-OE0000194)

Focus on V2G segments with the best economics first

- Busses, depot charged fleet vehicles more likely in early deployments
  - Regionally specific circumstances may drive some LDV Passenger Cars V2G
- Passenger Cars: The priority for utilities will likely be V1G first, then later V2G
- Economics will differ by ISO, utility, node location, season, and time

"Vicious cycle" **vs Virtuous cycle impacting the business model**

- Virtuous cycle: the Network Effect greater value w/more nodes
- Vicious cycle: Fixed Demand, but eventually oversupply

PEV-Grid Coordination Roadmap

Developing Increasing Amounts of Capability Over Time

1st Generation (Today): Plug-In & Charge

"V1G" Power flows *Only To* Vehicle

No Coordination: Immediate Charging

Little Impact Today Given Modest Number of Vehicles

Off-Peak Charging Encouraged via Utility EV-TOU tariffs

Program Charge Time via Car Console, Browser, or App

No PEV-Grid Communications Capability

2nd Generation: Basic DR

Peak Shaving via Pause in Charging

Utility DR Signals Similar to Smart Thermostats

3rd Generation: Smart-Charging

Vary Charging to Peak Shave, Align with Renewables, Mitigate Ramp Rates, Reduce Costs/Grid Stress

V2H

Power flows *To & From* Vehicle

Home Backup

4th Generation: V2G*

Vary Power Level/Direction to maximally Peak Shave, Align with Renewables, Mitigate Ramp Rates, Reduce Costs/Grid Stress

Utility and/or ISO/RTOs Coordinates with Vehicles

DERMS to enable Grid-EVSE/PEV Communications via:
Home Broadband-Wi-Fi, Utility Backhaul, Cellular/Radio, Direct to Vehicle

Objective: Same EVSE Hardware w/ only Software Upgrades

Dr. David P. Tuttle

* Most Complex PEV-Grid Interaction

Electric Vehicle V2L, V2H/V2B, V2P *Microgrids*

Off-Grid Capabilities to Provide Power to Individual Loads, Homes, or Premise

Vehicle-to-Load (V2L)

Power*To* Vehicle via PEV Charge Port,
Power Receptacles provide *ePTO output*

No PEV-Grid or Load Communications Capability Required

Standard NEMA 5-20R/120V, NEMA L14-30R/240V Receptacles for loads (Similar to a Generator)

Source: Ford

Power Tools,
Emergency Communications
TVs, Radios, Sat-Dish
Refrigeration

Vehicle-to-Home (V2H) or Vehicle-to-Building (V2B)

Power flows *To & From* Vehicle Via PEV Charge Port

Home/Premise-PEV Communications via EVSE

One PEV, One Home

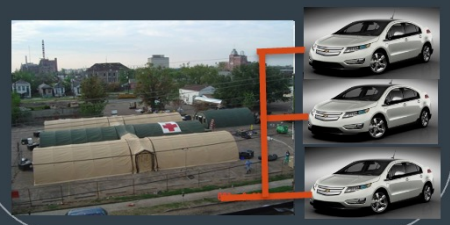
PEV acts as storage and/or Backup Generator for single Home

Source: GM

Vehicle-to-Premise (V2P)

Two+ PEVs, 1+ Buildings

PEVs acts as storage and/or Backup Generator for Premise



Dr. David P. Tuttle

Summary

Increasing Responsive Demand is essential: V1G/Intelligent Charging + other DR programs

VPPs using DERs should be deployed

EV Batteries are a compelling DER resource

- **Likely see progressively more sophisticated VGI/VPE over time**
- **Need low-cost bidirectional charging infrastructure**
- **Interoperability Standards**
- **Auto Manufacturers Experience & Comfort with battery cycling wear**
- **Utility/ISO tariff structure and market rules**
- ***Integration with Utility SCADA and Billing Systems for V2G***
- **Expect focused deployments based upon economics & policy**
- **We need to appreciate the sophistication of the business & profit models**