Renewable Energy – Long Term Vision and Opportunities for Hydrogen Storage at Scale

NREL H2@Scale Workshop, Golden Colorado November 2016

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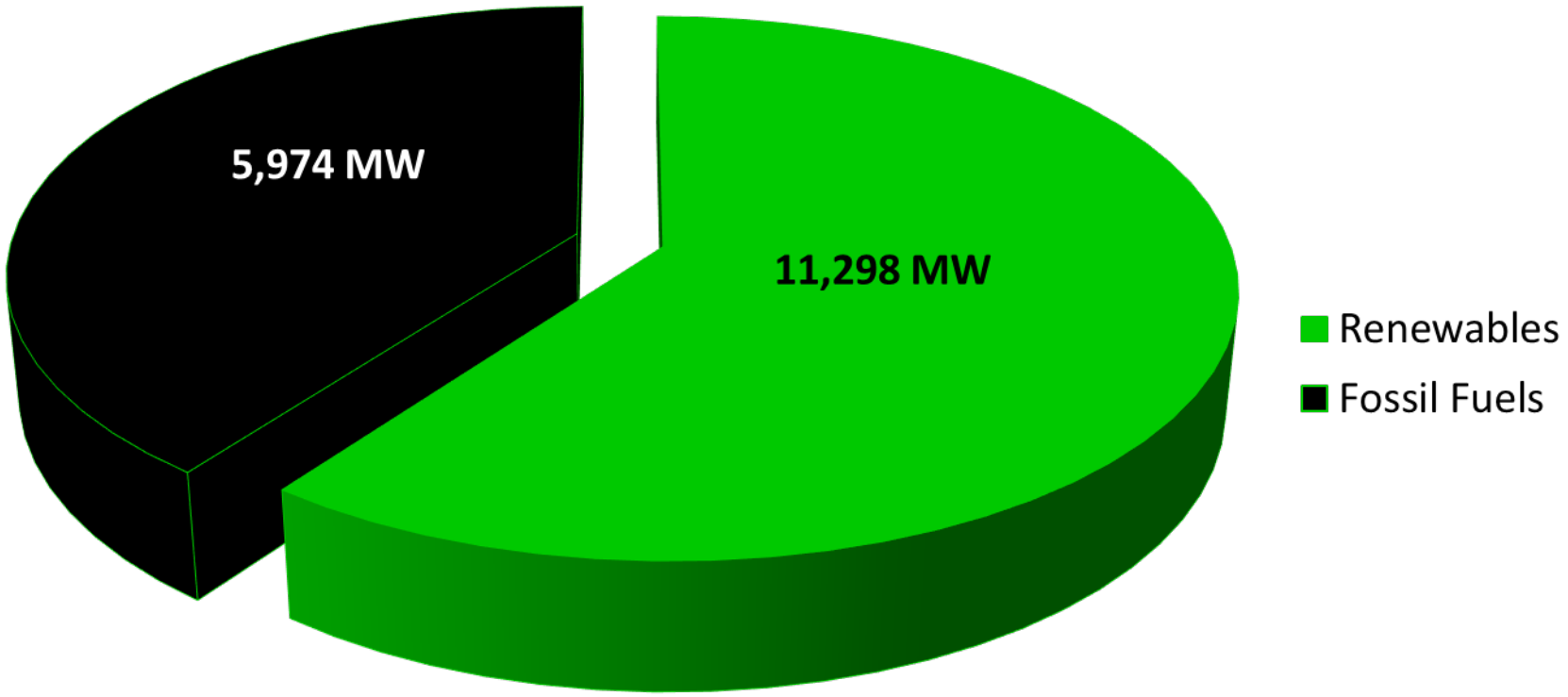
Founder Renewables 100 Policy Institute

Top Trends Transforming U.S. Electricity Sector

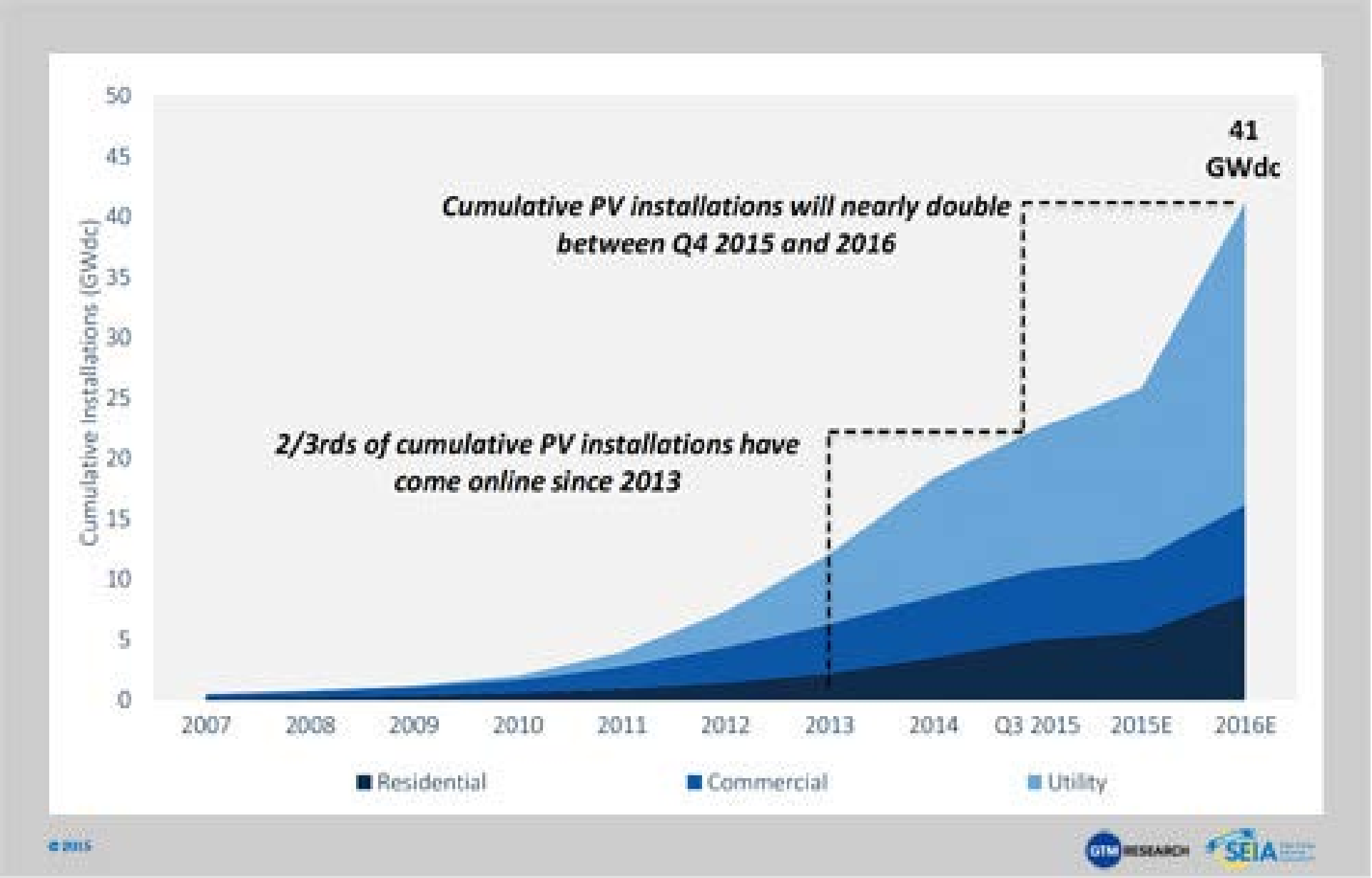
- Coal power in decline
- Natural gas growing fast (bridge fuel)
- Renewables reaching grid parity
- Utilities face growing load defection
- Utilities getting in on solar (utility-scale, commercial and maybe rooftop)
- Continuing debates over rate design reforms
- Utilities modernizing the grid
- Utilities buying into storage
- Utilities becoming more customer-centric (prosumers are emerging)
- Utility business models are changing

Renewable Energy Represented 65% of New US Electric Generation Capacity in 2015

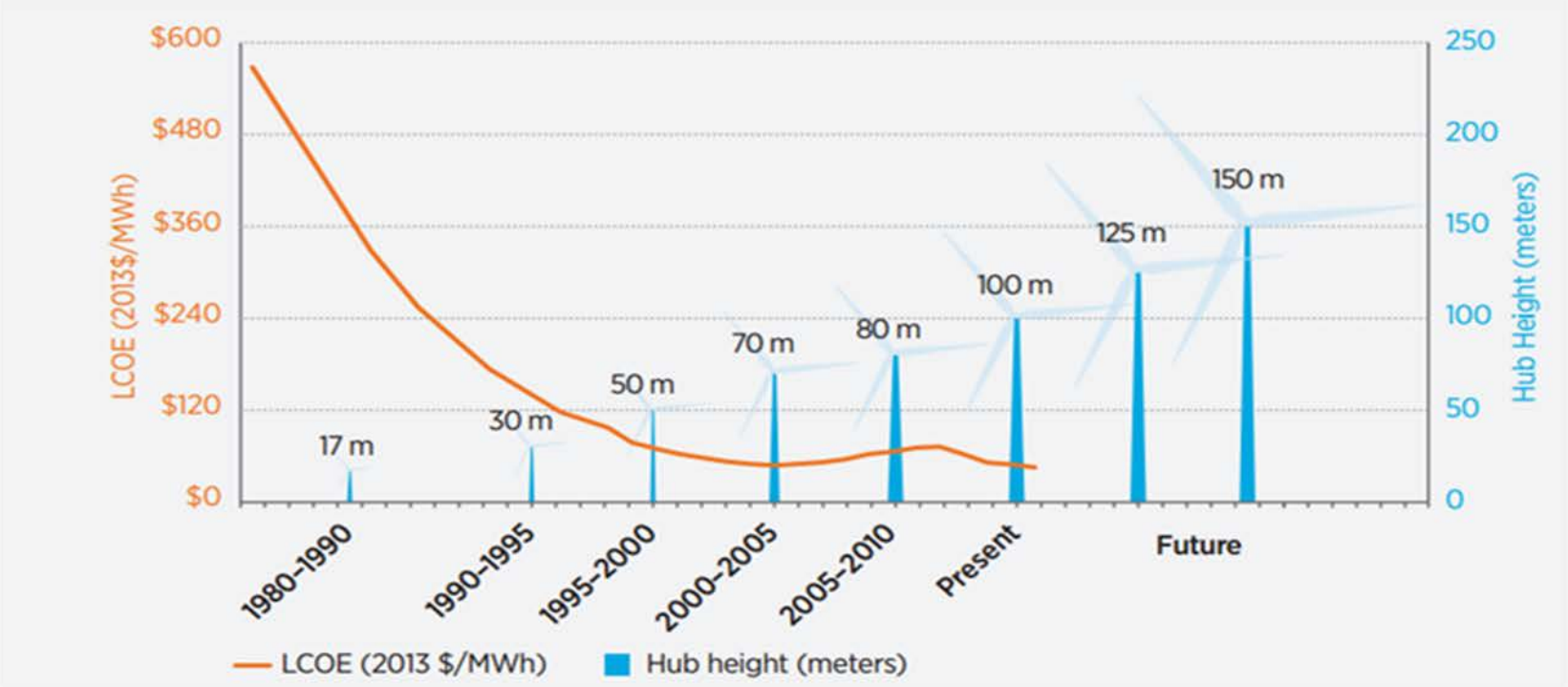


Source: FERC Energy Infrastructure Update, January-December 2015

U.S. PV Installed Capacity, 2007-2016

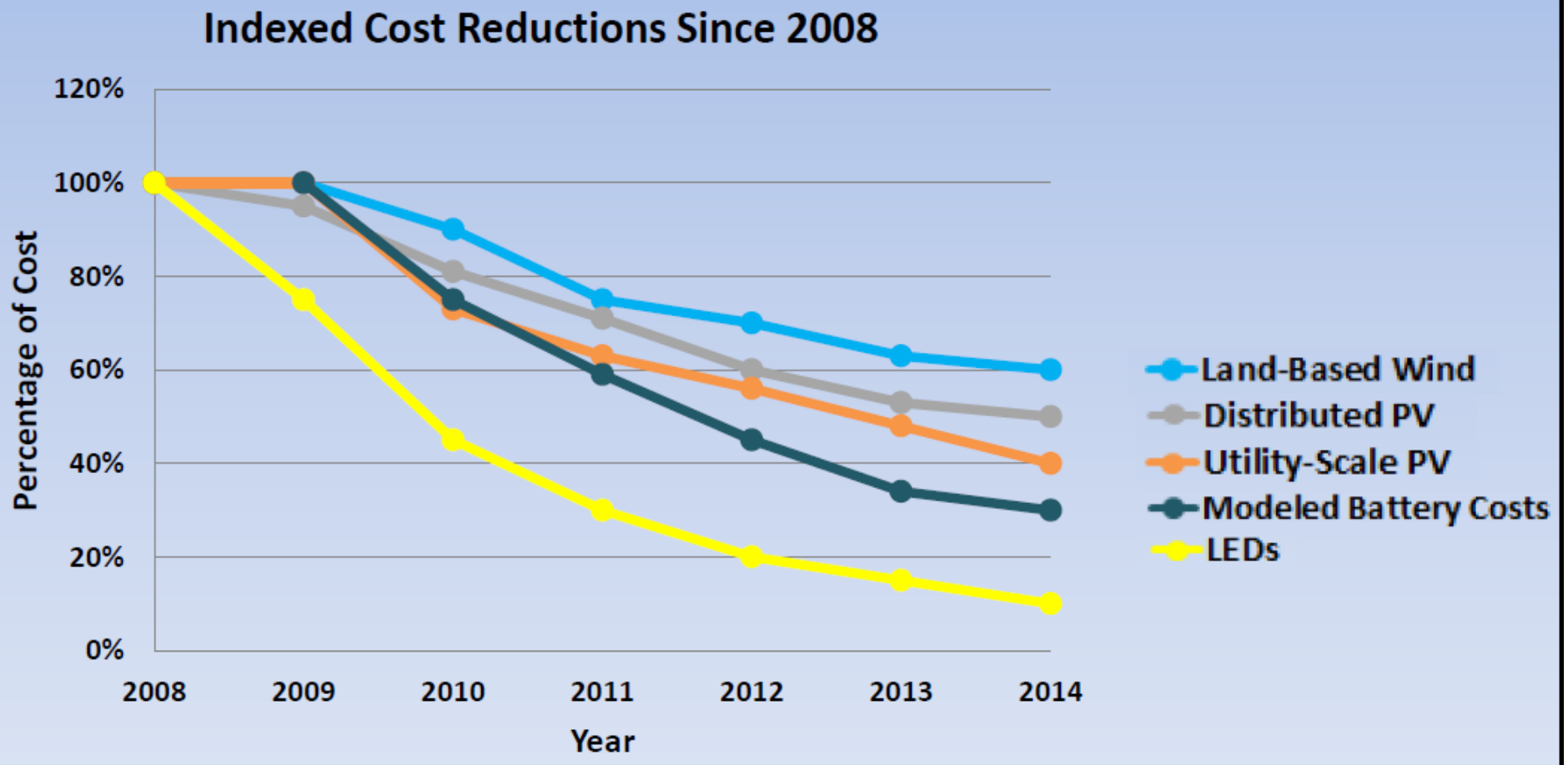


Falling Cost of Wind Energy

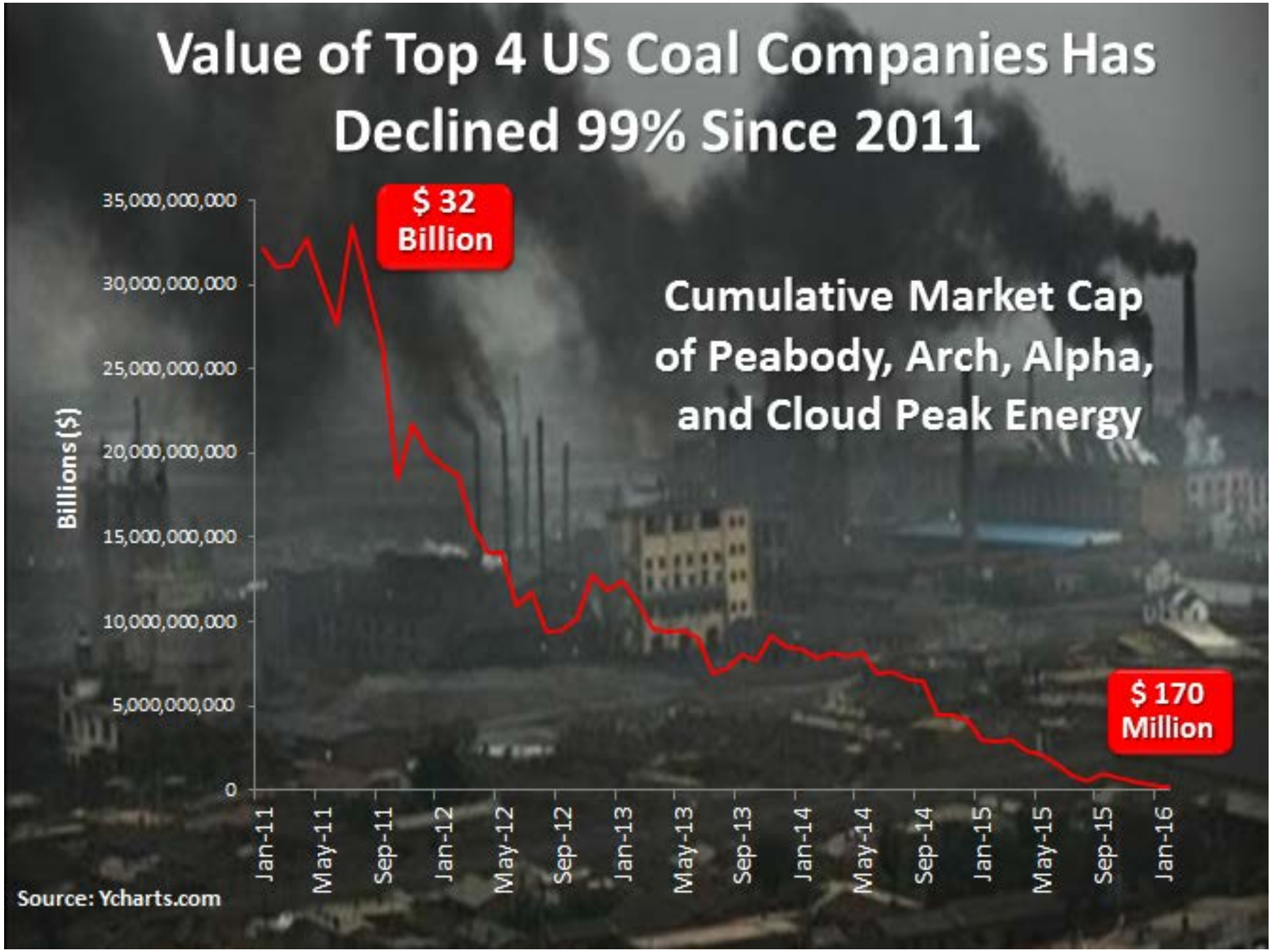


- Wind costs have fallen by 66% in the last six years (Source: LBNL)
- 2015 DOE *Wind Vision* report shows that with continued cost reductions and turbine technology advancements, wind energy can supply the U.S. with 20 percent of the country's electricity by 2030.

The Falling Cost of Clean Energy Technologies



Source: DOE Report, Revolution Now, The Future Arrives for Five Clean Energy Technologies, 2015


Value of Top 4 US Coal Companies Has Declined 99% Since 2011
$ 32 Billion
Cumulative Market Cap of Peabody, Arch, Alpha, and Cloud Peak Energy
$ 170 Million
Billions ($)
35,000,000,000
30,000,000,000
25,000,000,000
20,000,000,000
15,000,000,000
10,000,000,000
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0
Jan-11
May-11
Sep-11
Jan-12
May-12
Sep-12
Jan-13
May-13
Sep-13
Jan-14
May-14
Sep-14
Jan-15
May-15
Sep-15
Jan-16
Source: Ycharts.com

PEABODY FILES FOR BANKRUPTCY, APRIL 2016 COAL FUTURES NOT SO BRIGHT

James River Coal Company

Alpha Natural Resources

We fuel progress around the world.®

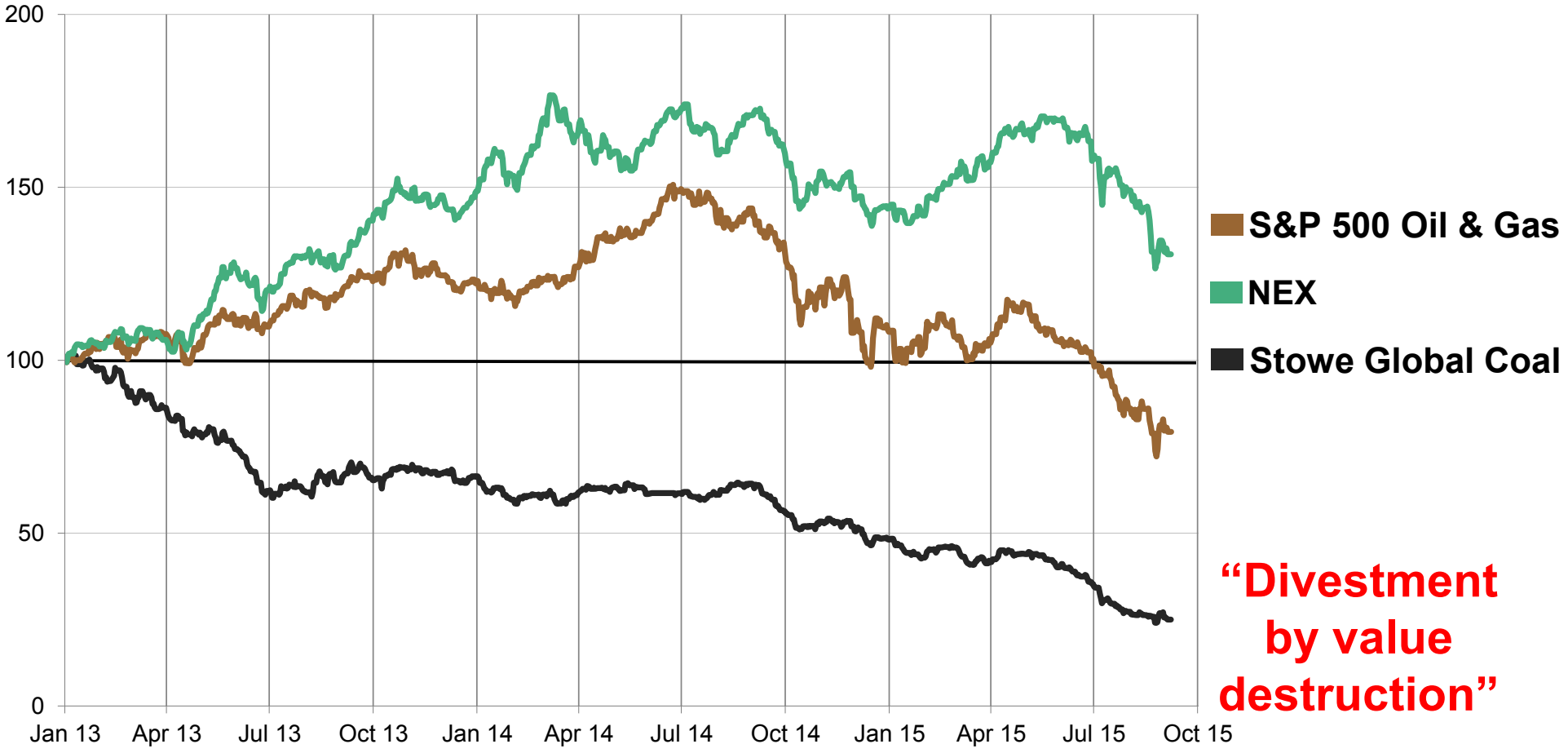
WALTER ENERGY®

BUMI Investment Pte

PATRIOT COAL

Image: various company sources

NEX clean energy index 2013 – 2015 ytd

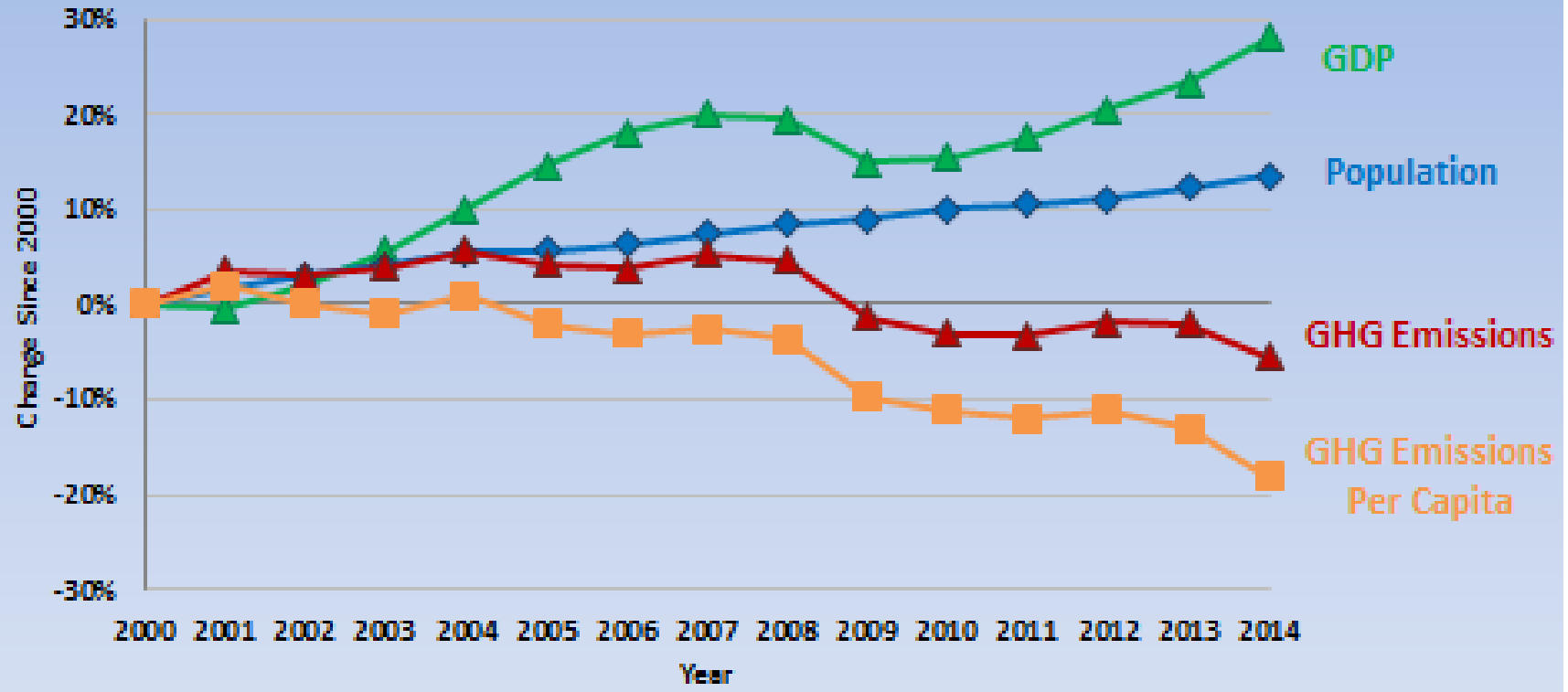


"Divestment by value destruction"

Note: Values as of 08 September 2015; Stowe and S&P 500 rebased to 100 on 01 Jan 2013

Source: Bloomberg New Energy Finance

Since 2001, California's GDP Has Grown by 28% While Emissions Have Fallen by 8%



Metric	Associated 2014 Value
GDP	2.31 trillion
Population	38.7 million
GHG Emissions	441.5 MMTCO_2e
GHG Emissions Per Capita	11.4 metric tons CO_2e per person

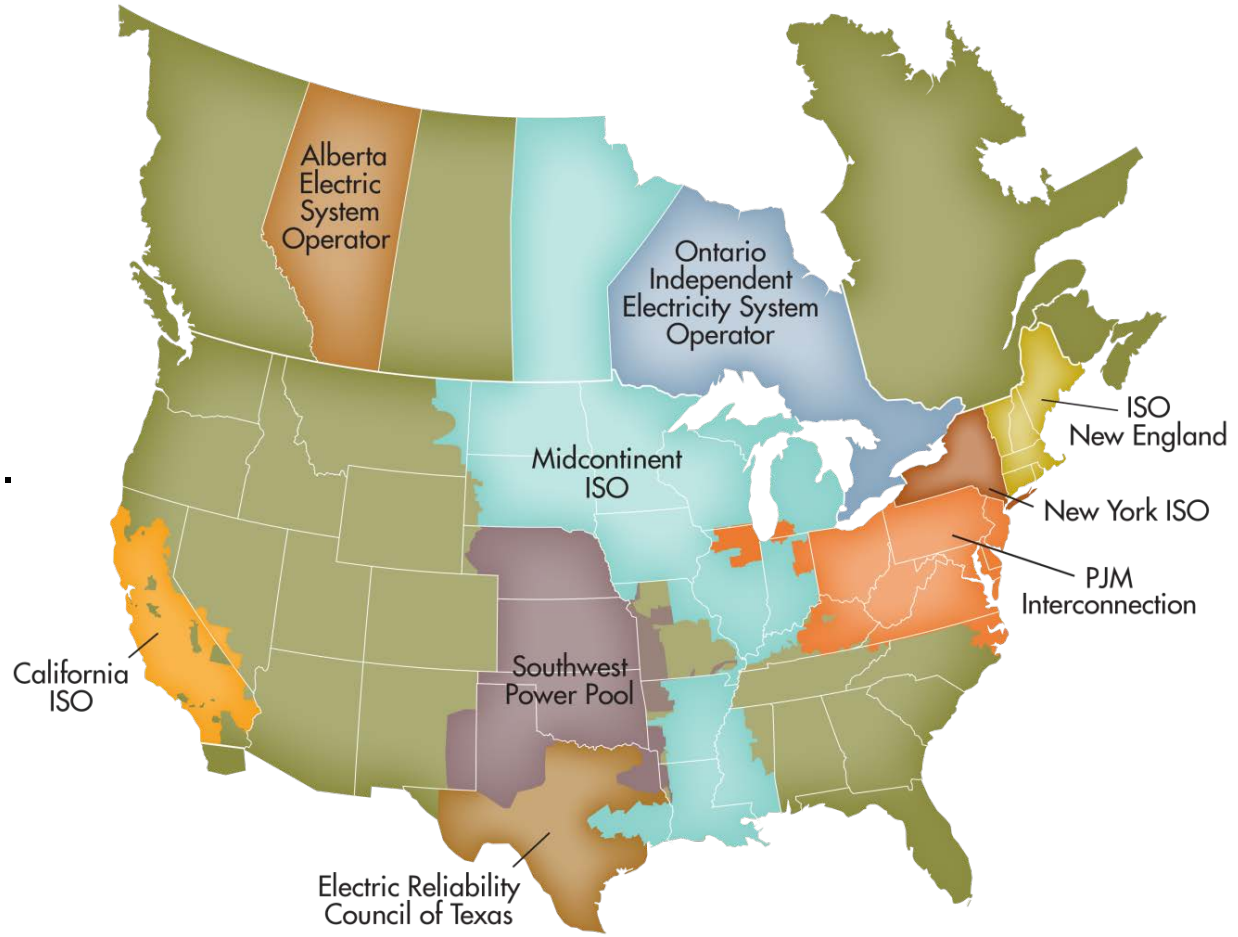
Source: *CA Air Resources Board*

SB 350: Clean Energy and Pollution Reduction Act of 2015

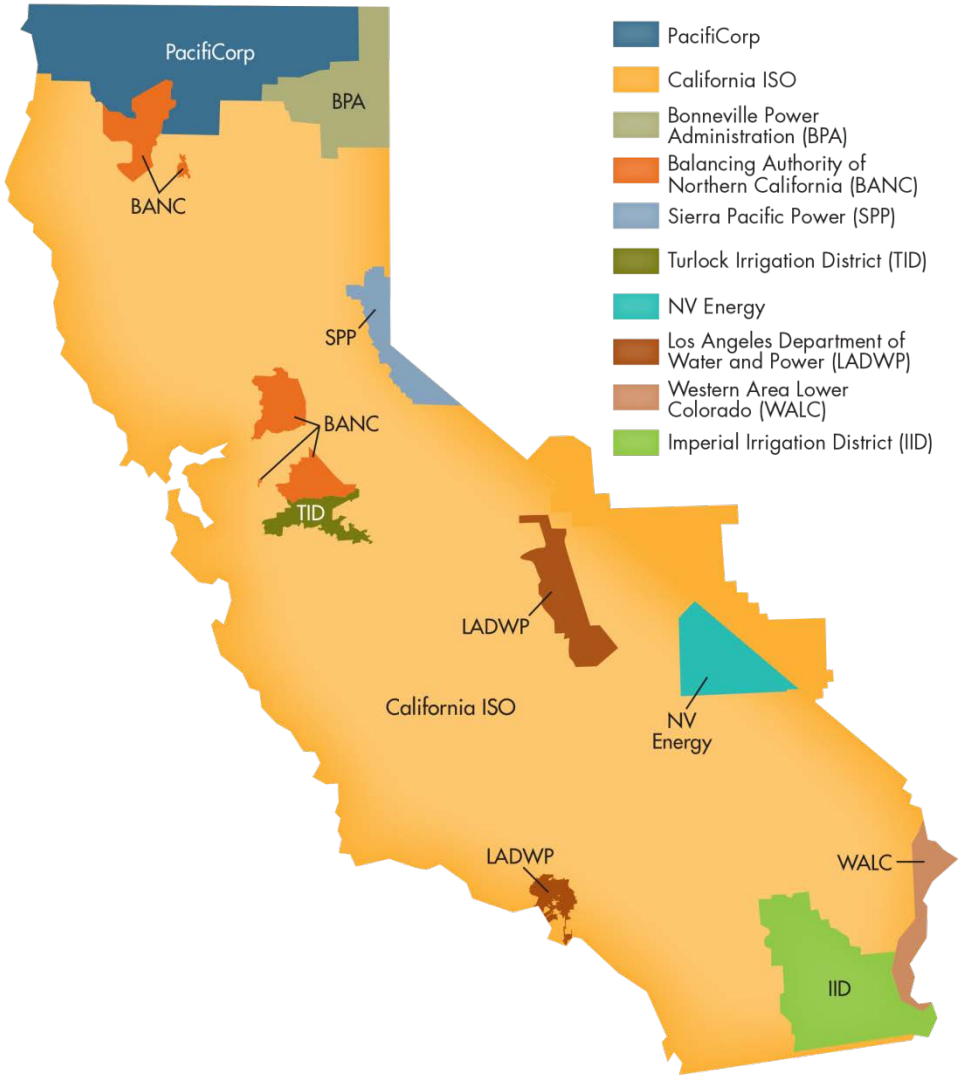
- Increase Renewable Portfolio Standard from 33% to 50% by 2030
- Double energy efficiency in buildings
- Encourage increased investments in transportation electrification, including charging infrastructure
- Begin transition for the California ISO to become a multi-state western regional transmission organization

The California ISO Posed to Play a Major Role

One of nine grid operators in North America.



ISO by the Numbers



- **Serves 30,000,000 Californians**
- **80% of state**
- **26,000 wire-miles**
- **65,000 MW system**

CAISO's Role

- Maintain reliability
- **Implement State policy**
- Operate wholesale market

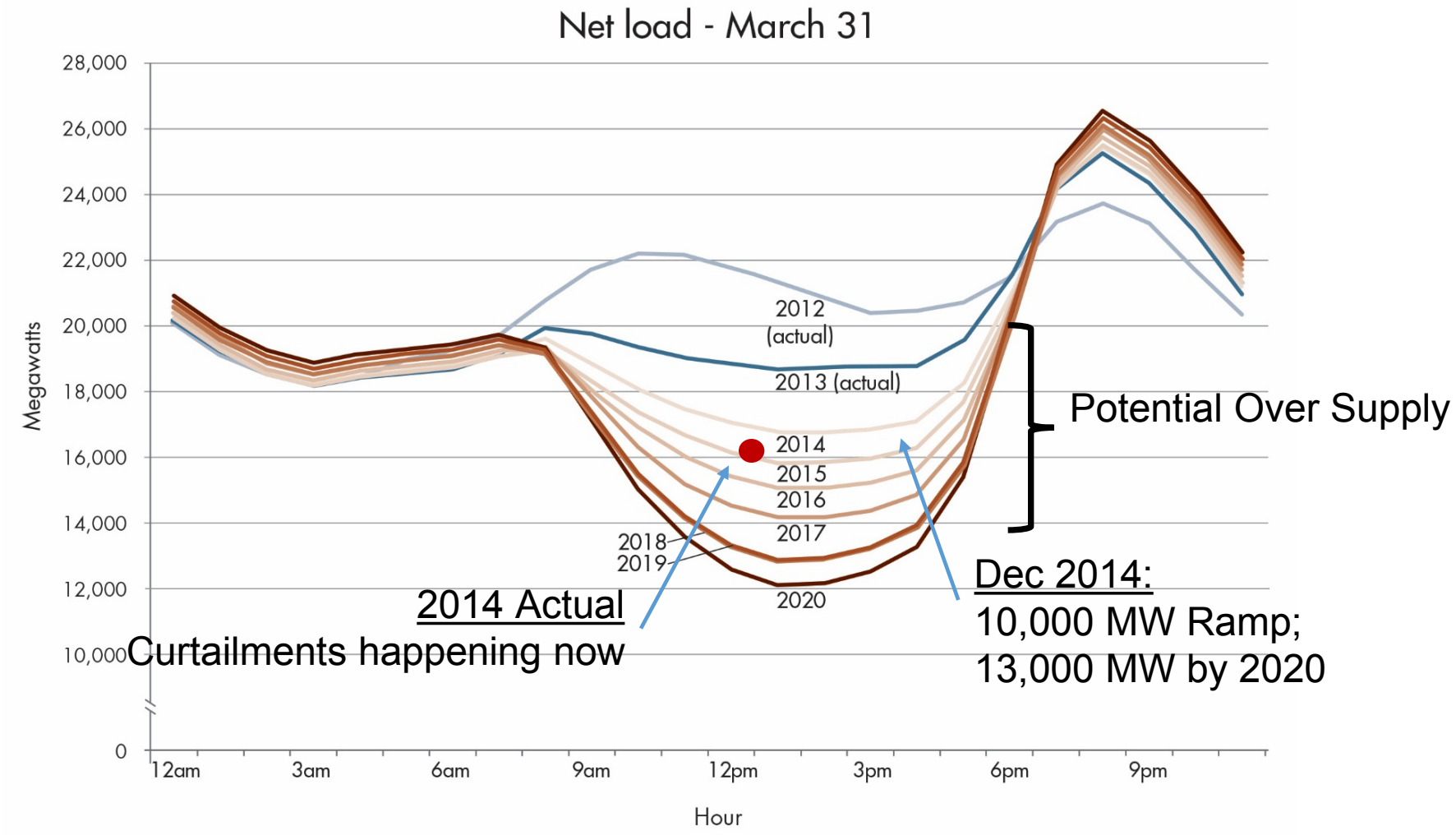
- Plan for system expansion
- Interconnect resources

Coordinate with Many Masters

- Governor's Office
- CEC
- CPUC
- ARB
- FERC
- WECC Compliant

Over Supply and Ramping

Significant Challenge for Grid Operators



Implications of “Duck” Chart

- Net load = hourly demand minus wind and solar
- Midday net load drops 22,000 MW ➔ 12,000 MW
  - Solar pushes gas off the system in the middle of the day

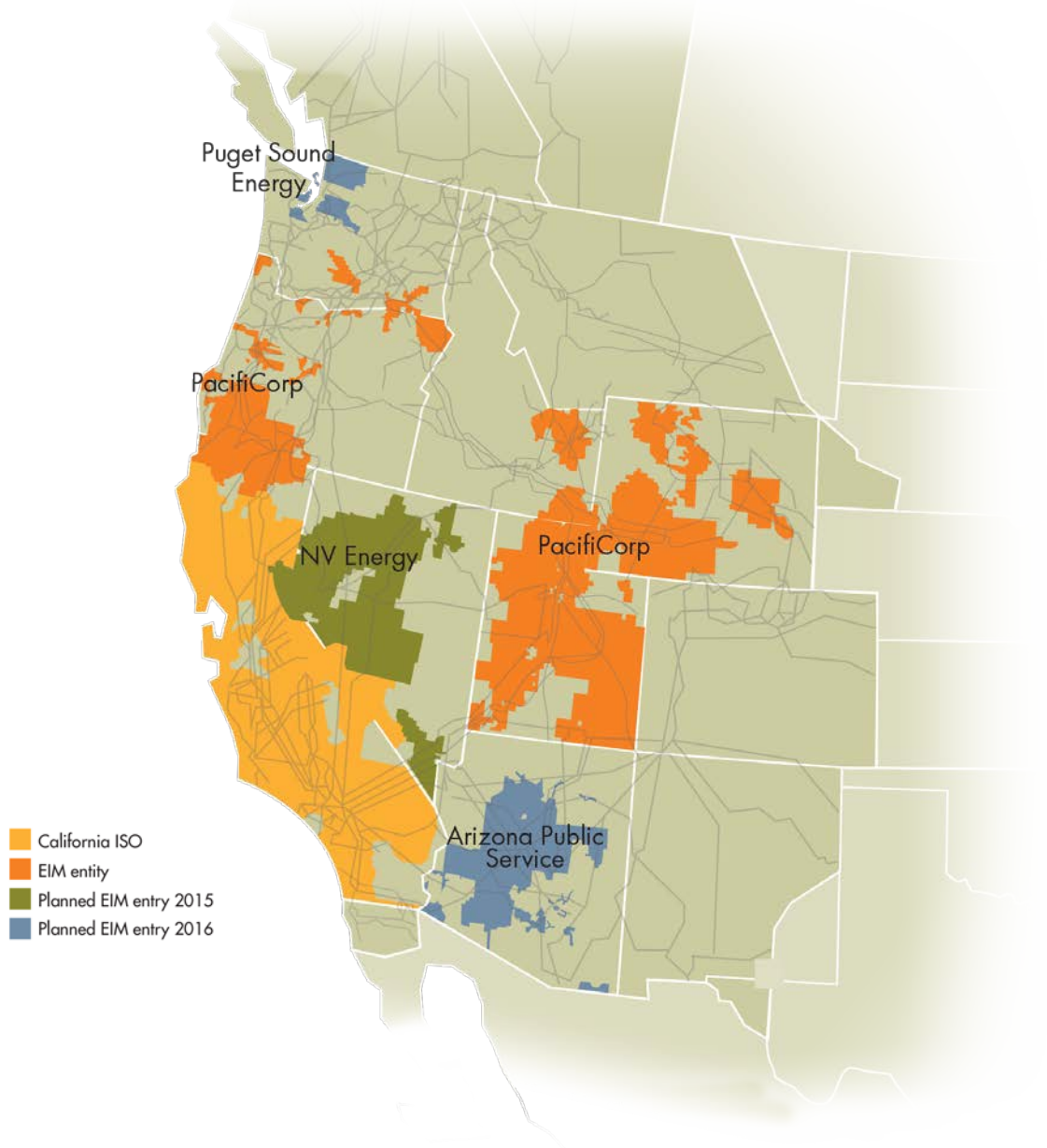
Peak power not 2-5 pm but 6-8 pm; solar at zero

- Presents operational challenges
- Underscores need for flexible generation solutions, gas, customer and utility scale storage solutions that can respond quickly to system needs
  - Steep ramps – as much as 13,000 MW in 3 hours by 2020
  - Multiple ramps per day

Regional Collaboration is helps to manage surplus power

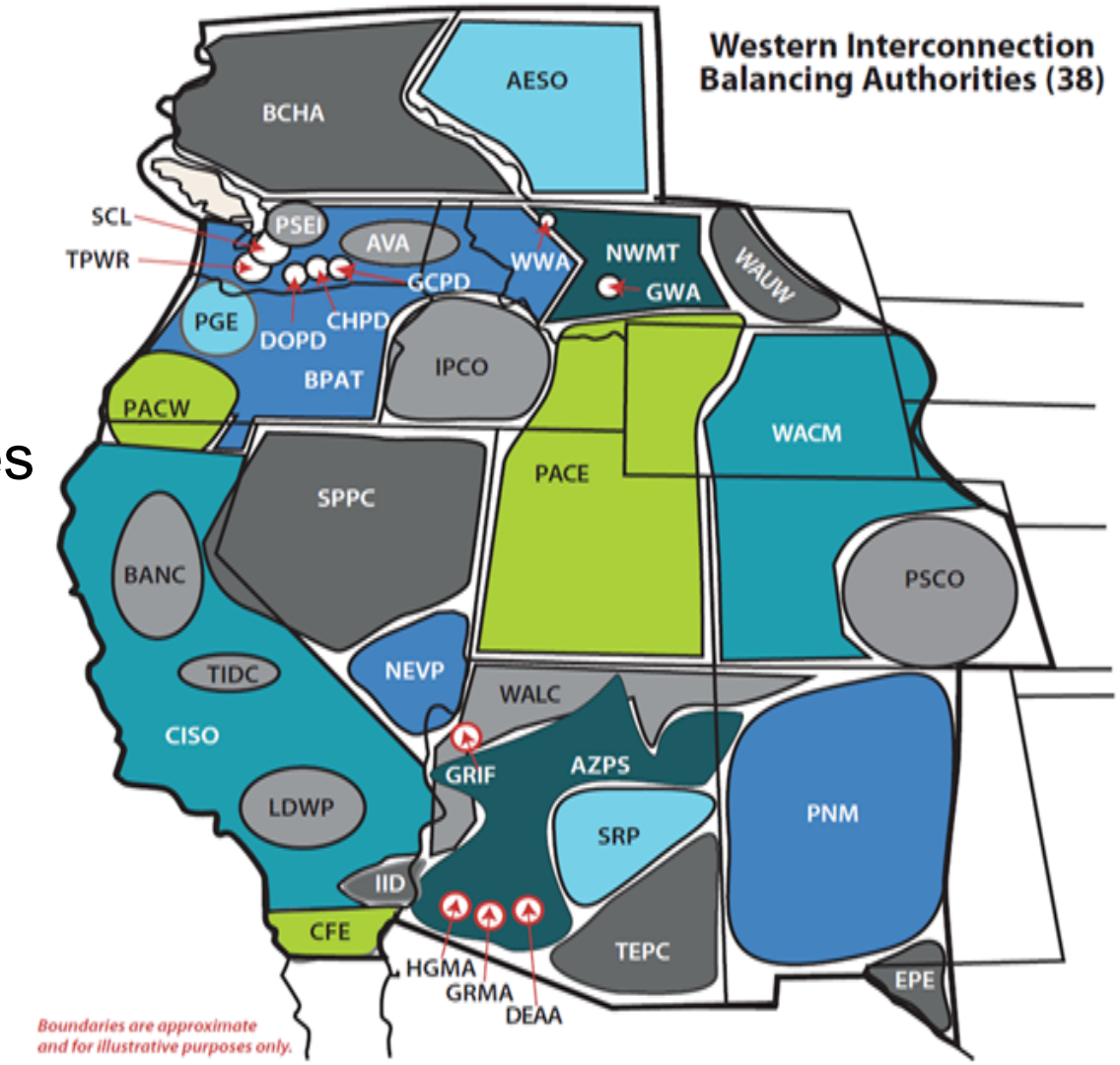
Energy Imbalance Market

- ✓ 5 minute market
- ✓ Regionally diverse fleet
- ✓ Optimize existing assets
- ✓ New governance model



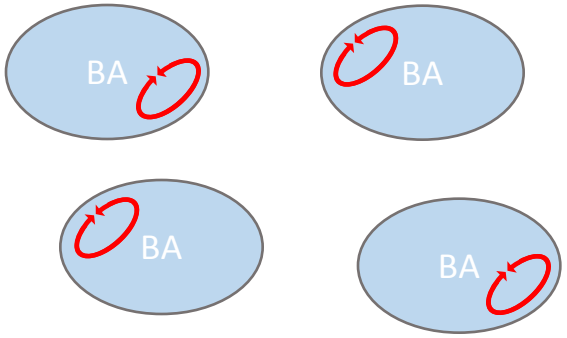
A balancing authority (BA) is responsible for operating a transmission control area.

- Each matches generation with load and maintains electric frequency of the grid
- 38 balancing authorities in the western interconnection
- Today, each BA balances load and generation separately from other BAs



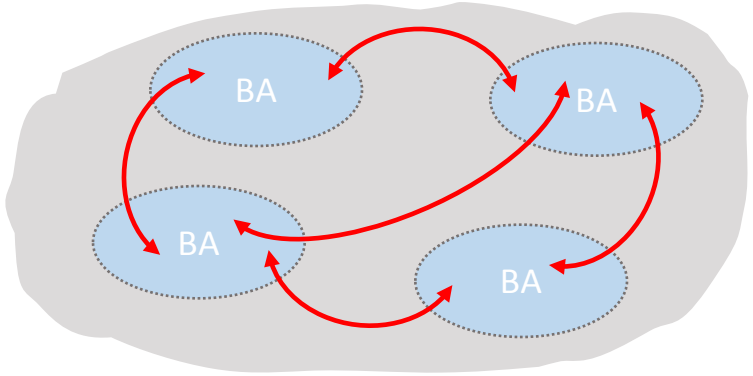
Today vs. EIM

Today:
Each BA must balance loads and resources w/in its borders.



- Limited pool of balancing resources
- Inflexibility
- High levels of reserves
- Economic inefficiencies
- Increased costs to integrate wind/solar

In an EIM:
The market dispatches resources across BAs to balance energy



- Diversity of balancing resources
- Increased flexibility
- Decreased flexible reserves
- More economically efficient
- Decreased integration costs

Gross economic benefits since start of EIM = $114.36M

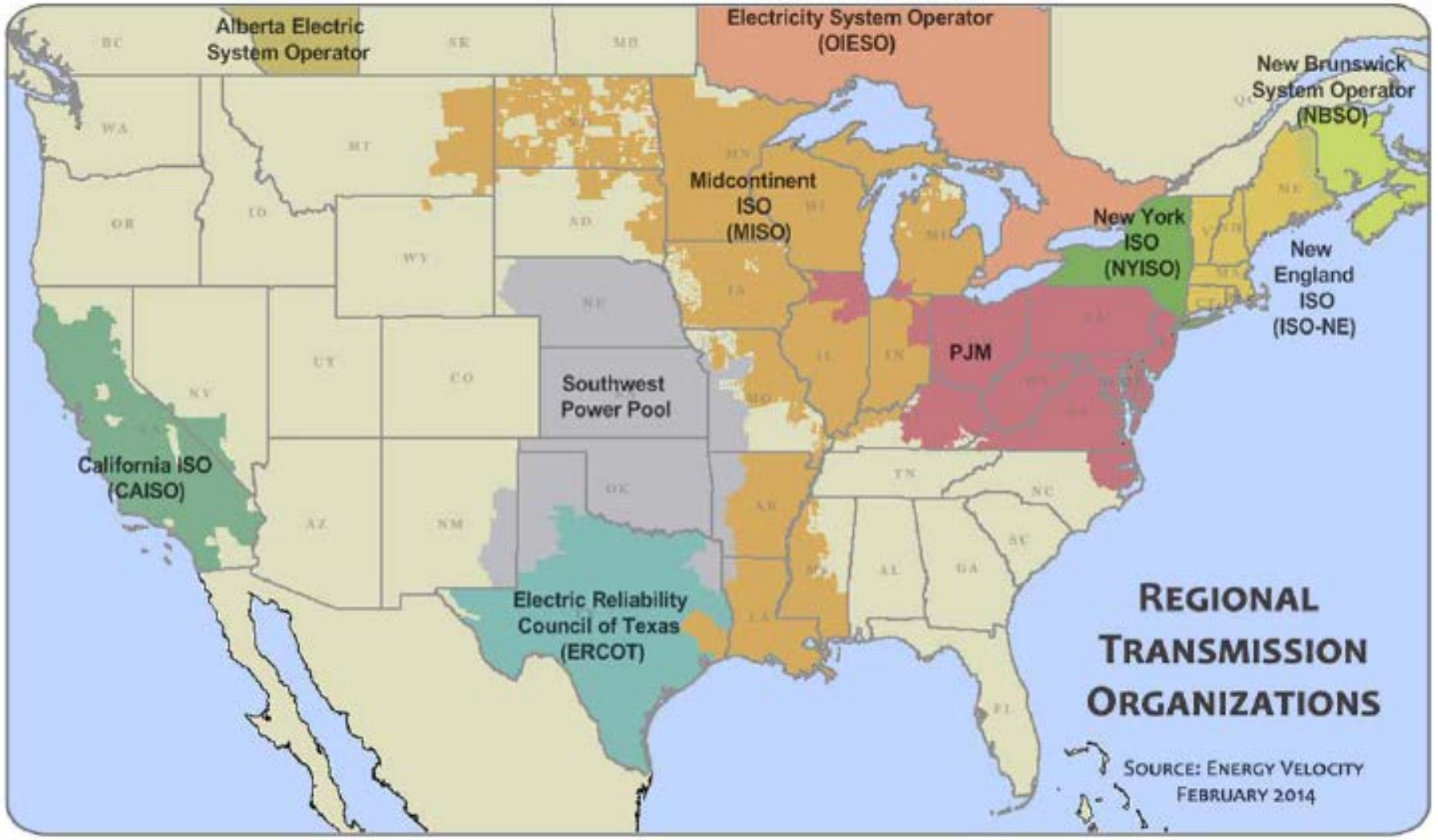
BAA	4th Qtr 2014	1st Qtr 2015	2nd Qtr 2015	3rd Qtr 2015	4th Qtr 2015	1st Qtr 2016	2nd Qtr 2016	3rd Qtr 2016	Total
CAISO	1.24	1.44	2.46	3.48	5.28	6.35	7.89	5.44	33.58
NVE	-	-	-	-	0.84	1.70	5.20	5.60	13.34
PAC	4.73	3.82	7.72	8.52	6.17	10.85	10.51	15.12	67.44
Total	5.97	5.26	10.18	12.00	12.29	18.90	23.60	26.16	114.36

BAA	July	August	September	Q3 – 2016 Total
CAISO	2.24	1.38	1.82	5.44
NVE	1.88	2.16	1.55	5.60
PAC	6.09	4.92	4.12	15.12
Total	10.21	8.46	7.49	26.16

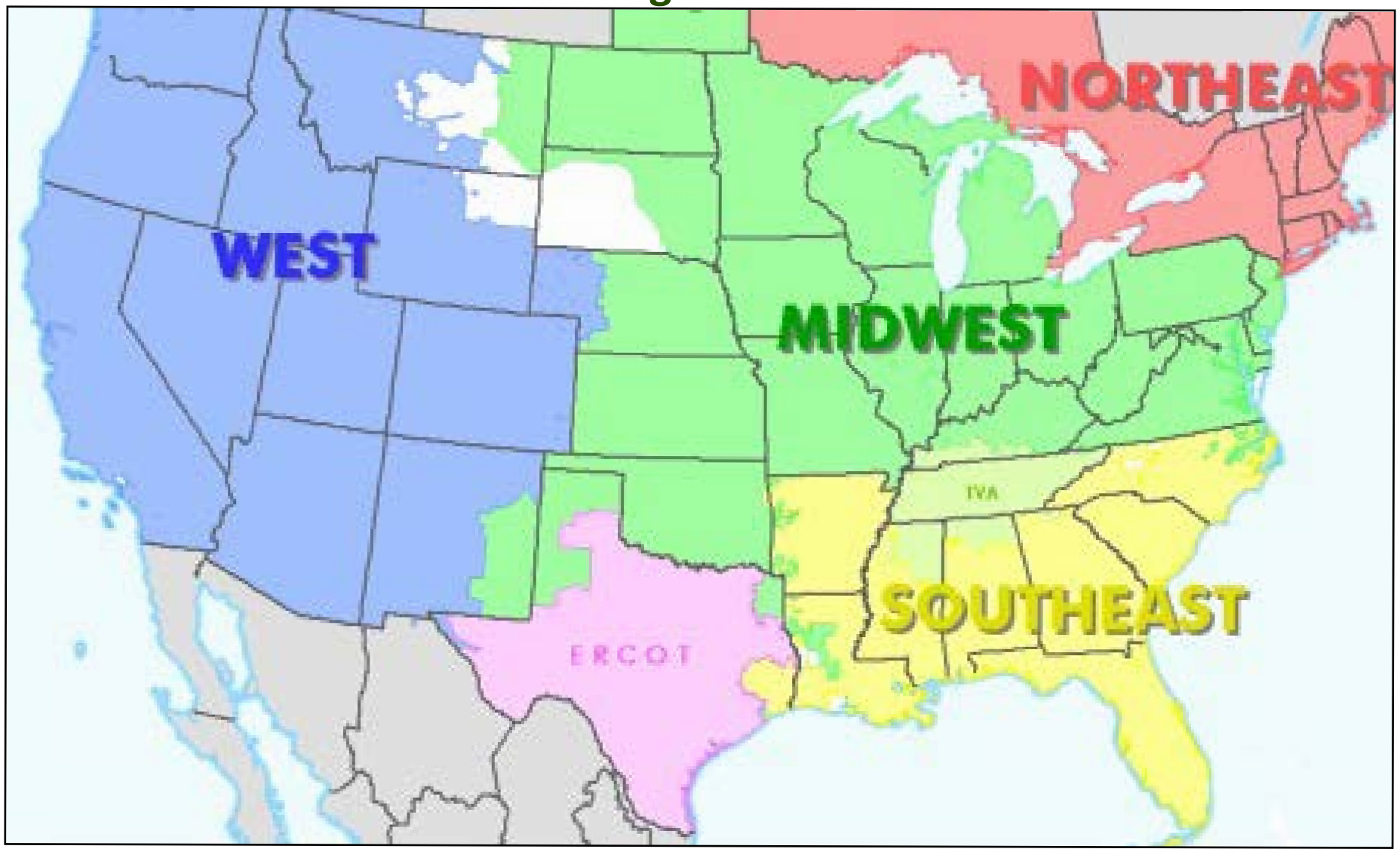
Avoided curtailment of 335,930Mwh of renewables, displacing an estimated 143,695 metric tons of CO2.

Reduced Renewable Curtailment	1st Qtr 2015	2nd Qtr 2015	3rd Qtr 2015	4th Qtr 2015	1st Qtr 2016	2nd Qtr 2016	3rd Qtr 2016	Total To-Date
Mwh curtailment avoided	8,860	3,629	828	17,765	112,948	158,806	33,094	335,930
Estimated metric tons of CO2 displaced	3,792	1,553	354	7,521	48,342	67,969	14,164	143,695

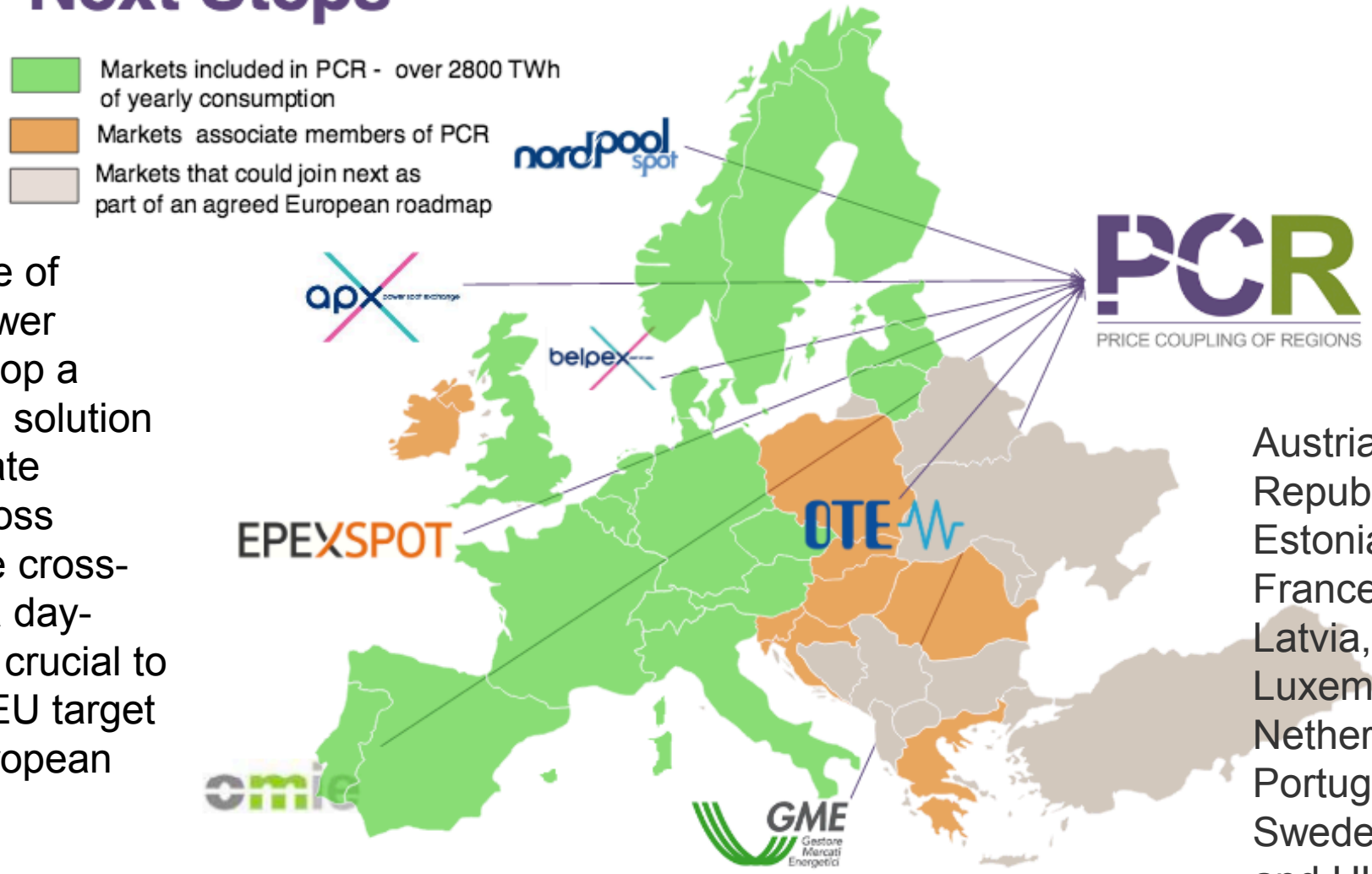
Regional Transmission Organizations



2000 Proposed FERC Wholesale Independent Electric Market Regions



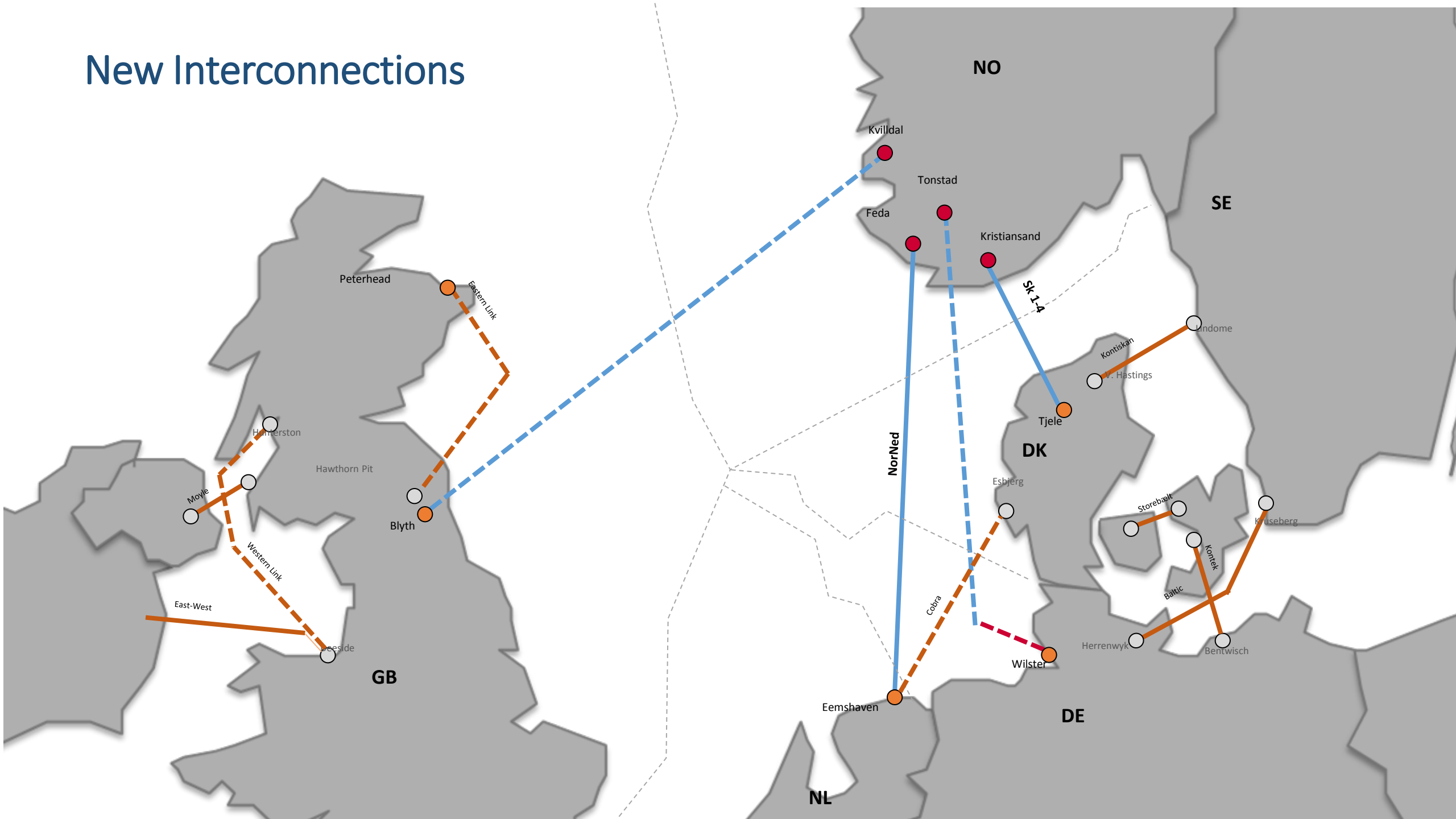
Towards Single European Market: Next Steps



(PCR) is the initiative of seven European Power Exchanges, to develop a single price coupling solution to be used to calculate electricity prices across Europe, and allocate cross-border capacity on a day-ahead basis. This is crucial to achieve the overall EU target of a harmonized European electricity market.

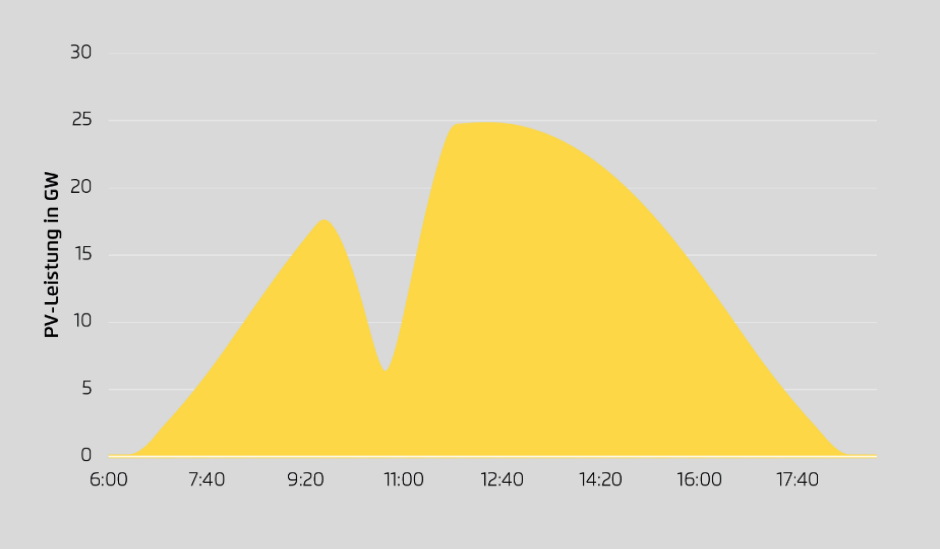
Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and UK.

New Interconnections



Don‘t be (so much)afraid of the duck curve: How Germany coped with the partial solar eclipse in March 2015

Solar power production on March 20, 2015



Agora Energiewende (2015): Die Sonnenfinsternis 2015

Prices and volumes traded on the Intraday market, March 20, 2015

www.epexspot.com

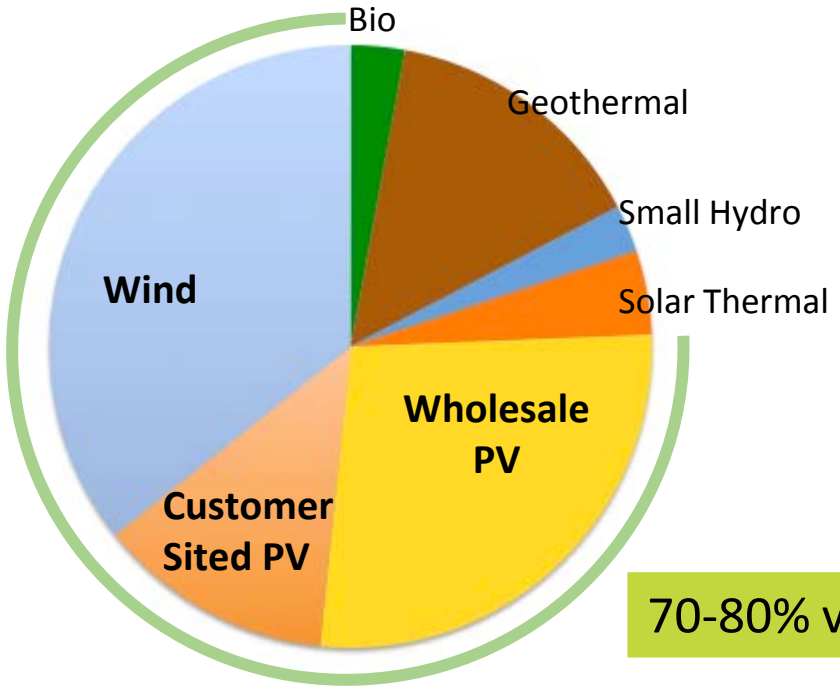
Growth of solar PV and wind connected to the California ISO grid

	2010	2016
Solar PV	85 MW	**7,000 MW PV** **800 MW Thermal** **4,800 MW BTM**
Wind	3,309 MW	**5,865 MW**

50% Renewable penetration will involve substantial Variable Resources

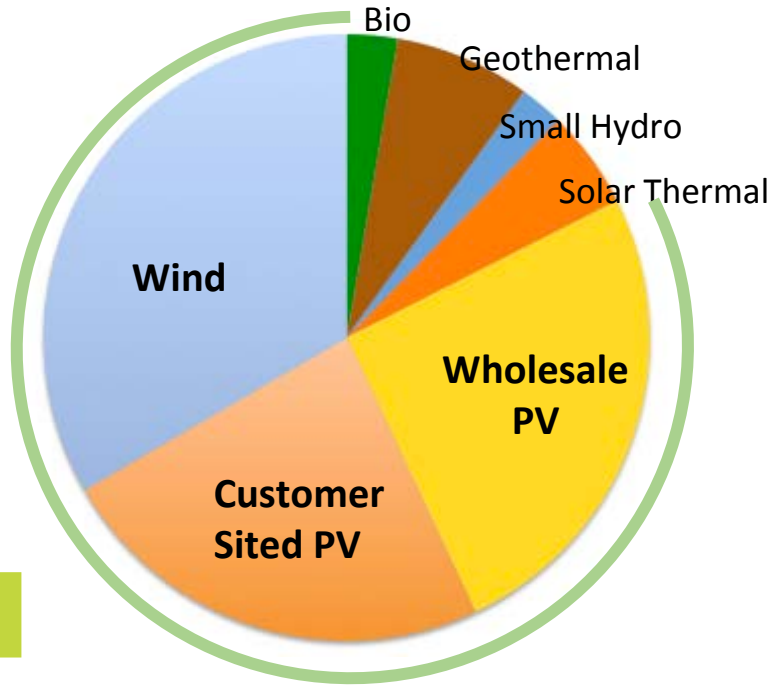
Alternative Renewable Energy Mixes in 2030

E3 PATHWAYS Study



70-80% variable

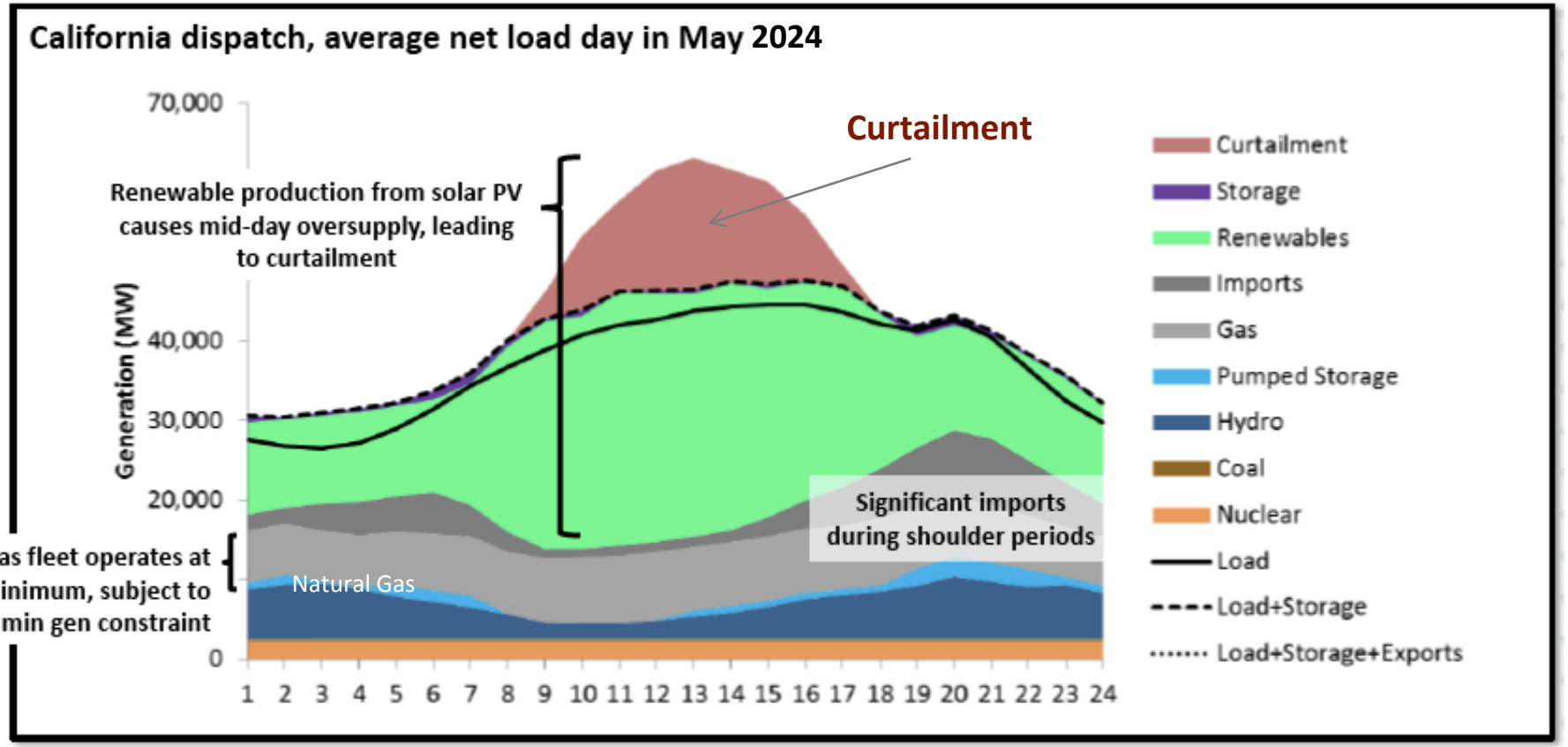
Low Carbon Grid 2030 Study



Source: E3 PATHWAYS Study, 2014
https://ethree.com/documents/E3_PATHWAYS_GHG_Scenarios_UCDavis_CCPM_final.pdf

Source: Low Carbon Grid 2030 Study, 2014: http://lowcarbongrid2030.org/wp-content/uploads/2014/08/LCGS-Phase-I-Results-Summary-Slides.pdf

High renewable penetration may lead to substantial amounts of curtailment



Renewable Penetration: 50%
(% of load)

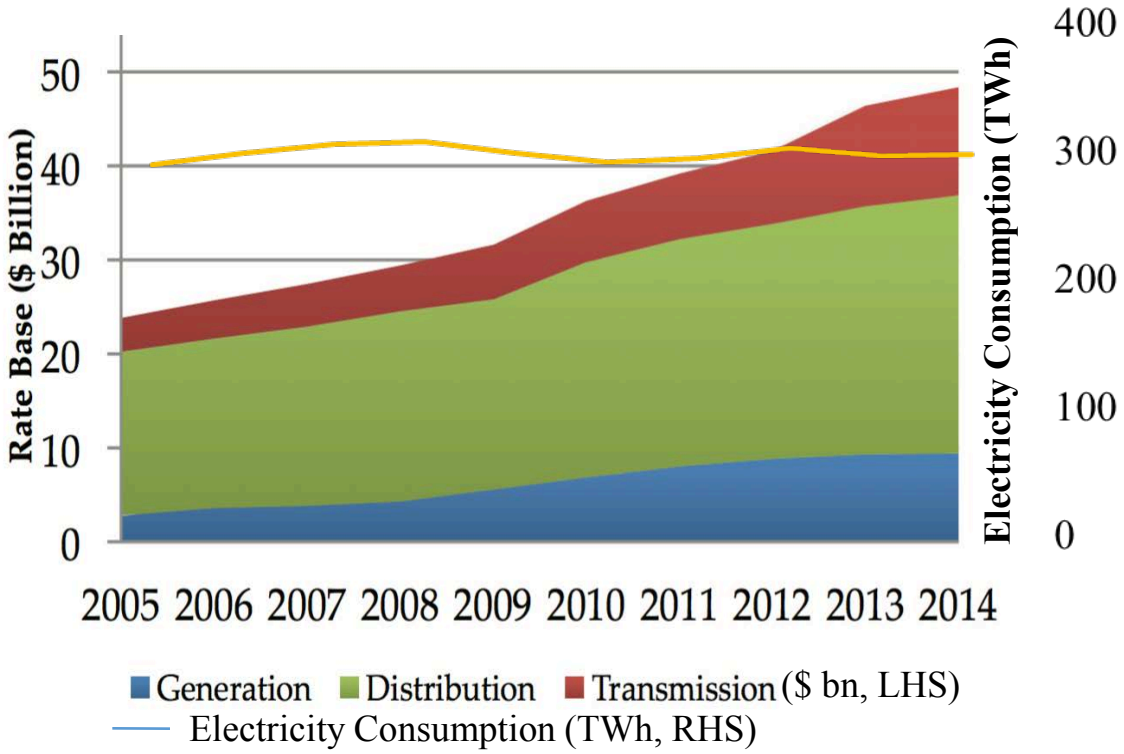
Renewable Curtailment: 8.7%
(% of annual renewables)

Curtailment Frequency: 20%
(% of hours per year)

Source:E3/NREL, Western Interconnection Flexibility Assessment, October 30 2015
http://westernenergyboard.org/wp-content/uploads/2015/10/10-30-15_CREPC-SPSC-WIRAB_schlag-olson_E3_flex_assessment.pdf

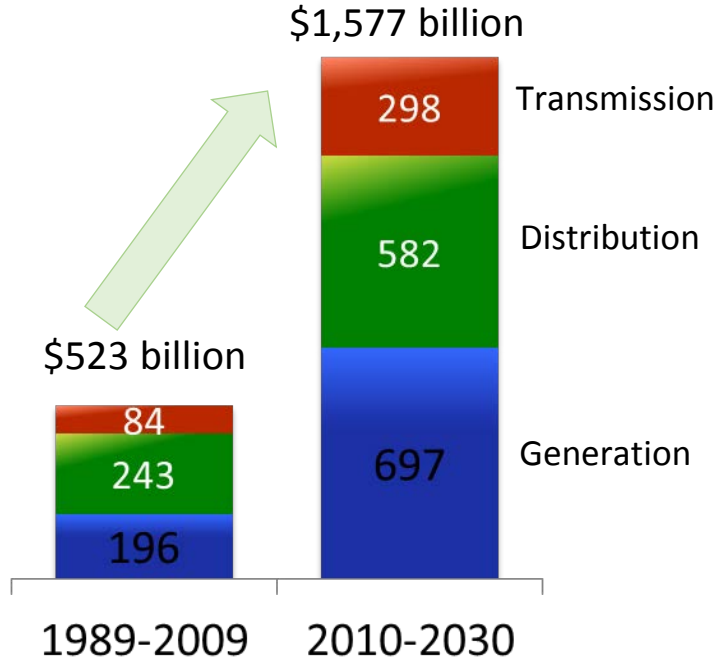
Investment in grid "assets" is expensive and growing

Historical Growth in California Utility Rate Base vs Electricity Consumption



Source: CPUC, Electric and Gas Cost Utility Report, April 2015; California Energy Commission

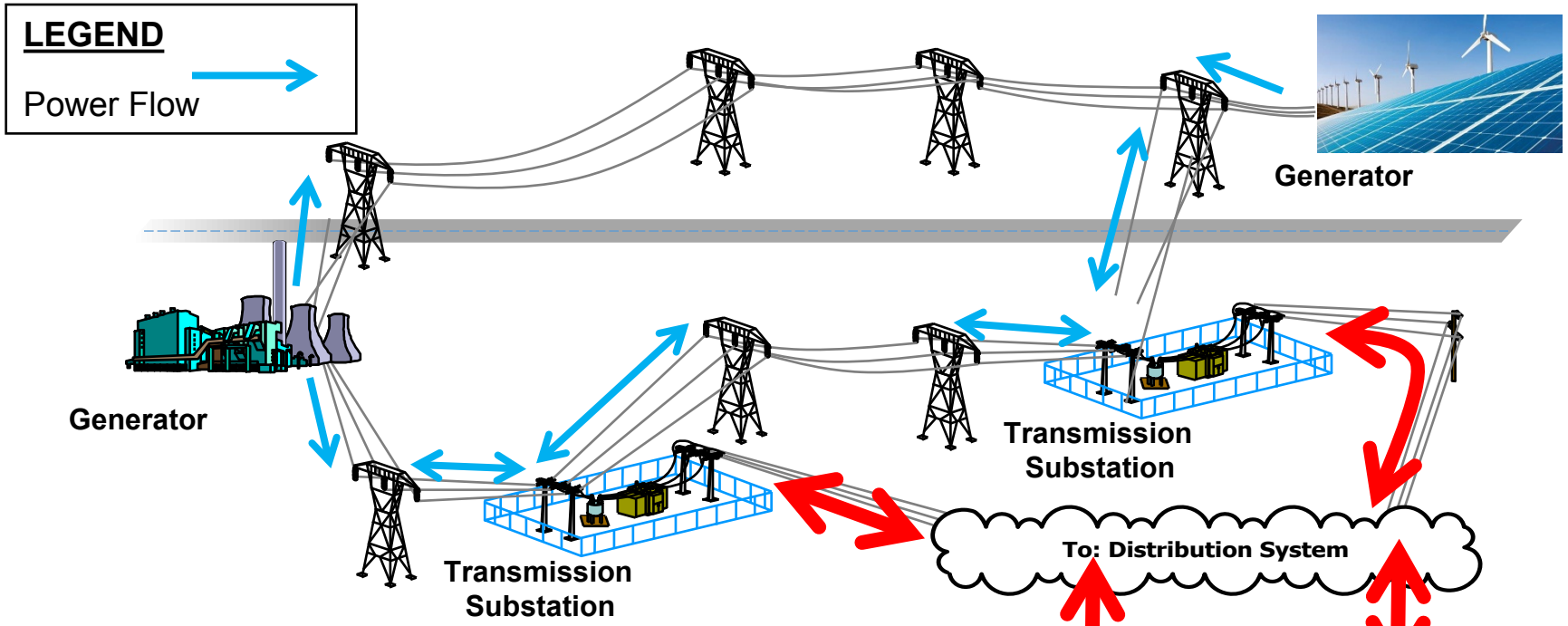
Projected Growth in US Grid Investments



Source: "Transforming America's Power Industry: The Investment Challenge 2010 – 2030", Chupka et al., Brattle for EEI, 2008 http://www.edisonfoundation.net/iei/Documents/Transforming_Americas_Power_Industry.pdf

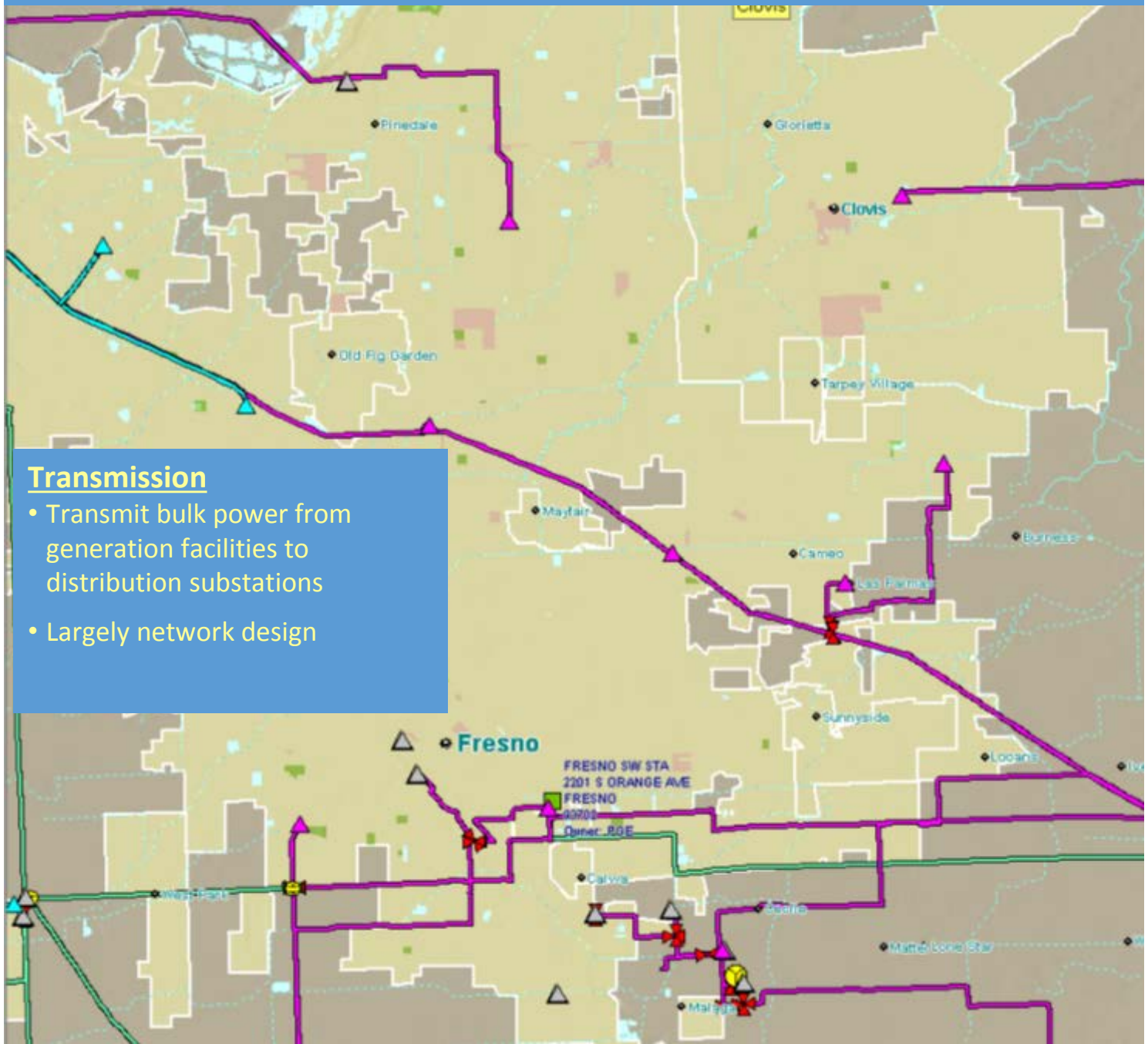
Potential Transmission Power Flow With High Penetration of DER

- Potential for power to flow bi-directional at the Transmission and Distribution Interface
- The current system is not designed or modeled to accommodate this potential bi-directional power flow which may move the system t into unstudied conditions



Potentially hundreds of thousands of injection points from rooftop solar, battery, and other distributed generation resources

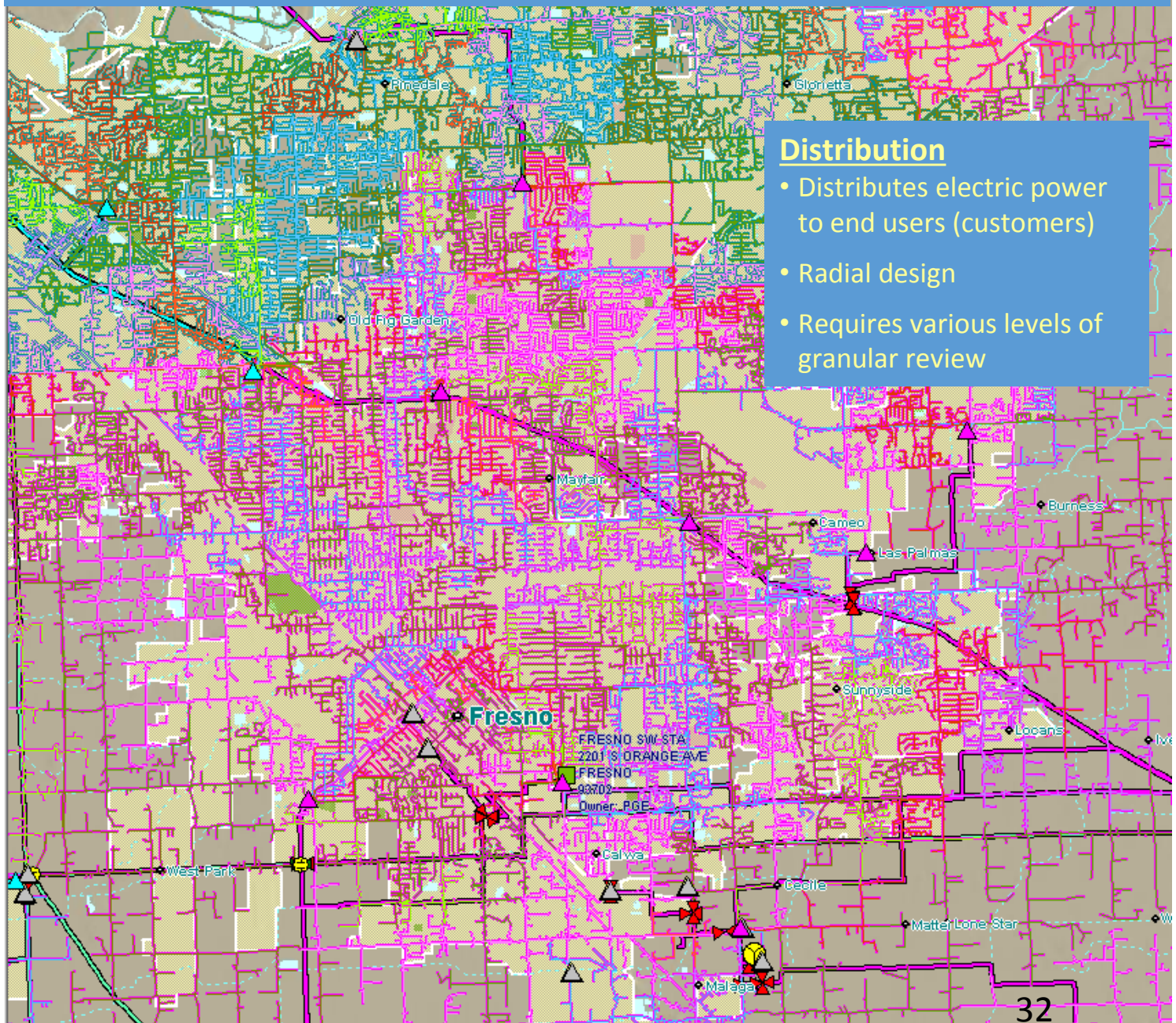
Central Fresno Transmission System



Transmission

- Transmit bulk power from generation facilities to distribution substations
- Largely network design

Central Fresno Transmission and Distribution Systems



Distribution

- Distributes electric power to end users (customers)
- Radial design
- Requires various levels of granular review

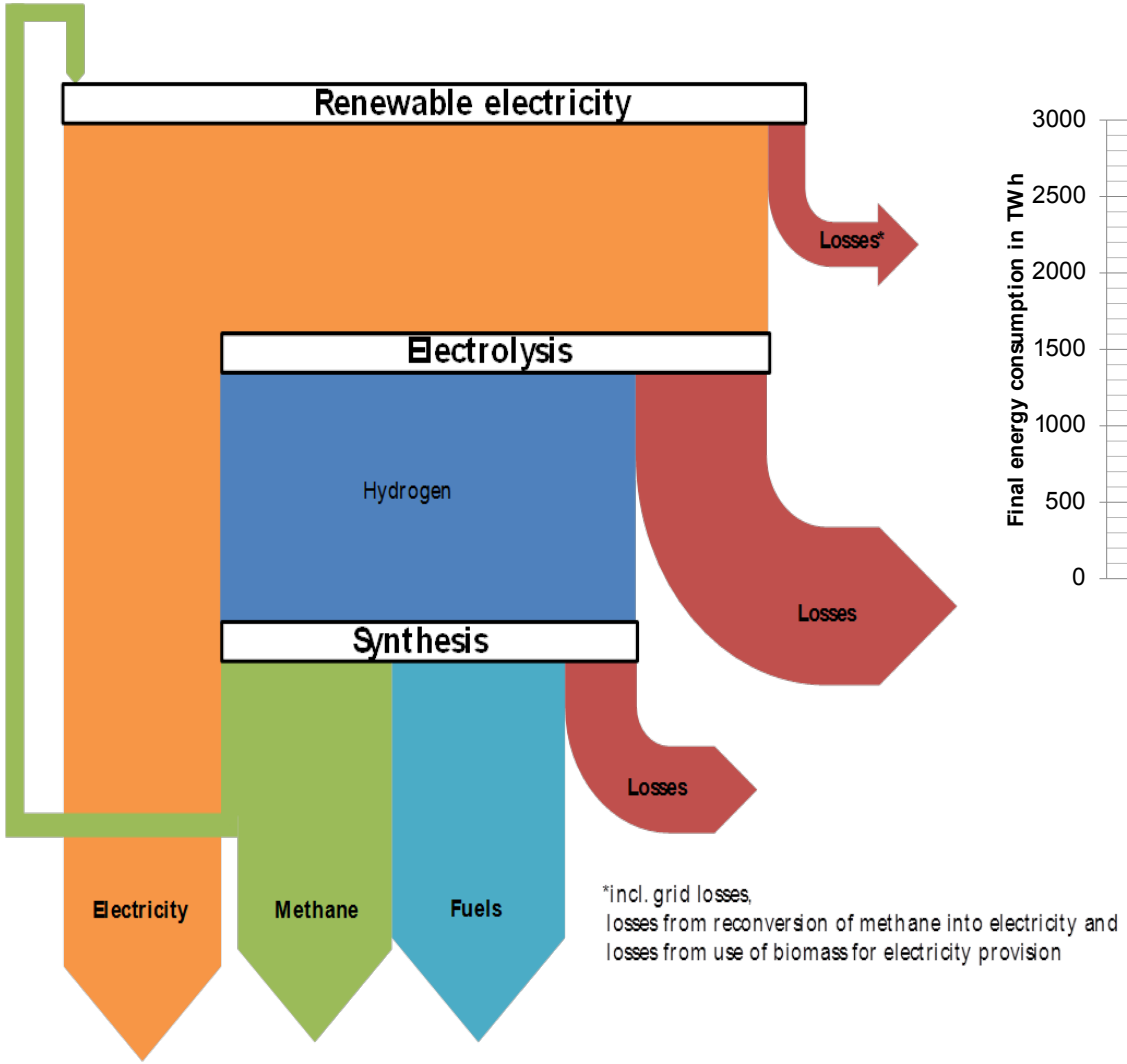
Why the Growing Interest in Hydrogen Solutions?

- Renewable hydrogen production: power-to-gas
- Stationary fuel cells – US and global context
- Fuel cell electric vehicles

Source BNEF

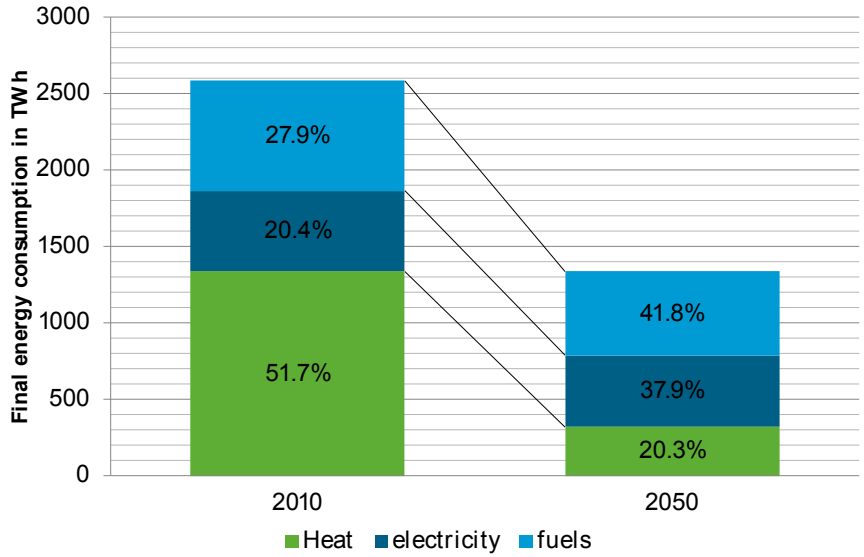
Greenhouse gas neutral Germany in 2050 -- UBA scenario

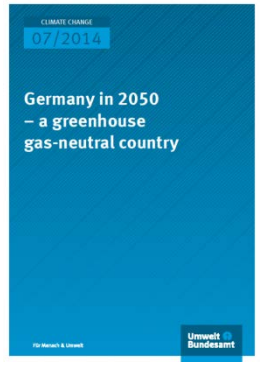
- UBA's scenario is based almost entirely on renewable electricity



*incl. grid losses,
losses from reconversion of methane into electricity and
losses from use of biomass for electricity provision

LINK for more information





Power to Mobility - direct use of electricity

- there will be a shift towards an electricity-based energy supply for most transport carriers

- Electricity (incl. Plug-in-Hybrid)
  - ➢Passenger car
  - ➢Trucks short haul
  - ➢possibly Trucks long haul as overhead wire
  - ➢Urban buses
  - ➢Rail traffic
- in UBAs scenario 15% of the final energy demand in transport will be met by electricity (direct)

Quelle: spiegel. de

Power to gas - hydrogen

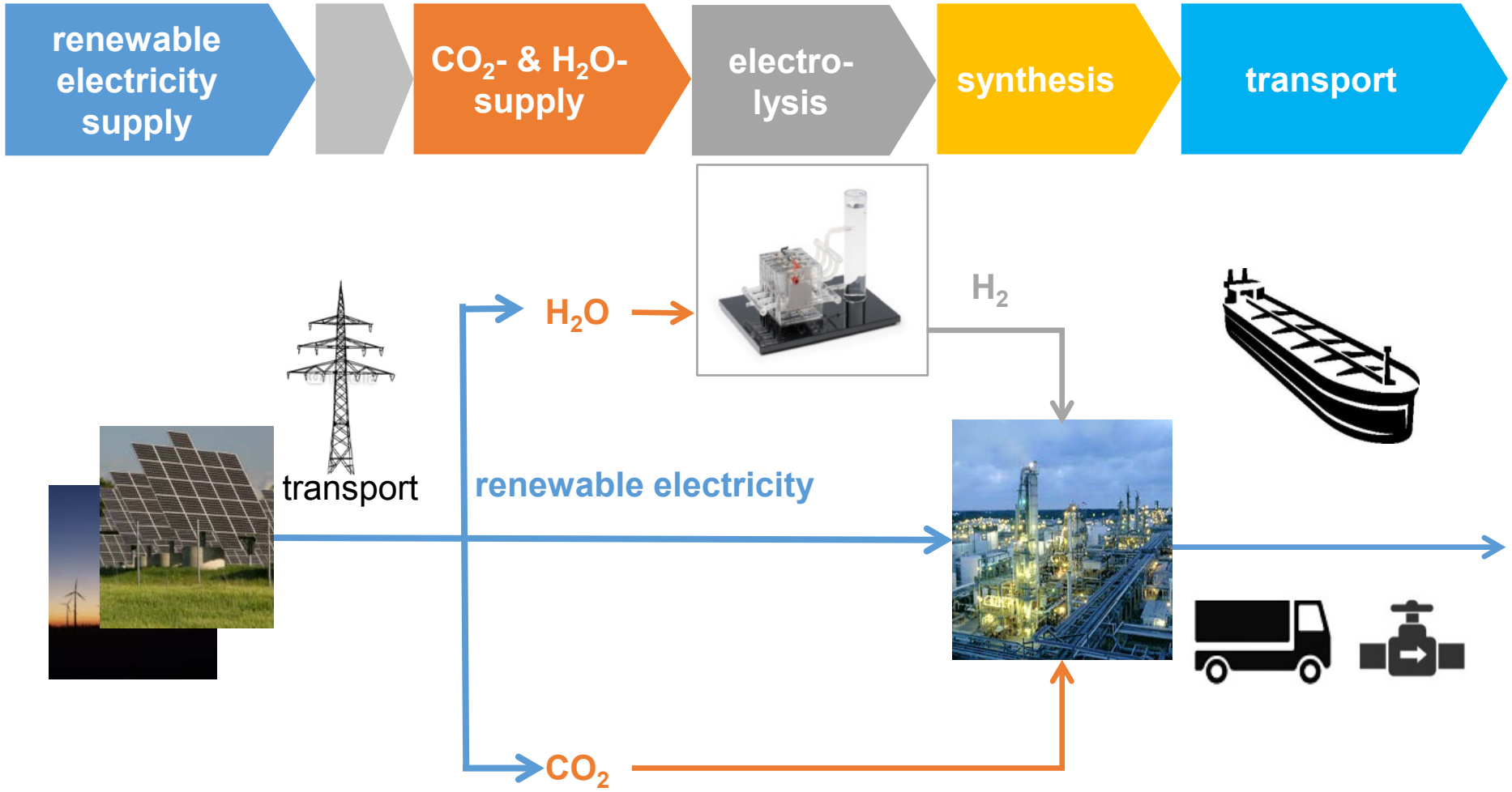
- Hydrogen is not yet used as an energy carrier
- but as a base material:
  - ammonia production
  - methanol production
  - Refineries

- Hydrogen
  - offers many major advantages compared to methane or liquid fuels – fewer conversion losses
  - but also disadvantages – lower energy density
  - needs new infrastructure

- Hydrogen as an energy carrier
  - chemical industry
  - possibly See transport - Short haul
  - possibly Trucks long haul

feedstock for renewable gas and liquid fuels

What is needed for Power to methane and Power to liquids



Inputs: renewable electricity, water and carbon dioxide or monoxide

Power to gas - methane

- renewable methane can substitute natural gas completely

- natural gas infrastructures is completely compatible and available on a large scale

- renewable methane is needed for
  - heat supply in industrial processes especially as a carbon source
  - chemical industry
  - storage
  - possibly traffic


Quelle:netzwerkerdgas.de


Quelle:greenmotorsblog.de

Quelle:focus.de

Power to liquid

• Production of liquid fuels by synthesizing renewable electricity, water and carbon dioxide

  ➢for example: methanol, kerosene, gasoline, diesel, waxes

• the use of a CO_2-free fuels is a key component next to traffic avoidance, modal shift and efficiency improvements

• power to liqiud produced fuels can be used with today's technology

• **for some transport carrier, there are hardly any alternatives**

  ➢**especially : Aviation**

• **renewable liquid fuels also needed for industry**

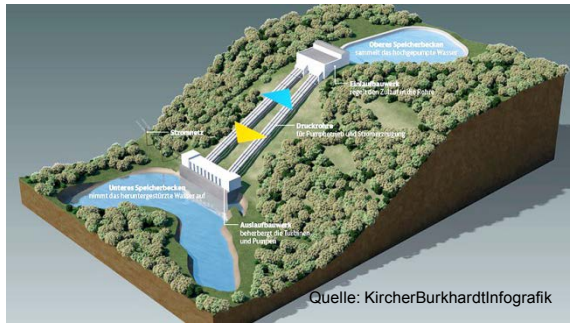
Power to storage / power to power

- in a renewable system storage is necessary to ensure a stable supply of electricity

- we need different storage solutions
  - ➢ **for short term to compensate daily/several days-fluctuation**
    - ✓ Load management (Power to X - all sectors)
    - ✓ battery storage
    - ✓ Pump storage

  - ➢ **and long term to compensate weeks/months/years-fluctuation**
    - ✓ Chemical storage:
      - renewable hydrogen storage (η=42%)
      - renewable methane storage (η=35%)

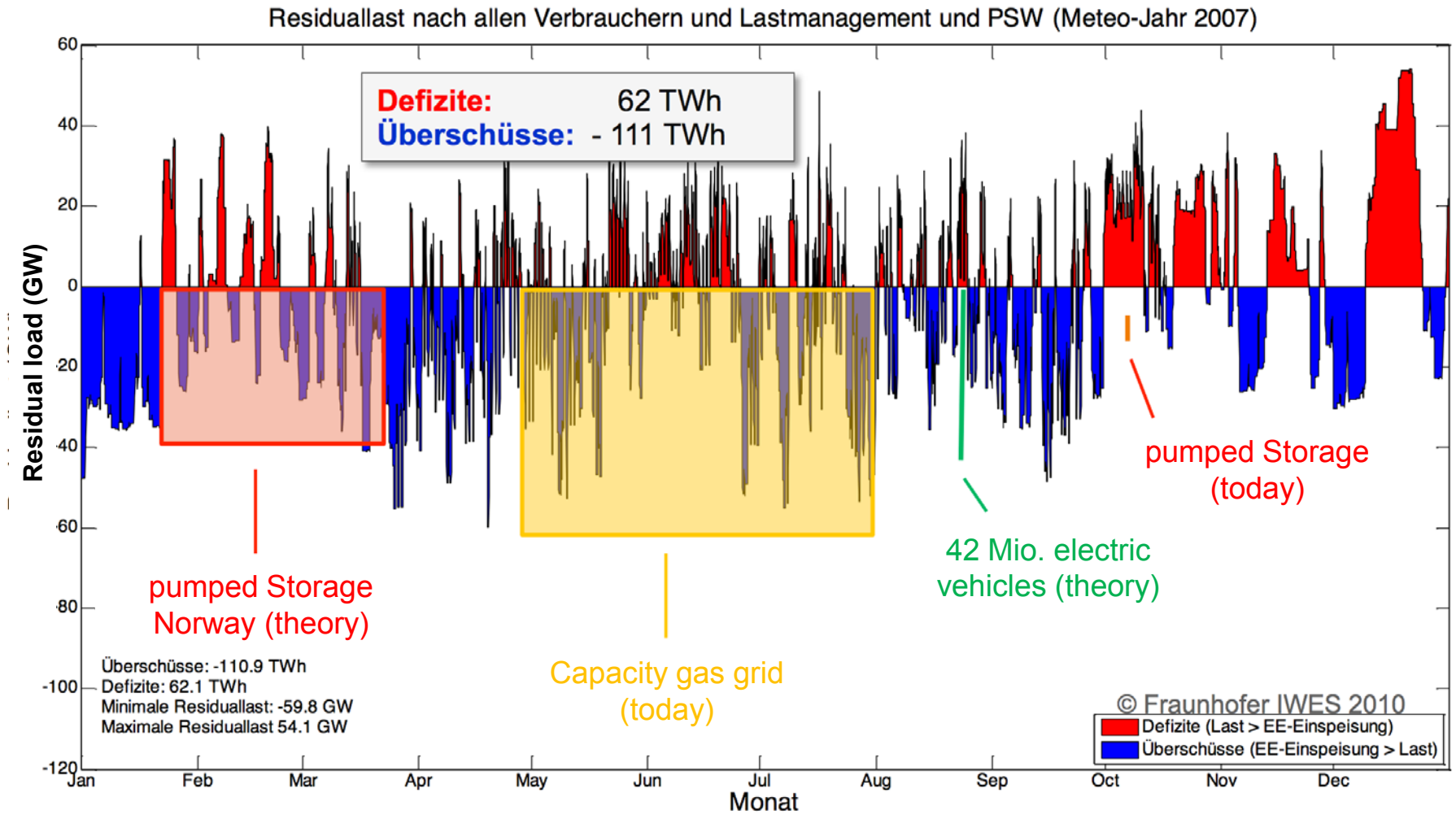

Quelle: Younicos.com


Quelle: KircherBurkhardtInfografik


Quelle:powertogas.info

Different Storage Systems in a 100% REN Elec. System

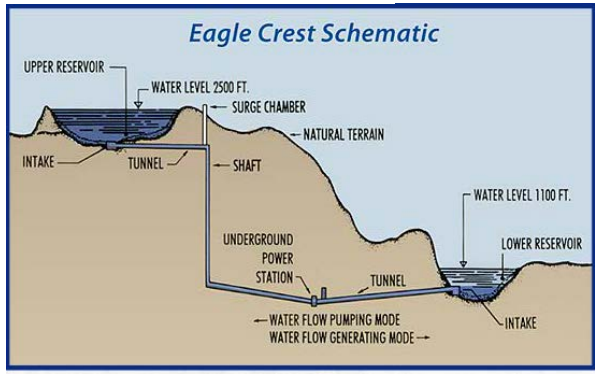
Total residual load (with load management and pump storage) in the year 2050, based on data from the meteorological year 2007



What is the future of the electricity industry?

Storage is a game changer

- Not just batteries!
- The greatest need is for longer-duration storage
- Focus on value stacking, not just cost reduction



Source: Eagle Mountain Energy, Inc: http://eaglemountainenergy.net

ENERGY STORAGE VALUES VARY DRAMATICALLY ACROSS LEADING STUDIES

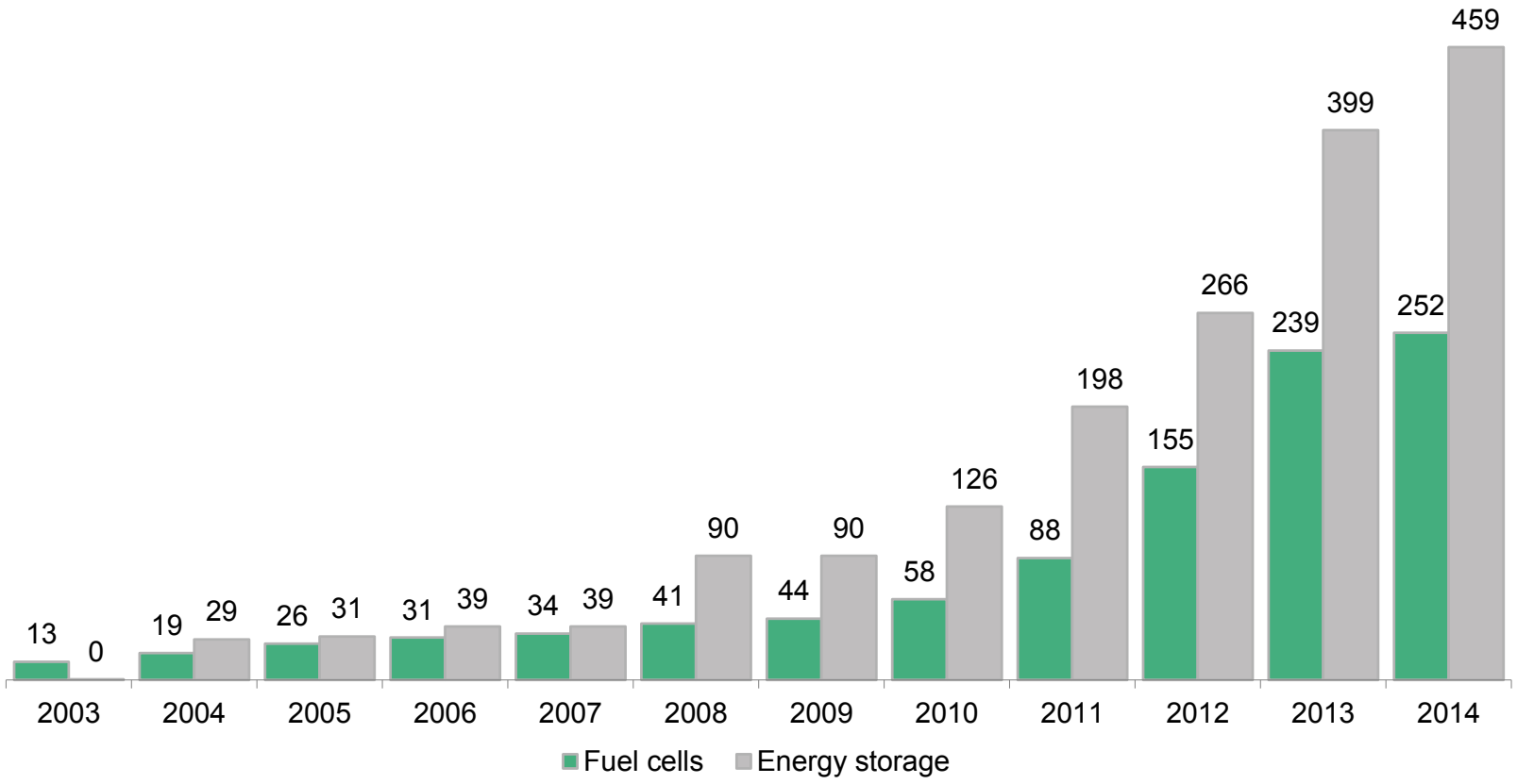
ISO/RTO SERVICES
- Energy Arbitrage
- Frequency Regulation
- Spin / Non-Spin Reserves
- Voltage Support
- Black Start

UTILITY SERVICES
- Resource Adequacy
- Distribution Deferral
- Transmission Congestion Relief
- Transmission Deferral

CUSTOMER SERVICES
- Time-of-Use Bill Management
- Increased PV Self-Consumption
- Demand Charge Reduction
- Backup Power

Source: Rocky Mountain Institute. The Economics Of Battery Energy Storage: How Multi-Use, Customer-Sited Batteries Deliver The Most Services And Value To Customers And The Grid www.rmi.org/electricity_battery_value

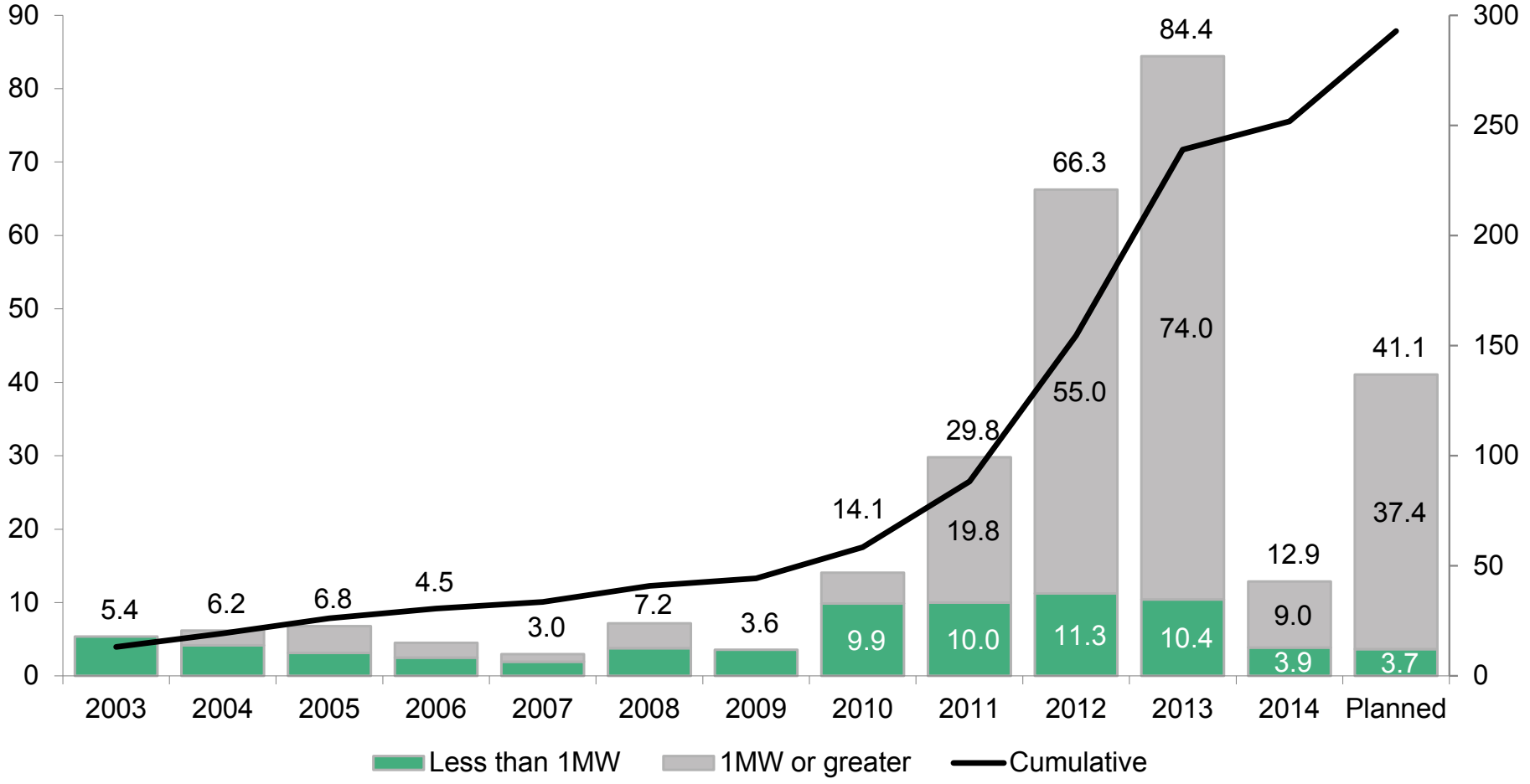
Cumulative fuel cell and energy storage capacity installed,(MW)



Note: Energy storage projects include batteries, flywheels, and aboveground compressed air energy storage; it does not include thermal storage, pumped hydro, or underground compressed air energy storage.

Source: Bloomberg New Energy Finance, Fuel Cells 2000

US stationary fuel cell capacity annual additions by project size (MW)



Note: Fuel cells installed before 2003 are excluded due to the expected 10 year lifetime.

Source: Fuel Cells 2000, Bloomberg New Energy Finance

Switching to Electric Vehicles will reduce emissions and can help stabilize the grid

Networked EVs can provide multiple grid services

- ☑ Absorb excess generation
- ☑ Improve local power quality
- ☑ Improve grid stability
- ☑ Reduce peak power flows
- ☑ Provide emergency backup power
- ☑ Speed recovery from grid outages

DriveEverGreen

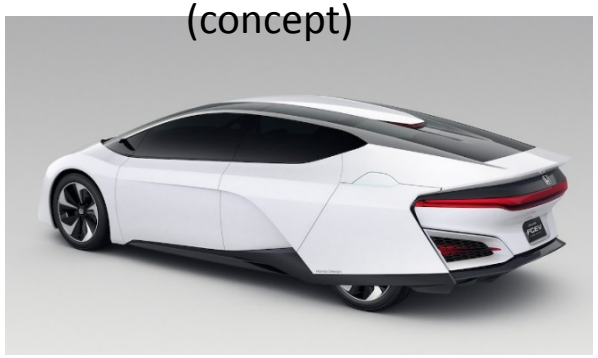
Opening up compensation for these grid services will reduce the total cost of vehicle ownership and speed adoption

Source Mark Ferron and CAISO

Introduction to fuel cell electric vehicles

	FCEVs	BEVs
Range (miles)	270-430	80-265
Specs	1.5-24kWh battery, 100kW power stack	24-85kWh battery
Refill time (minutes)	3-10	75-460
Cost of filling the tank ($)	30-70	0-8
Cost of the vehicle, upfront ($)	47,000 (including subsidies) -144,400	21,500 (including subsidies) – 72,000

Honda FCEV (concept)

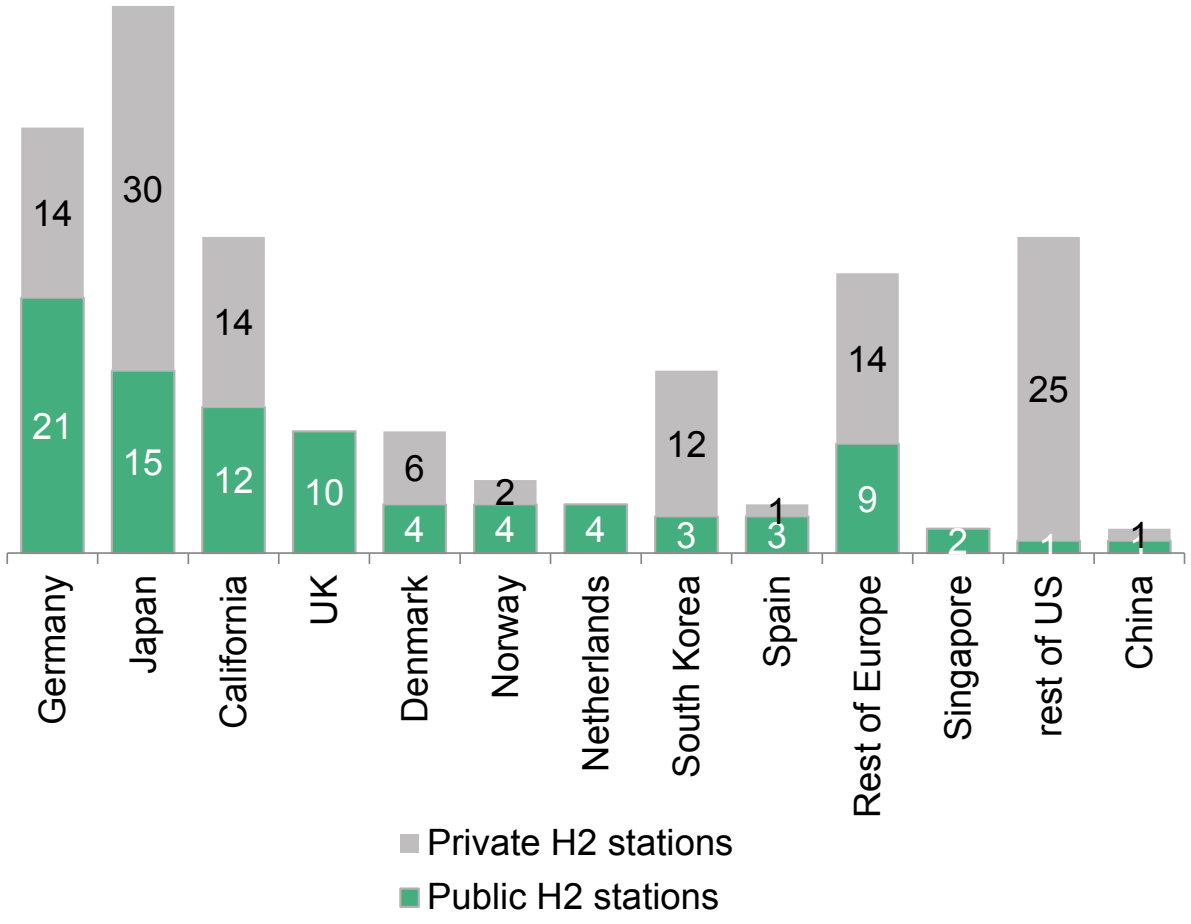


Toyota Mirai

Hyundai ix35/Tucson FCEV

Source: Bloomberg New Energy Finance

Barriers to further roll-out: hydrogen stations



Potential to dispense 24,000 and 124,000 kg per day

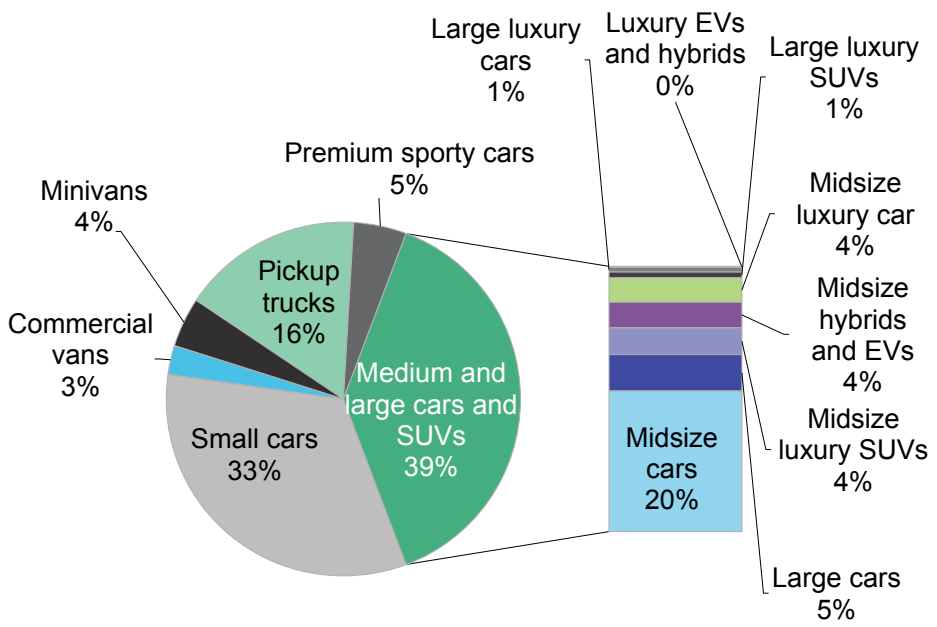
Sufficient capacity for thousands of FCEVs but most stations are private and in poor locations

Costs $2-5 million to build a station, compared to $1-2 million for a gasoline station

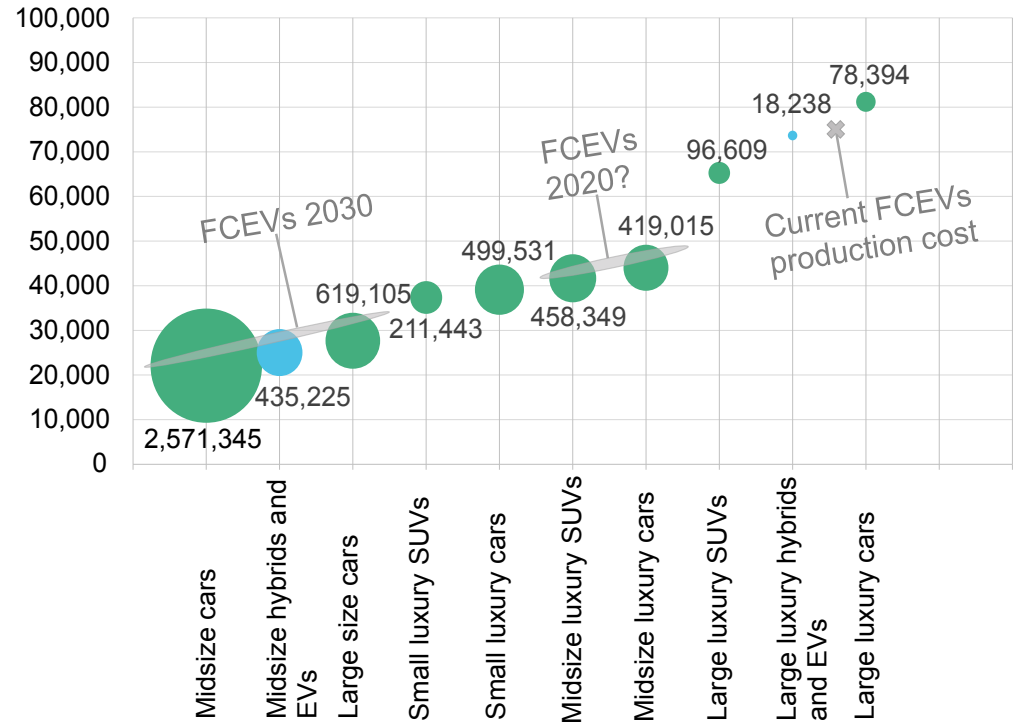
Source: Bloomberg New Energy Finance

US car sales market and how FCEVs might fit into it

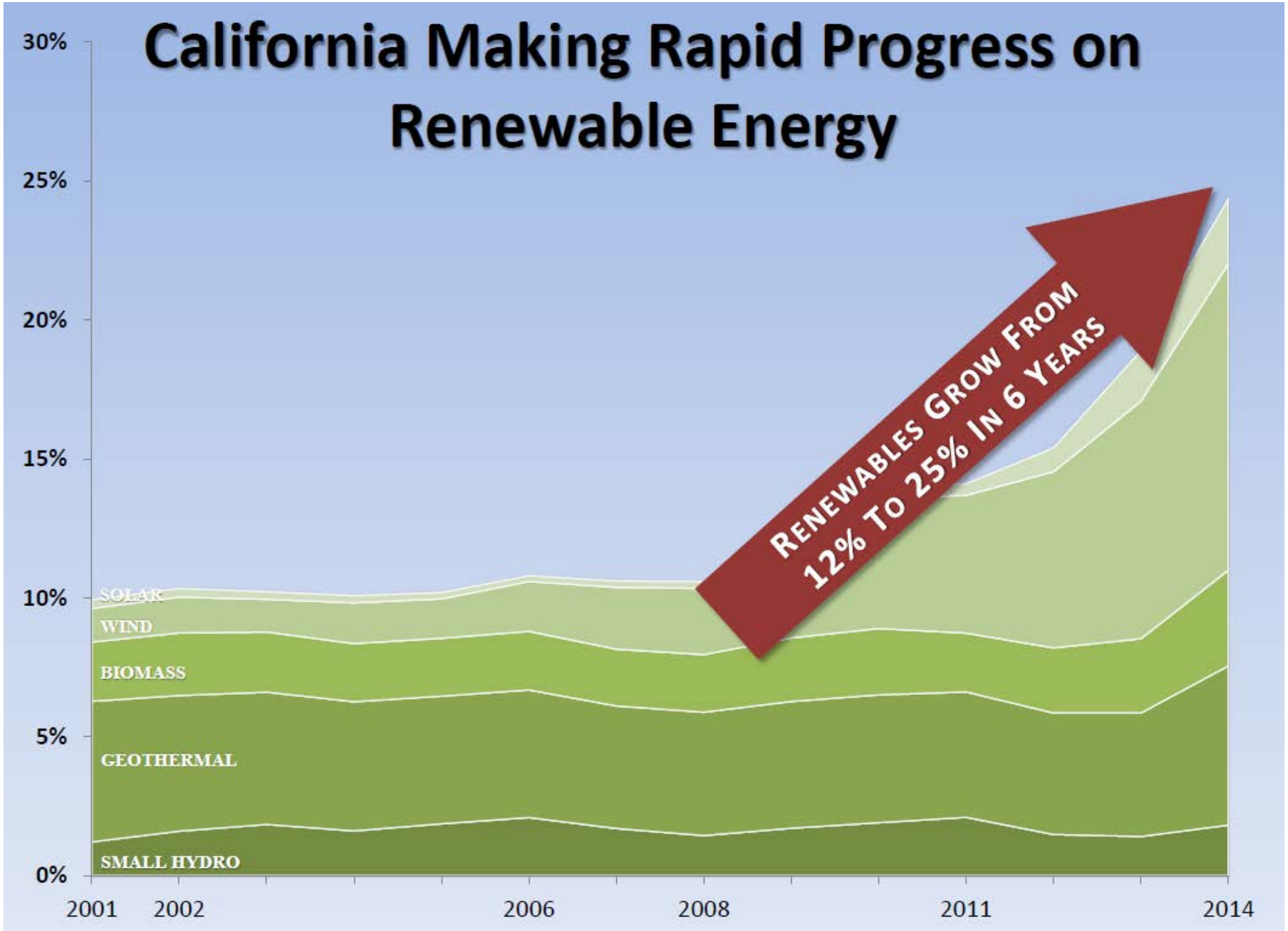
US CAR SALES BY SEGMENT, 2013



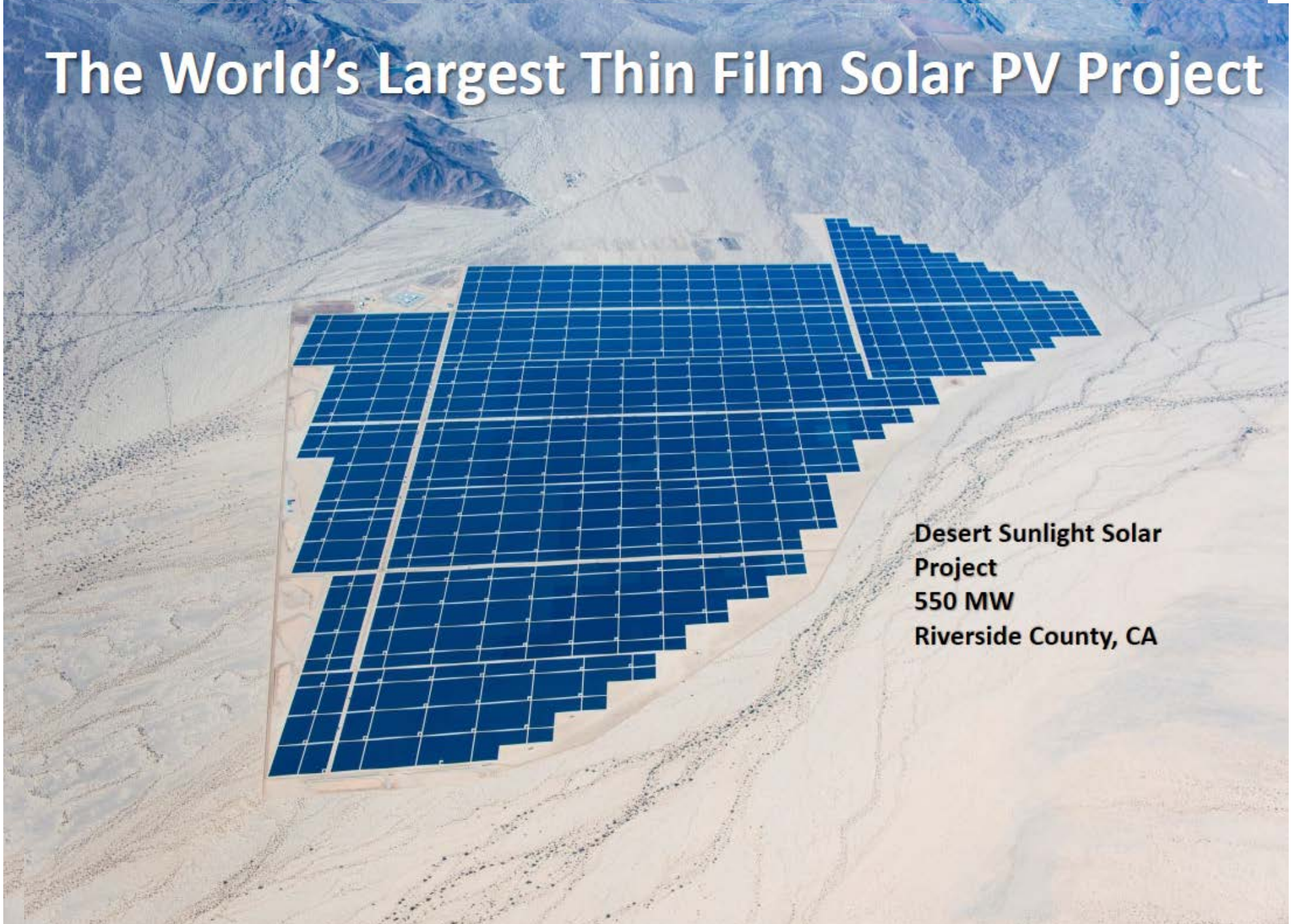
PRICE AND VOLUME OF SELECT US VEHICLE SEGMENTS WITH WHICH FCEVS MIGHT COMPETE, 2013 ($)



Source: Bloomberg New Energy Finance, auto manufacturer websites. Note: Prices are manufacturers' suggested retail price (MSRP) and does not include taxes nor subsidies.


California Making Rapid Progress on Renewable Energy
30%
25%
20%
15%
10%
5%
0%
2001
2002
2006
2008
2011
2014
SOLAR
WIND
BIOMASS
GEOTHERMAL
SMALL HYDRO
Renewables Grow From 12% To 25% In 6 Years

The World's Largest Thin Film Solar PV Project



Desert Sunlight Solar Project
550 MW
Riverside County, CA

The World's Largest Wind Project

The World's Largest Geothermal Power Plant

Geysers Geothermal Power Plant
955 MW
Lake County, CA

The World's Largest Solar Thermal Power Plant (Trough)


The World's Largest Solar Thermal Power Plant (Tower)
Ivanpah Solar Thermal Project
393 MW
San Bernardino County, CA

The World's 3rd Largest Silicon PV Project

Largest Manufacturing Plant in CA Produces Electric Vehicles

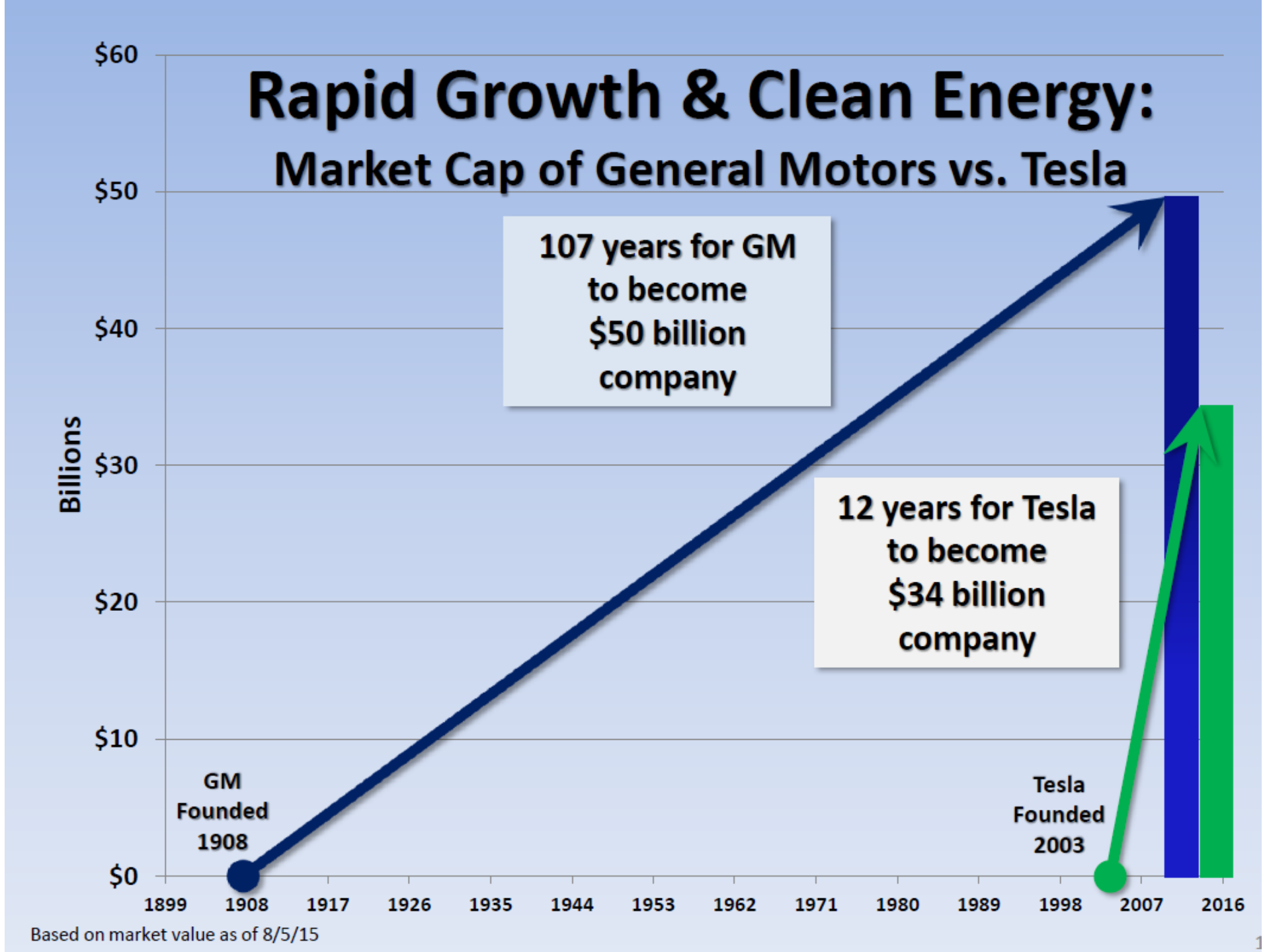
Tesla employs 15,000 people

Tesla Factory
Fremont, CA

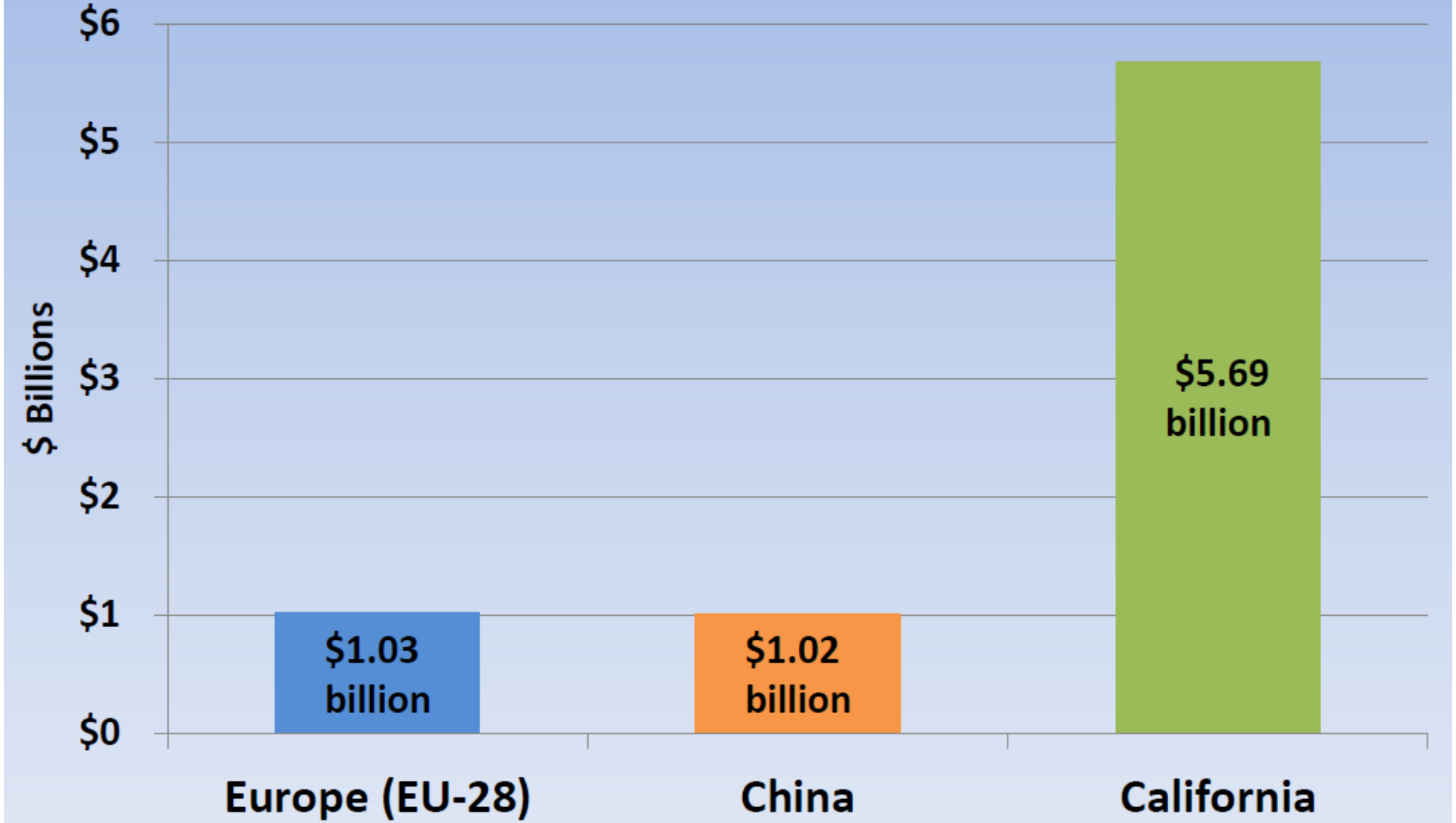
ALMOST 250,000 ELECTRIC VEHICLES IN CALIFORNIA TODAY

The Future of Energy Storage: 1.3 GW by 2020

$5 B Tesla Battery Factory under construction

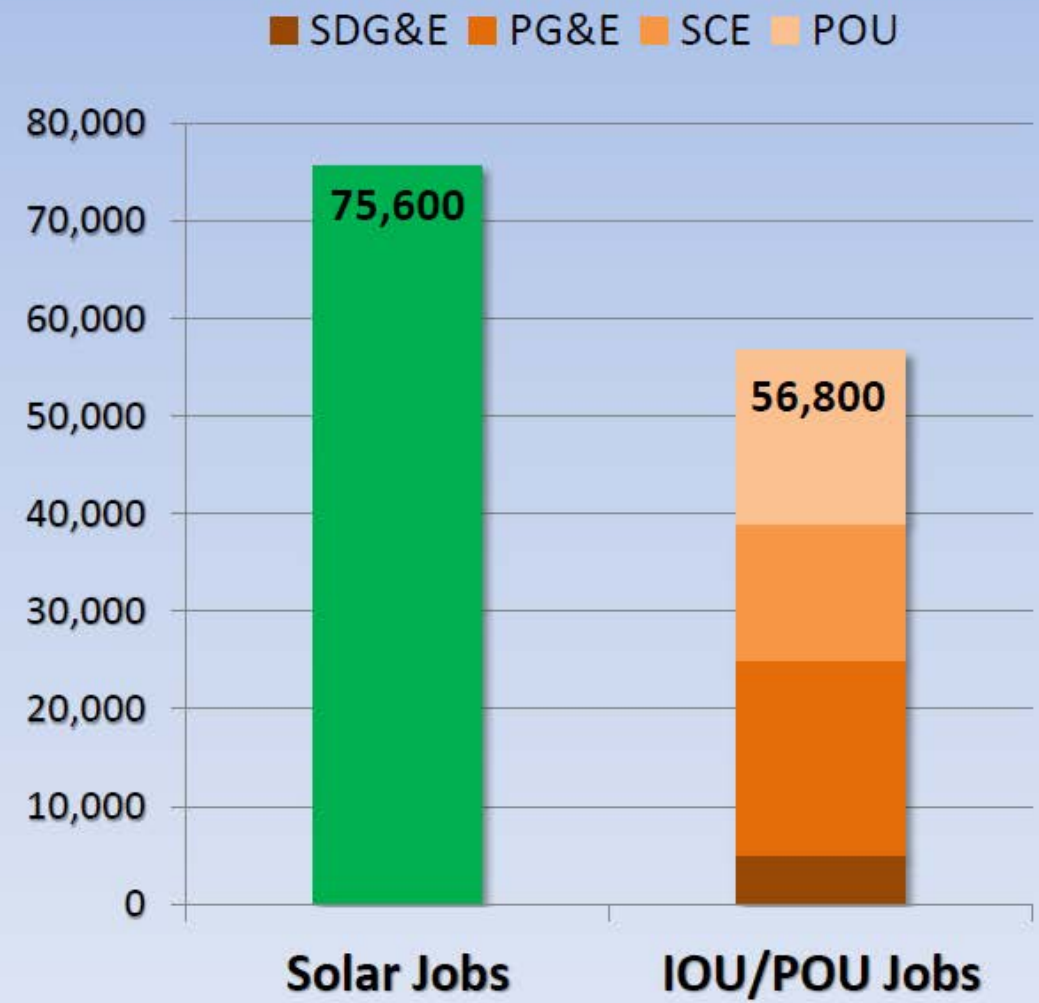

Rapid Growth & Clean Energy:
Market Cap of General Motors vs. Tesla
Billions
$60
$50
$40
$30
$20
$10
$0
107 years for GM to become $50 billion company
12 years for Tesla to become $34 billion company
GM Founded 1908
Tesla Founded 2003
1899
1908
1917
1926
1935
1944
1953
1962
1971
1980
1989
1998
2007
2016
Based on market value as of 8/5/15

More Cleantech VC Investment into CA than all of Europe and China Combined



Source: Next 10 California 2014 Green Innovation Index

More Californians Work in the Solar Industry Than for All Utilities Combined



Sources:

Solar Foundation, 2015 Solar Jobs Census

U.S. Securities and Exchange Commission, Form 10-K, 2014
http://www.sec.gov/edgar/searchedgar/companysearch.html

Toward 100% Renewables and the Electrification of Almost Everything

Now Selling: The All-Electric Home

CityVentures all-electric homes
Bellflower, CA

2015: Stanford University Converts Space and Water Heating from Natural Gas to Electricity

Reduces water use and GHG emissions by 2/3 and annual energy bills by 1/3

High Speed Rail is Coming to California and it will be 100% Powered by Renewables…

To power the whole world with solar energy requires only: 0.07% of the World Land Area

If we capture 2 minutes of the solar irradiation that hits the Earth everyday we can power our world for a year…

Renewables in Perpetuity	terawatt hours **EACH YEAR**
Direct Solar Radiation	350,000,000
Wind	200,000
Ocean Thermal	100,000
Biofuel	50,000
Hydroelectric	30,000
Geothermal	10,000
Tidal	1,000

Energy Stored in the Earth	terawatt hours **TOTAL**
Coal	6,000,000
Uranium 235	1,500,000
Petroleum (US ½ Gone 1970)	1,000,000
Natural Gas (US ½ Gone 2005)	400,000
Tar Sands	200,000

2004 Global consumption of stored energy = 80,000 terawatt hours/year

Renewables 100 Policy Institute

National Leaders Moving Toward Right Direction of 100% Renewable Energy

Image: Michael Kappeler/picture-alliance/dpa/AP Images/Associated Press

PARIS2015
UN CLIMATE CHANGE CONFERENCE
COP21·CMP11

June 2015 G7 Leaders' Declaration:

Decarbonize Economies by 2100

Renewables 100
Policy Institute

100% RE: Global Call to Action RENFORUS

PARIS2015
UN CLIMATE CHANGE CONFERENCE
COP21·CMP11

UNESCO

LABEL
PARIS2015
UN CLIMATE CHANGE CONFERENCE
COP21·CMP11

Expansión

renforus

2014 El Hiero Declaration:

Call To Action for 100% Renewable Energy

RENFORUS Forum in Madrid November 19, 2015

Call for Action COP 21 100% Renewable Energy

Renewables 100
Policy Institute

“There is an urgent need to develop sources of renewable energy.”

Pope Francis

Picture: Wikimedia

Thank you

Renewables 100 Policy Institute

Questions?

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a.galiteva@renewables100.org