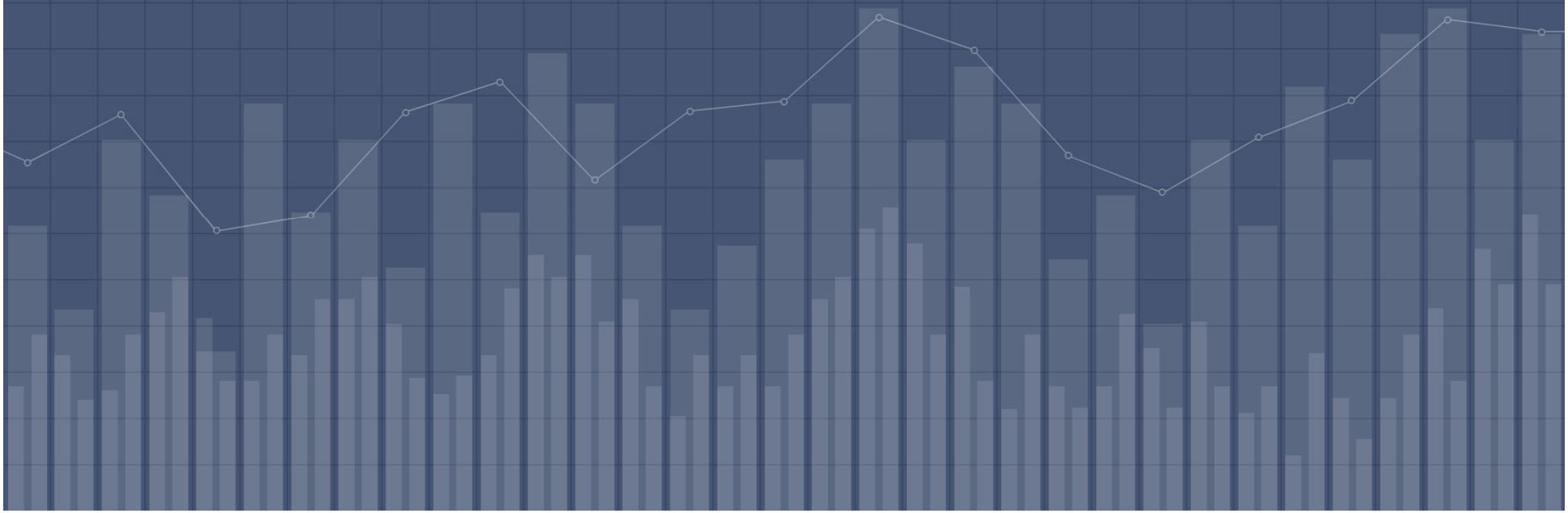
Powering the Future:

A Look at the Coming Decade's Power Grid



- *Nuclear Power*
  - *Where is spent fuel stored? Show google earth picture*
  - *From 104 to 99 to… zero run at full capacity, cant compete with natural gas*
  - *Why don't we reprocess like France*
    - *France built all there power plants on the border to export power*
- *Natural gas – almost free fuel*
  - *Practically free by-product of Oil (rig count)*
  - *US is now an exporter of LNG (2 ports)*
  - *How can we store fuel on site?*
  - *Rapid response time to demand*
  - *Wild fluctuations in pricing during demand events $21.80/MWH to $2000.00/MWH*
- *Hydro – why is it not green?*
  - *Old hydro plants (TVA) are not considered green as they impacted the environment*
- *Solar and Wind the ~~Renewables~~ Unreliable*
  - *Solar constant, efficiency,*
  - *Sometimes its cloudy*
  - *Has an ROI for residential consumers, utilities hate (duck curve) 4PM to 9PM*
- *Ethanol – brazil and sugar cane and an Elephant*
- *Storage*
  - *Moore's law for batteries – 10 years for a doubling of power density*
  - *18650, 2170*

This discussion will demonstrate the current shift that is happening in the utility space

Migrating slowly at first from large centralized power plants to perhaps a host of small distributed systems. We will examine the federal government's current forecast for utility mix in the next 30 years and see how it will impact the mix of generation from coal to nuclear to natural gas to renewables.

We will look at the benefits and possible pitfalls of adding and taking away certain types of power generation. We will take another look at nuclear to see and discuss the art of the possible, what technologies are available and what can be done.

We will look empirically at what has happened over the last few years with the 'peak demand curve' and the 'duck curve' to see why some utilities (California) stopped buying back power at peak times.

ELECTRICITY GENERATION

Last year **2/3** of generated electricity went wasted and unused

Renewable energy capacity increased **2X** In the last ten years

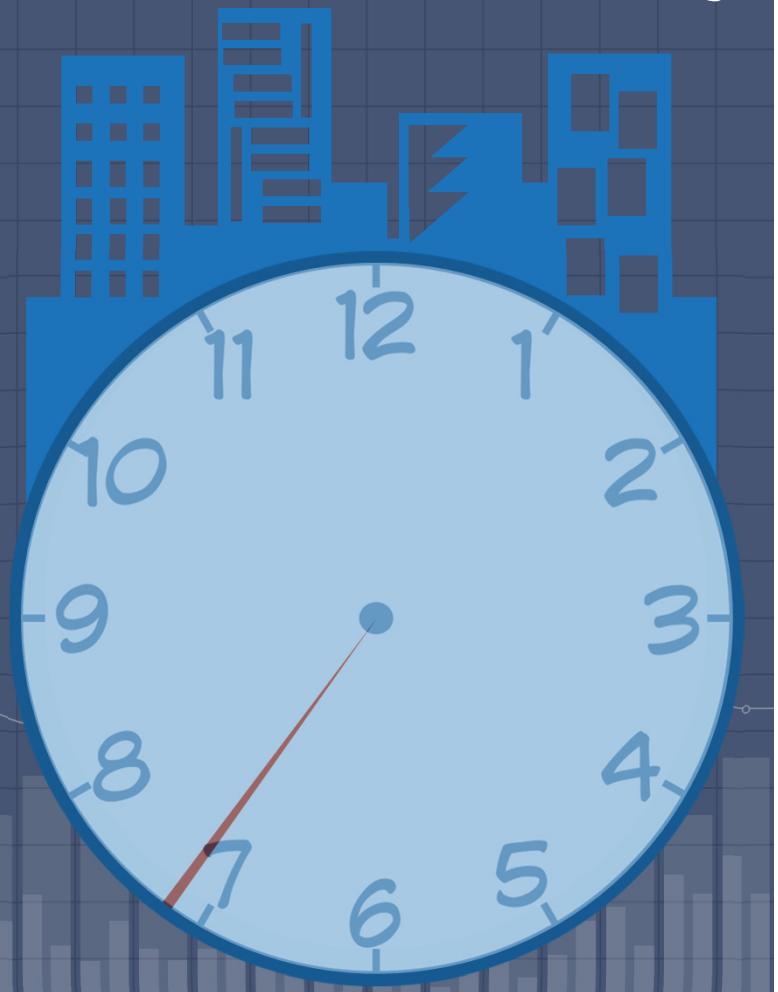
$104B spent on energy in the US (2017)

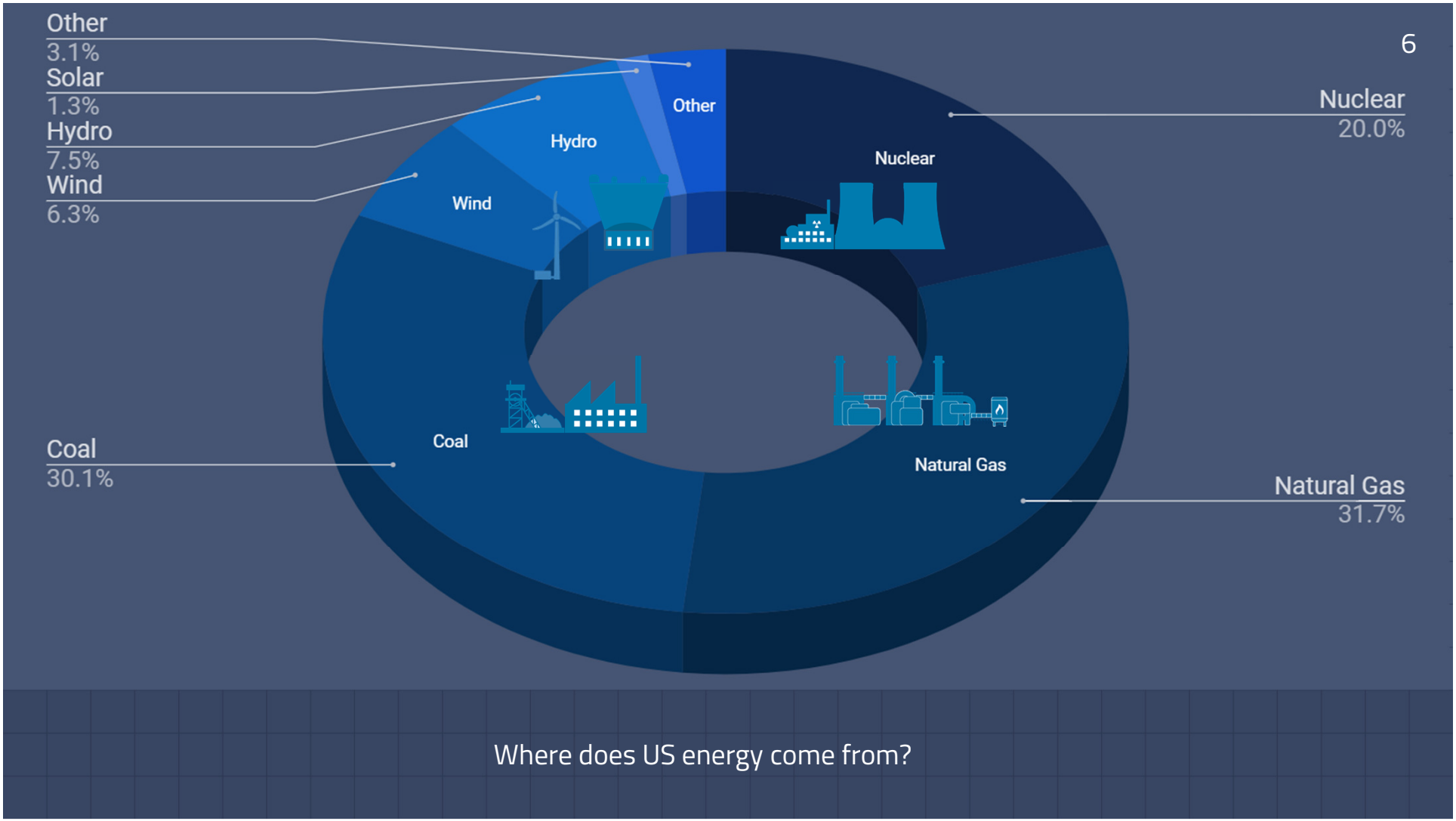
350,000GWh of energy was used in the US

570 Million man-hours of disruption due to non weather-related outages

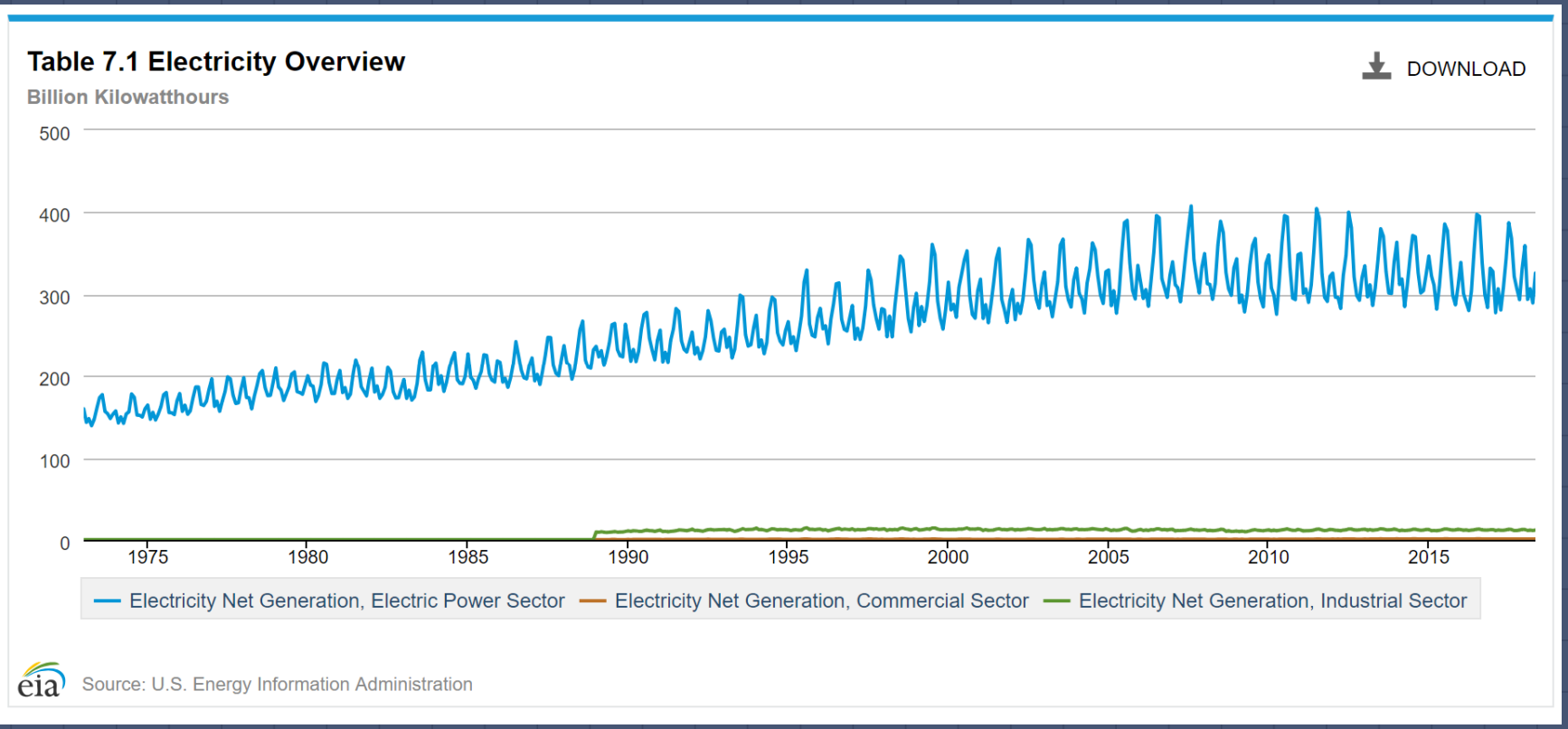
99.98%
Grid Availability

17 seconds without power each day –
you don't get to choose which ones





Where does US energy come from?



Power demand has largely stagnated in recent years

The Infrastructure of Today

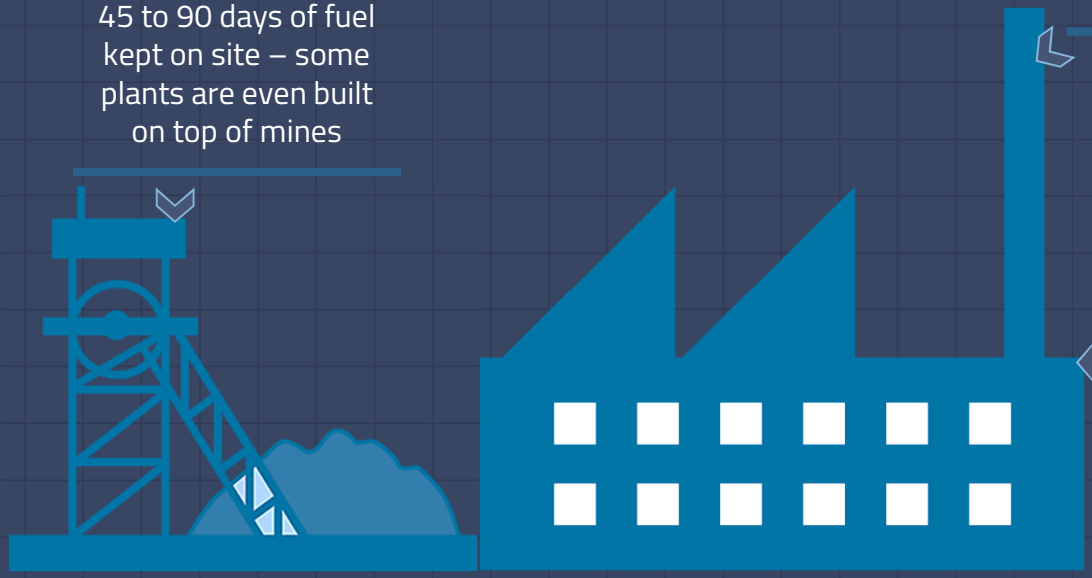
What factors shaped our current grid?
What factors will shape its future?

1

Coal – massive reduction in usage in last 3 years!

45 to 90 days of fuel kept on site – some plants are even built on top of mines

Emission scrubbers are used to reduce high sulfur footprint



Slow startup time – must get to heat rating

Produces:

300 to 3000 MW

Predicted Capacity Change by 2021:

-18,757 MW

Coal presently accounts for

30%

of domestic energy

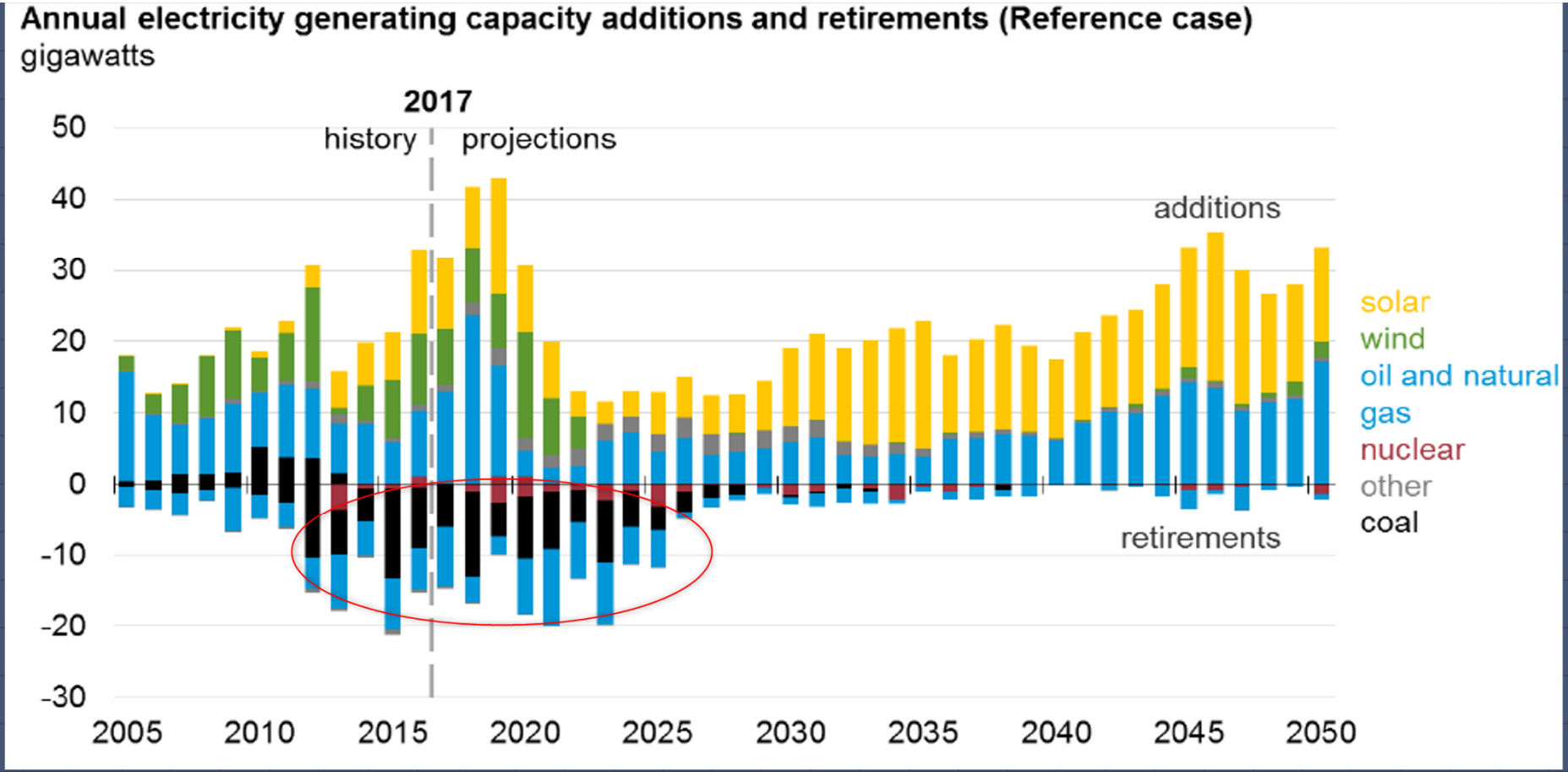
Coal

Pros

- Cheap to burn and mine
- Abundant and stable supply
- Infrastructure already established
- Provides baseload for power

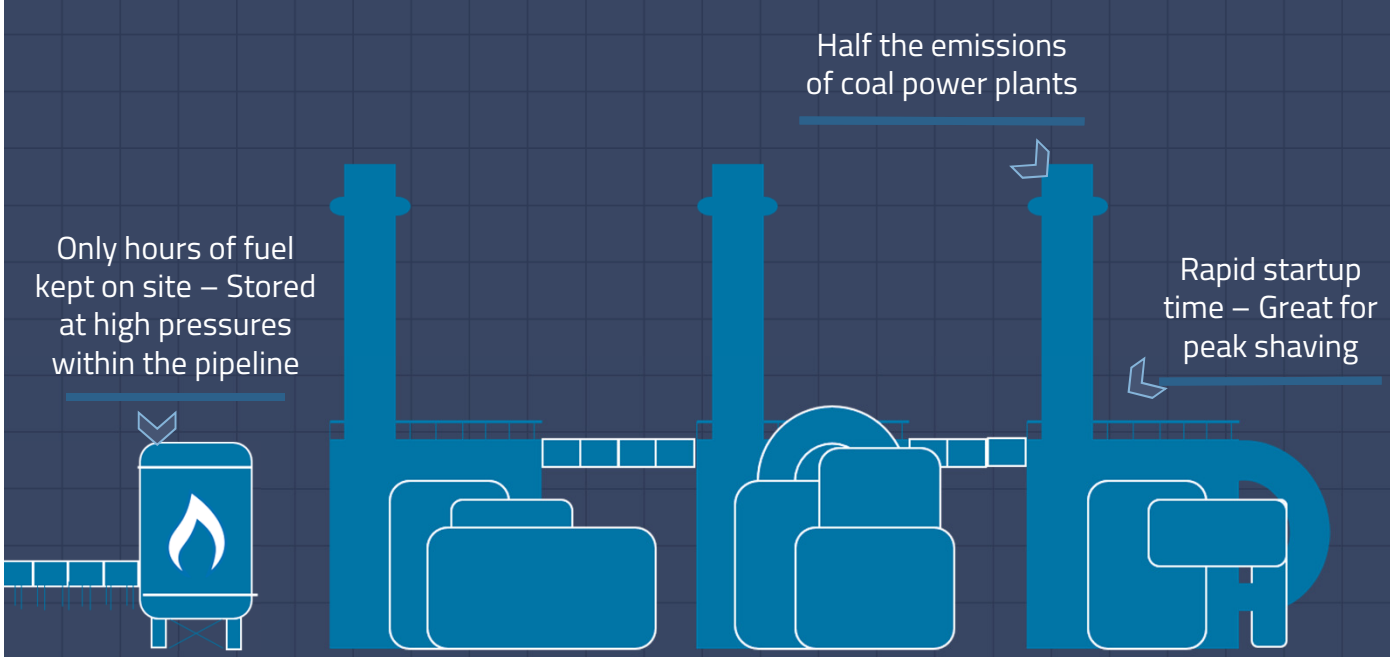
Cons

- High carbon footprint
- Slow startup time



Coal plants being rapidly decommissioned

Natural Gas – rapidly proliferating



Produces:

50 to 100 MW per stack

Predicted Capacity Change by 2021:

+57,253 MW

Nat. Gas presently accounts for

32%

of domestic energy

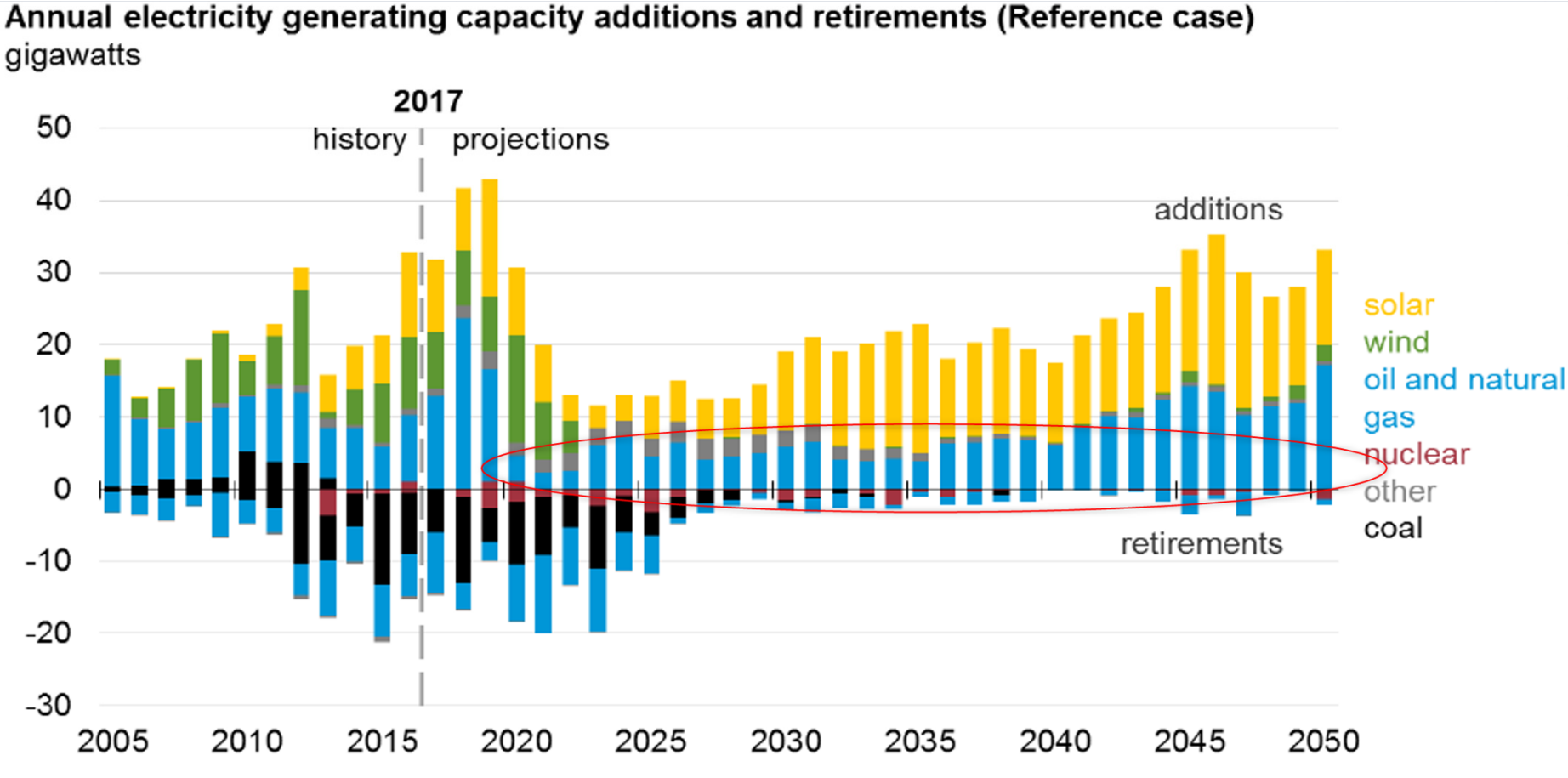
Natural Gas

Pros

- Cheap to pump (at the moment)
- Abundant supply
- Rapid startup time
- Can provide a baseload for power

Cons

- Carbon footprint is still very large
- Gas pipelines are heavily protested
- Exports now impact our domestic pricing



Natural gas plants being continuously deployed at utility scale

Nuclear – a carbon free baseload solution

Only 10% of nuclear fuel needed each year is produced domestically

Zero carbon footprint – making it one of the cleanest baseloads

Each reactor has an 18 month fuel cycle

Always operational – not economic to shut down

Produces:

600 to 4,000 MW

Predicted Capacity Change by 2021:

+2,312 MW

Nuclear presently accounts for

20%

of domestic energy

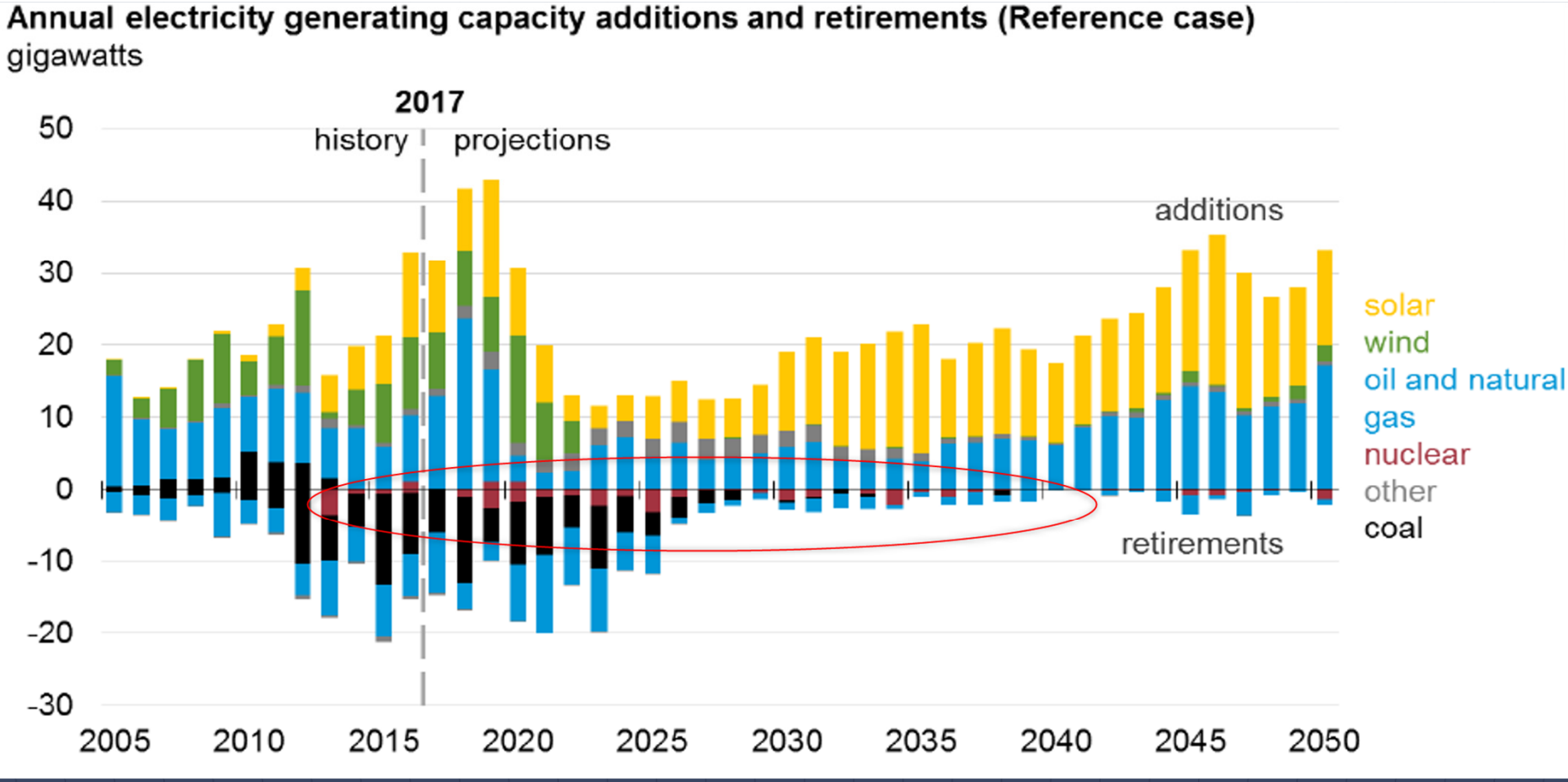
Nuclear

Pros

- Zero carbon emissions
- Most reliable source of power
- Highest energy yield per power plant
- Most stable baseload provider

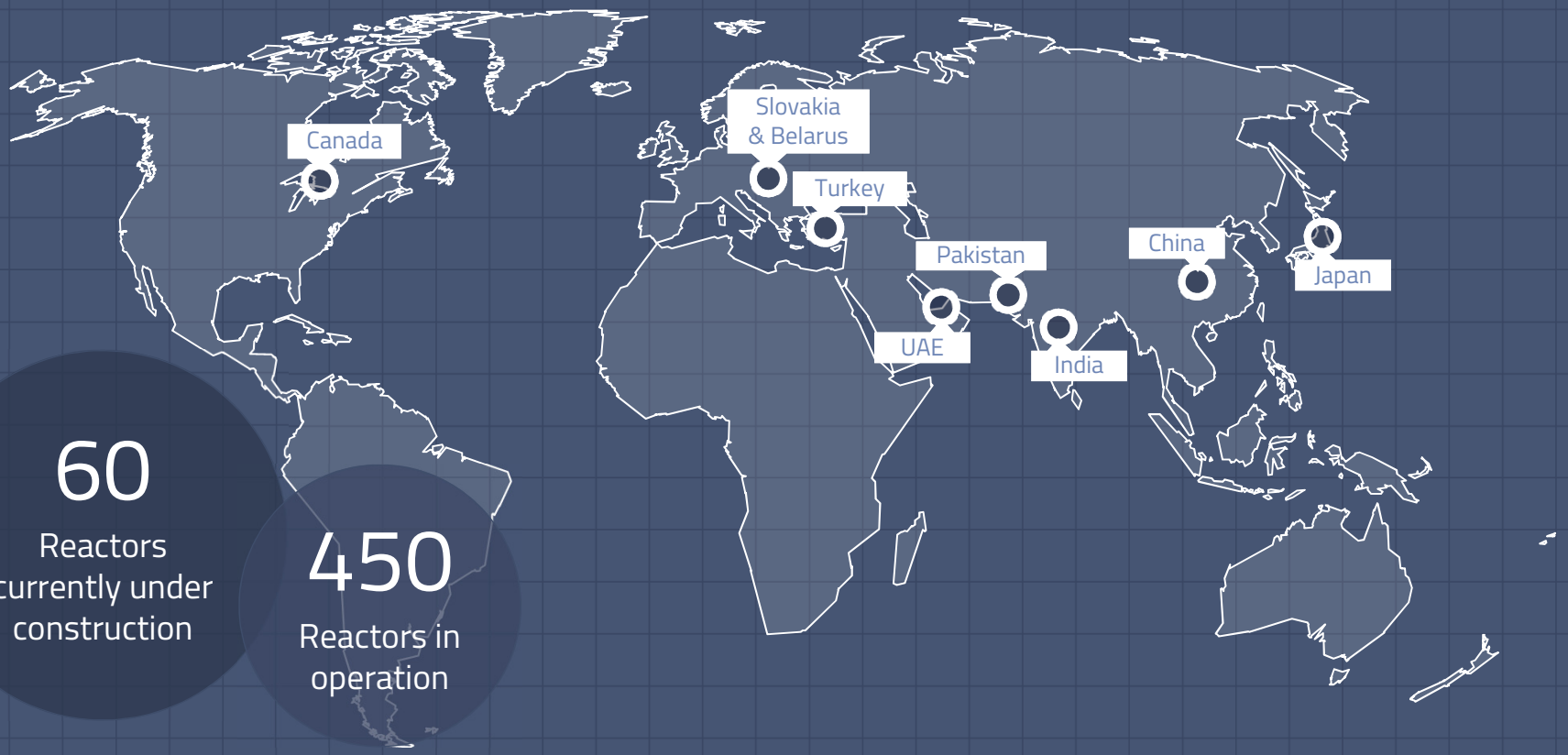
Cons

- Health and safety concerns
- Existing plants are becoming dated
- New proposals are met with great opposition



Nuclear plants diminishing for the next 20 years!

Who is developing nuclear right now?



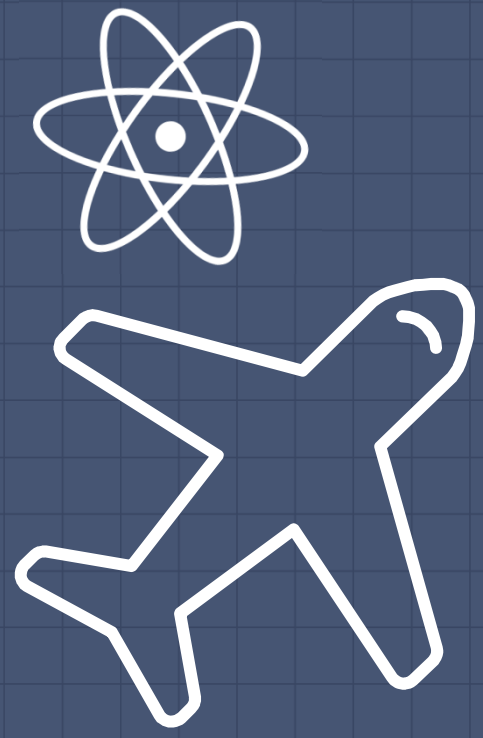
60

Reactors currently under construction

450

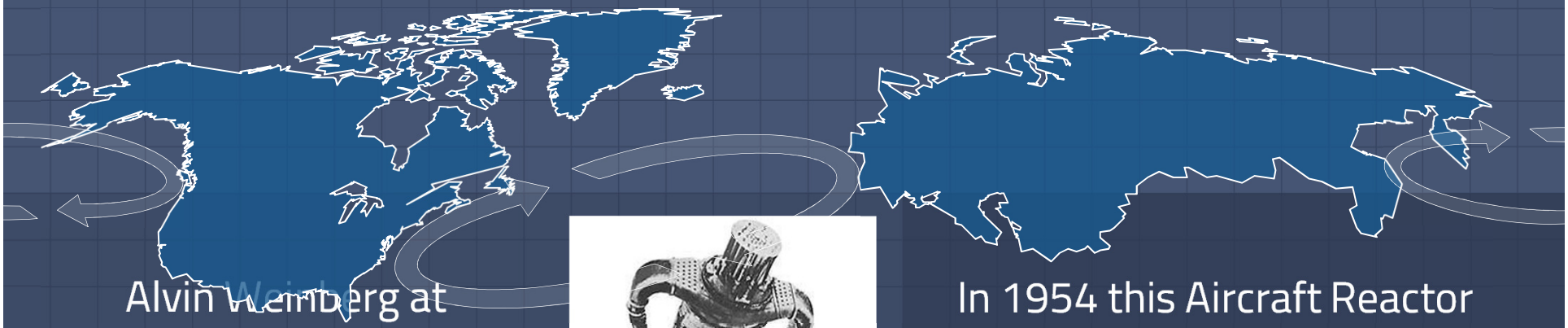
Reactors in operation

AIR FORCE STORY



The development of the MSR and what it might mean for our future

In the early 1950s the US sought a bomber that could fly nonstop during the rising tension of the cold war



Alvin Weinberg at ORNL used the funding to develop the MSR

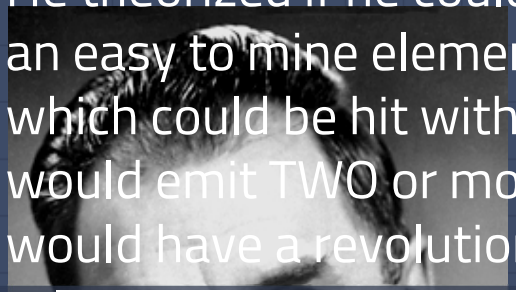
The HTRE-3 without supporting structure.

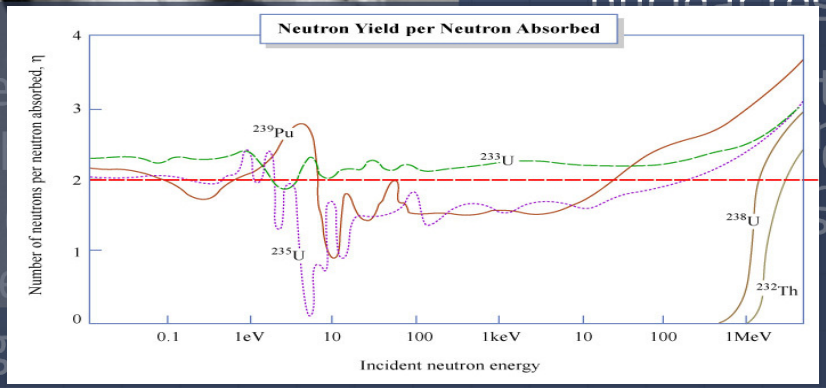
In 1954 this Aircraft Reactor Experiment produced up to 2.5 MW of thermal power at a red-hot 860°C at low pressure

Thorium – An alternative fuel

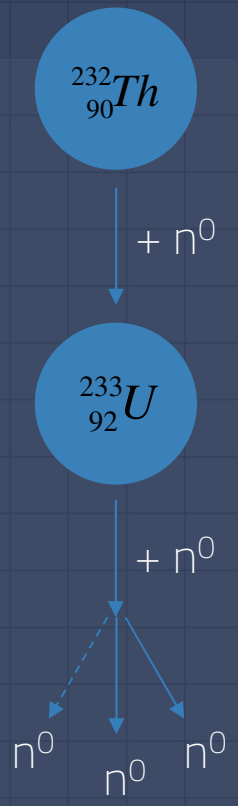
Glenn Seaborg began experimenting with new nuclear fuels in December 1942

He theorized if he could find an isotope of an easy to mine element …
which could be hit with ONE neutron and would emit TWO or more as a result, he would have a revolutionary new fuel





	16	LEAD
	15	GALLIUM
10 ppM	10	THORIUM
	7	SAMARIUM
	6	GADOLINIUM
	6	PRASEODYMIUM
	3	BORON
	3	BROMINE
	2.5	URANIUM
	2	BERYLLIUM
	1.5	TIN
1000 ppG	1	TUNGSTEN
	1	MOLYBDENUM
100 ppG	0.2	MERCURY
	0.1	SILVER
	0.018	URANIUM-235
	0.005	PLATINUM
	0.002	GOLD



"You have just made a $50 quadrillion discovery"

The resulting reaction put out 2.5 neutrons on average!

-Glenn Seaborg (to John Gofman)

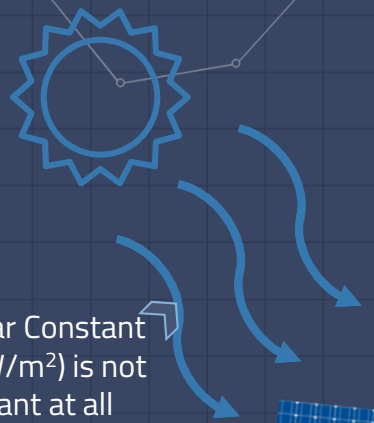
Thorium

A cheaper and safer alternative to current generation nuclear fuels

Can we get more MSR and LFTR technologies in the US?

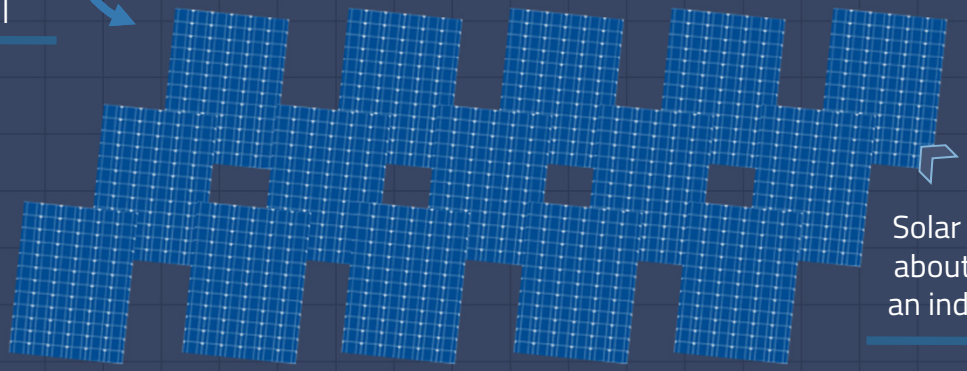
Can it be profitable?

Solar – needs a lot of real estate



Clouds, nighttime, and other natural disruptions make solar unreliable as a baseload energy

The Solar Constant (1361 W/m^2) is not constant at all



Solar efficiency is about 15-25% on an industrial scale

Produces:
50 to 600 MW

Predicted Capacity Change by 2021:
+14,258 MW

Solar presently accounts for

<1%

of domestic energy

Solar – needs a lot of real estate

- 42% at max ($10,000 for a small cell)
- Typical is 15 % to 20 % for commercial or residential use (high end 25%)
- About 300 watts per m^2 of panel - that is not great but fine for residential

Return on Investment of a 6kWh Solar Array

Years to breakeven = Cost of Solar Array

Utility Rate per kWh • Average 2,183 Hours of Sunlight per year • kW Output of Solar Array

Residential

= 13.15¢/kW

ROI

~10.5 years

Commercial

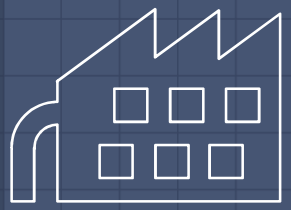
= 10.51¢/kW

ROI

~13.1 years

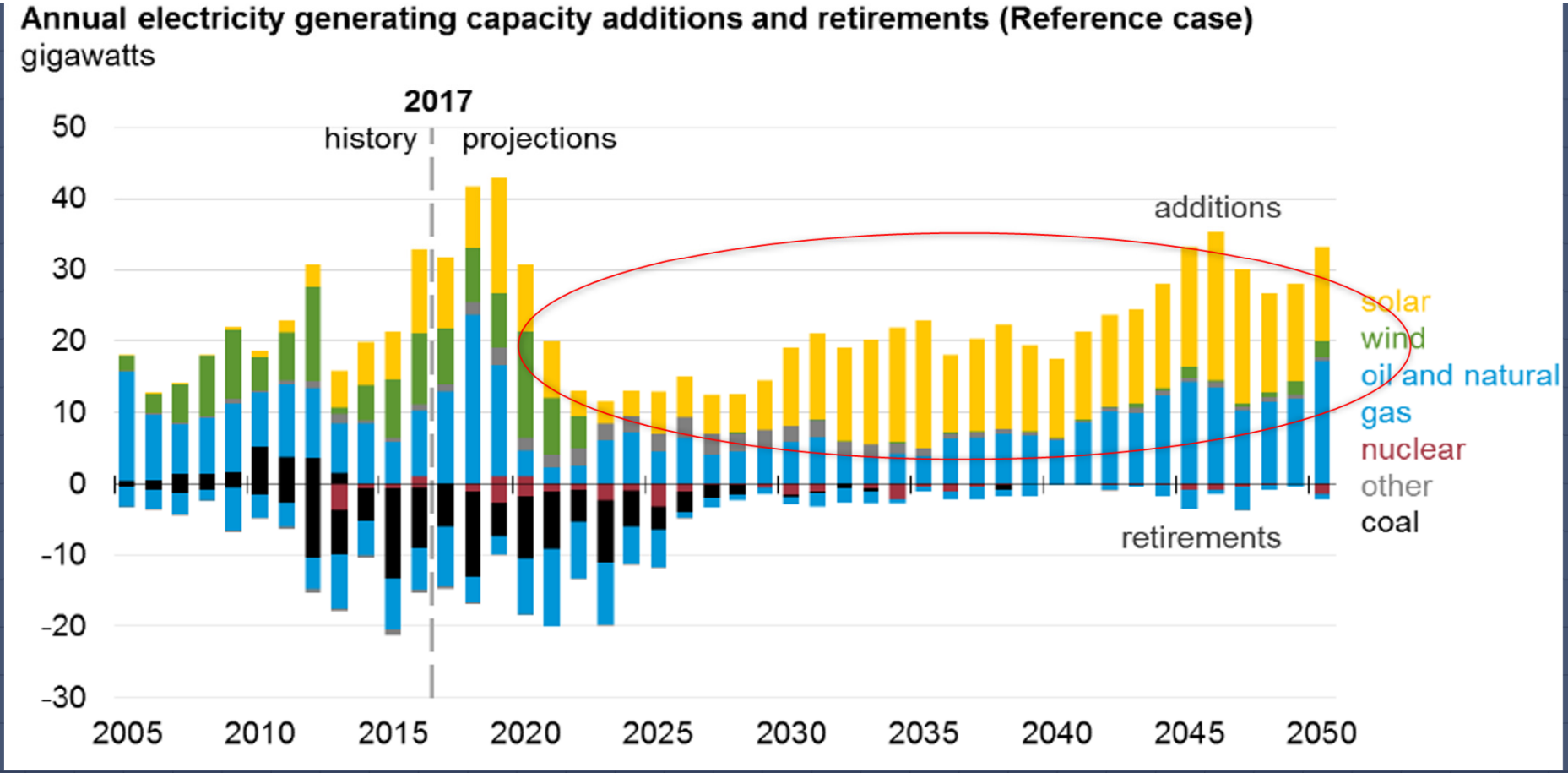
Industrial

= 6.82¢/kW



ROI

~20.2 years

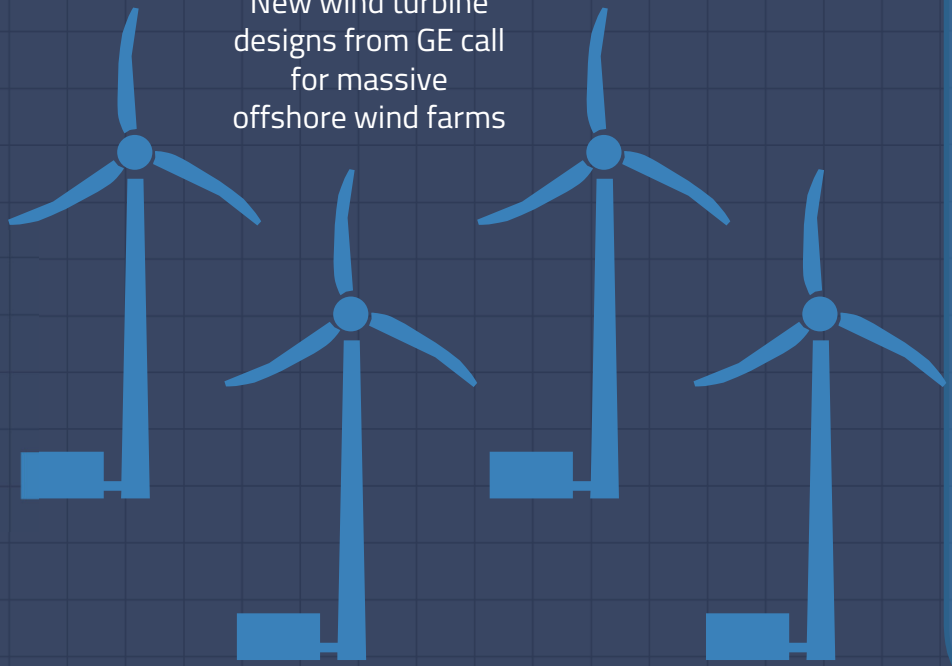


Solar projects show amazing growth… During the day of course!

Wind – frequently unreliable

Wind speeds can fluctuate often and unpredictably

New wind turbine designs from GE call for massive offshore wind farms



Produces:
2 to 3 MW per onshore turbine

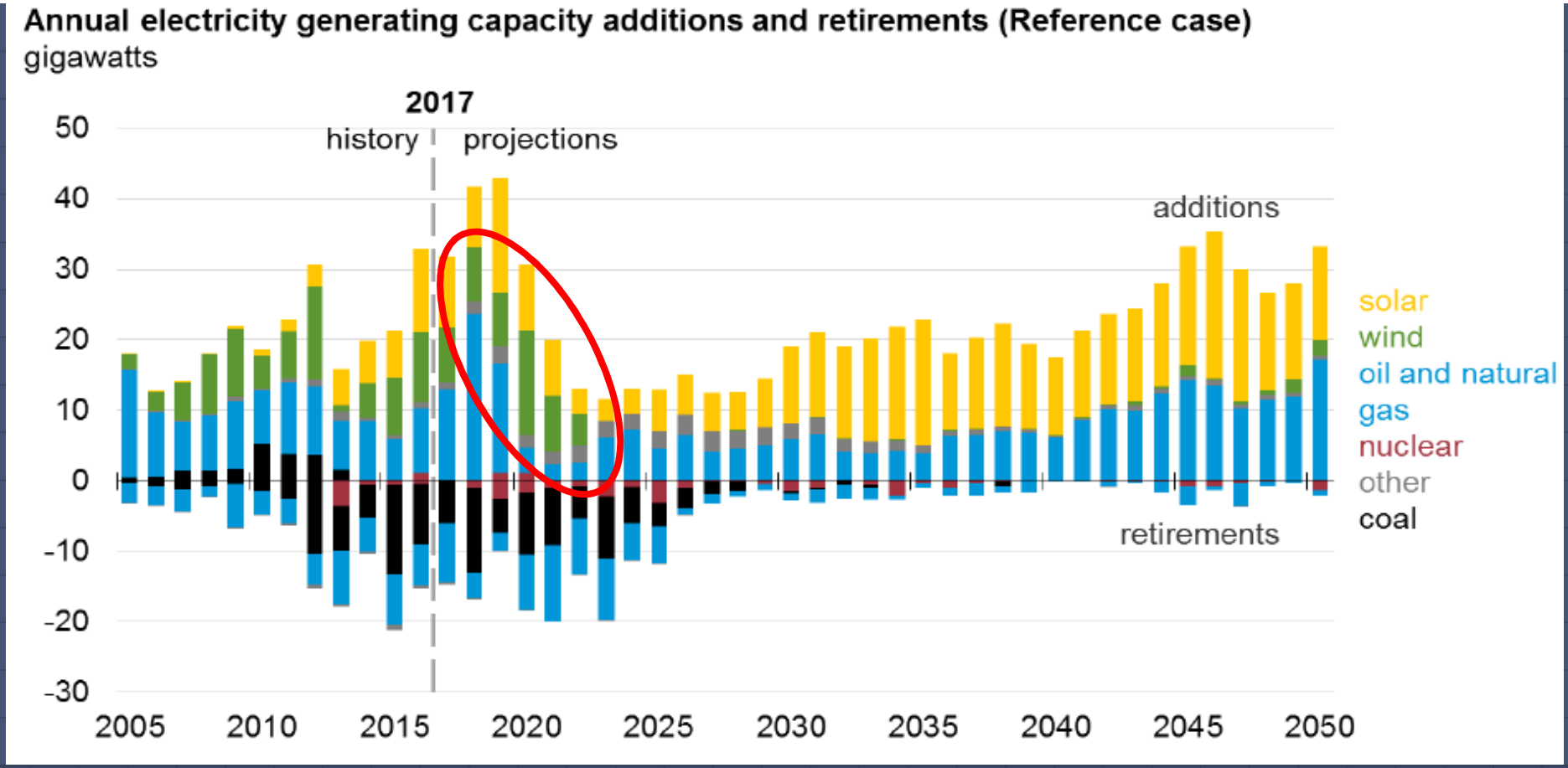
Predicted Capacity Change by 2021:
+25,362 MW

Wind presently accounts for

6.3%

of domestic energy


12 MW capacity
220-meter rotor
107-meter long blades
260 meters high
67 GWh gross AEP
63% capacity factor
38,000 m² swept area
Wind Class IEC: IB
Generates double the energy as previous GE Haliade model
Generates almost 45% more energy than most powerful wind turbine available on the market today
Will generate enough clean power for up to 16,000 European households per turbine, and up to 1 million European households in a 750 MW configuration windfarm
HALIADE-X 12 MW
GE Renewable Energy is developing Haliade-X 12 MW, the biggest offshore wind turbine in the world, with 220-meter rotor, 107-meter blade, leading capacity factor (63%), and digital capabilities, that will help our customers find success in an increasingly competitive environment.
1063 ft
324 m
853 ft
260 m
1046 ft
319 m
Eiffel Tower
Haliade-X 12 MW
Chrysler Building

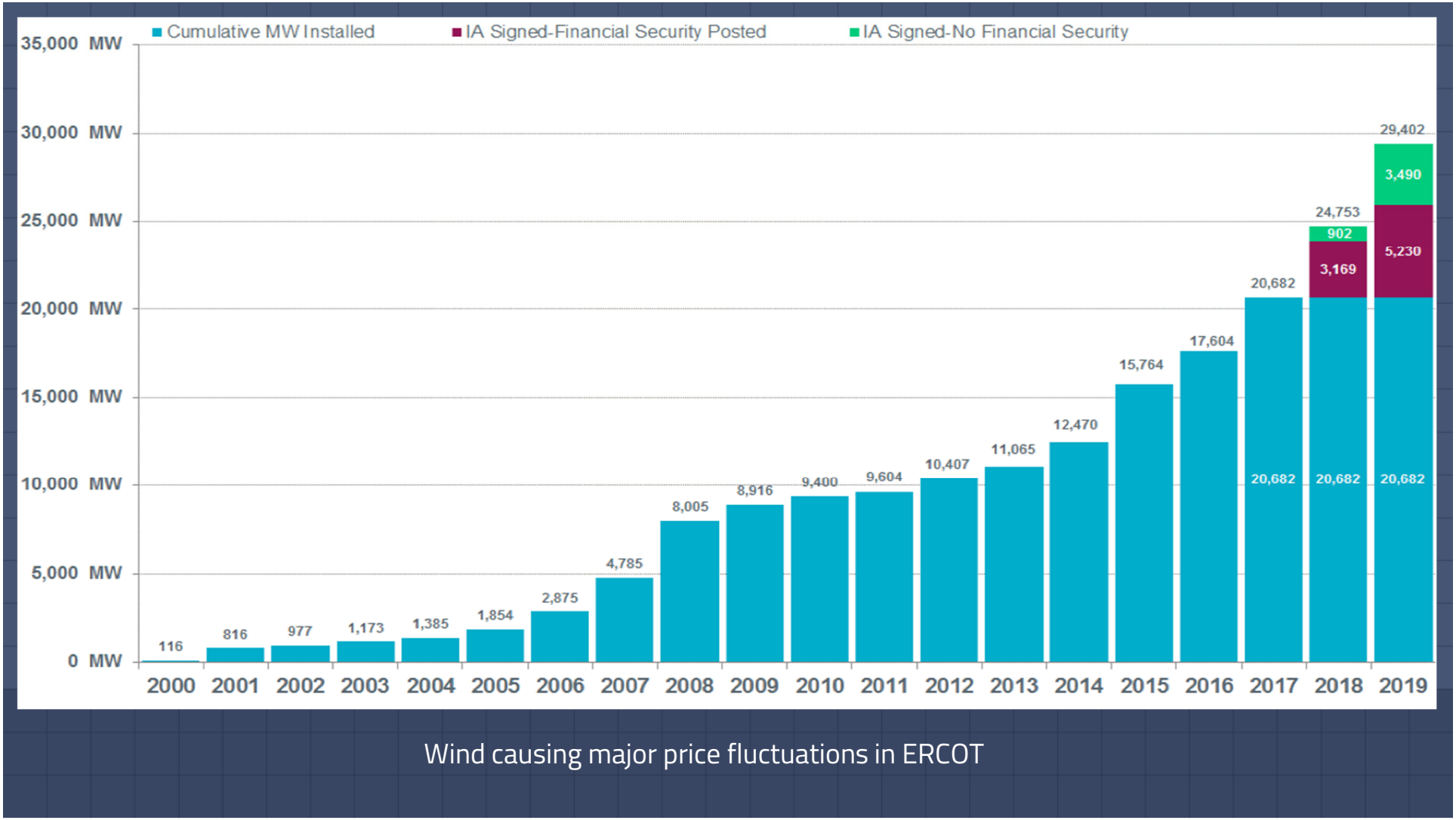


Wind projects taper off as soon as subsidies expire

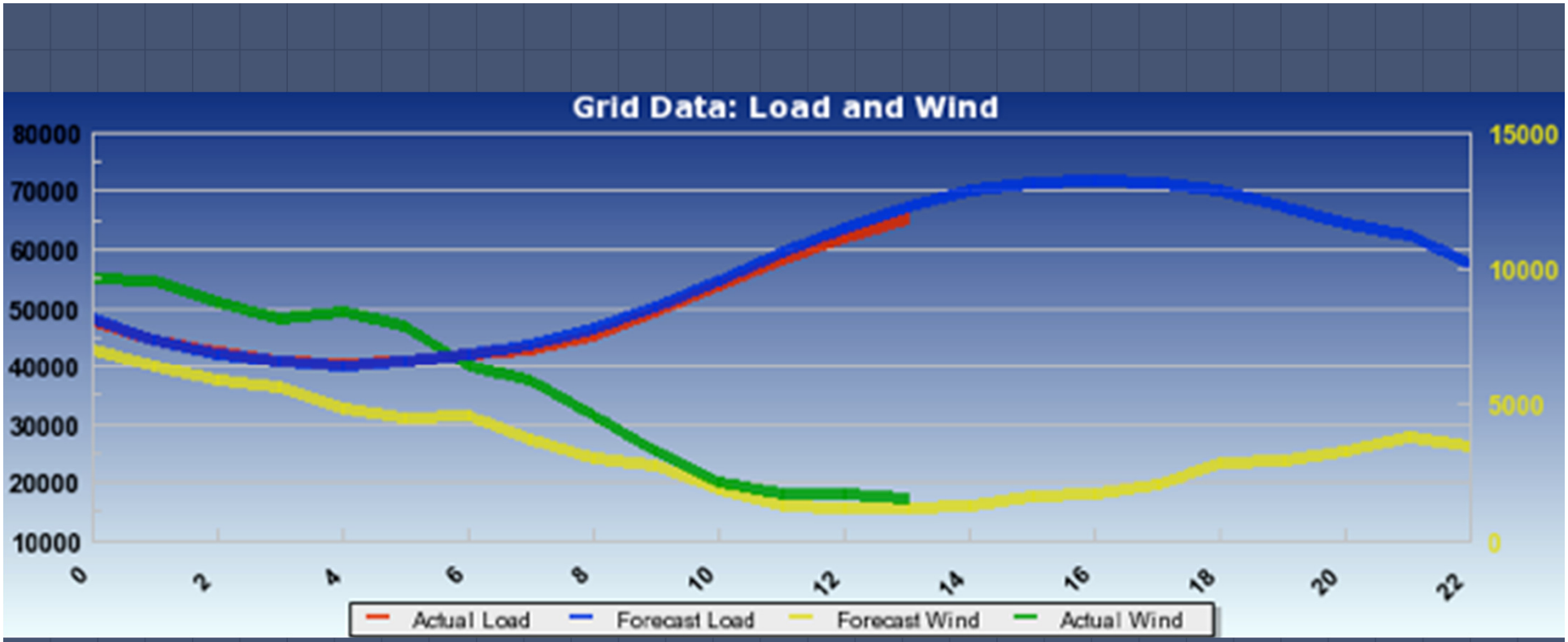
The Choice – Reliability vs Sustainability

And the problems that plague us

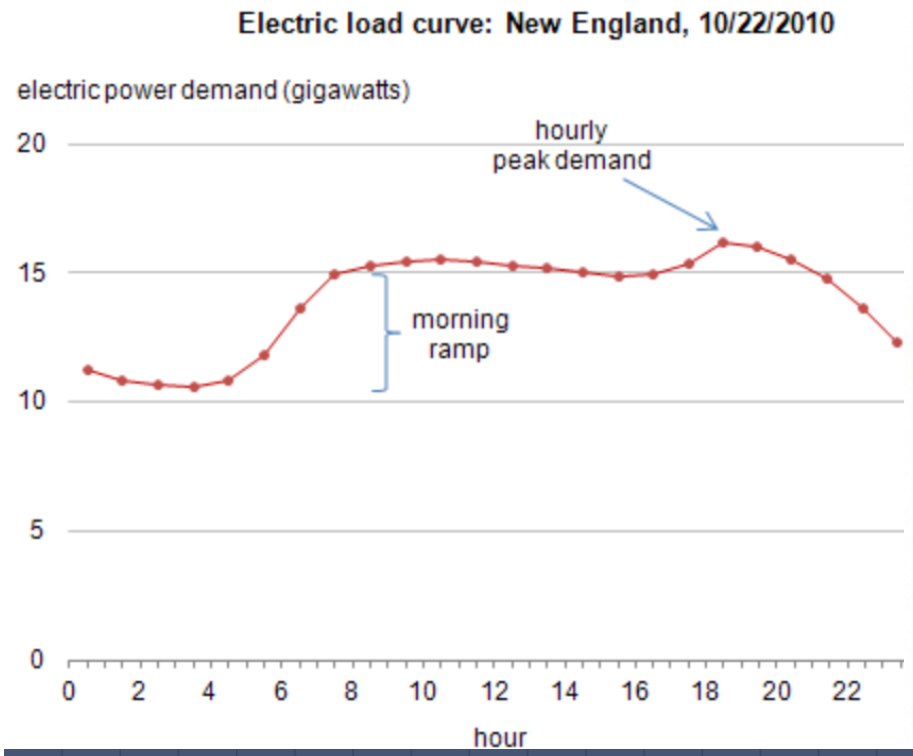
2

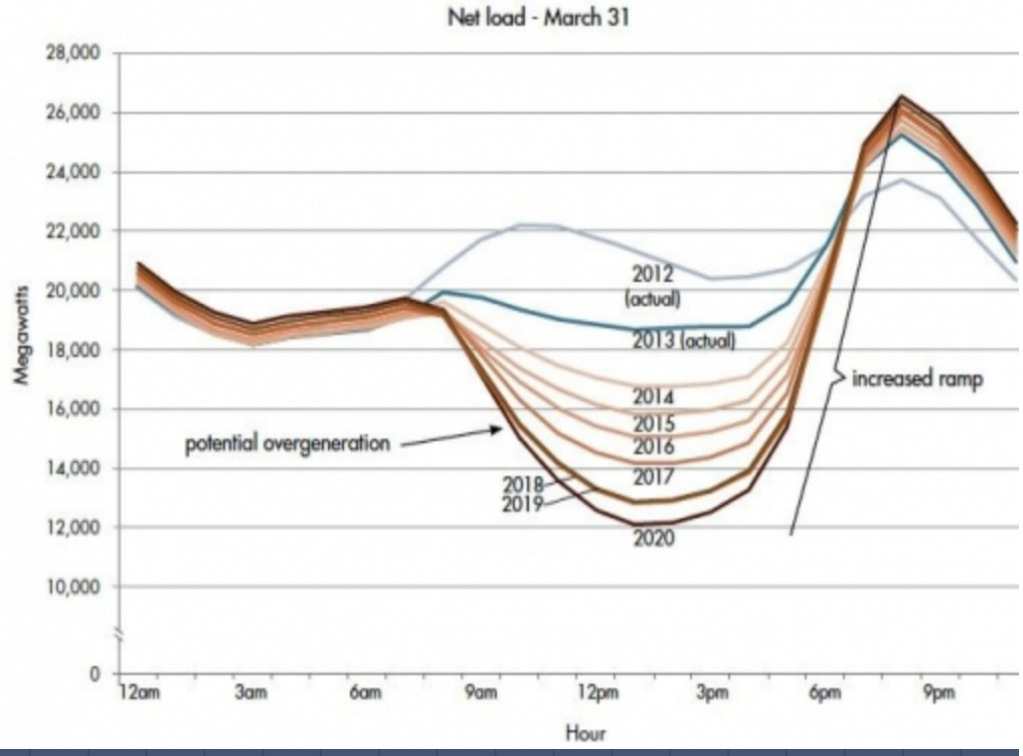


Wind causing major price fluctuations in ERCOT



Wind fluctuations on any given day





New England – vs – California

The Duck Curve in solar heavy communities

Technologies Paving the Way

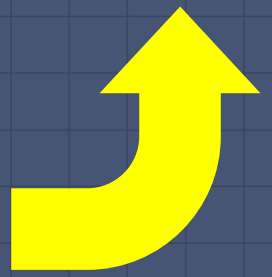
What are some solutions?
What should we look for in the coming decade?

3

Energy Storage Options

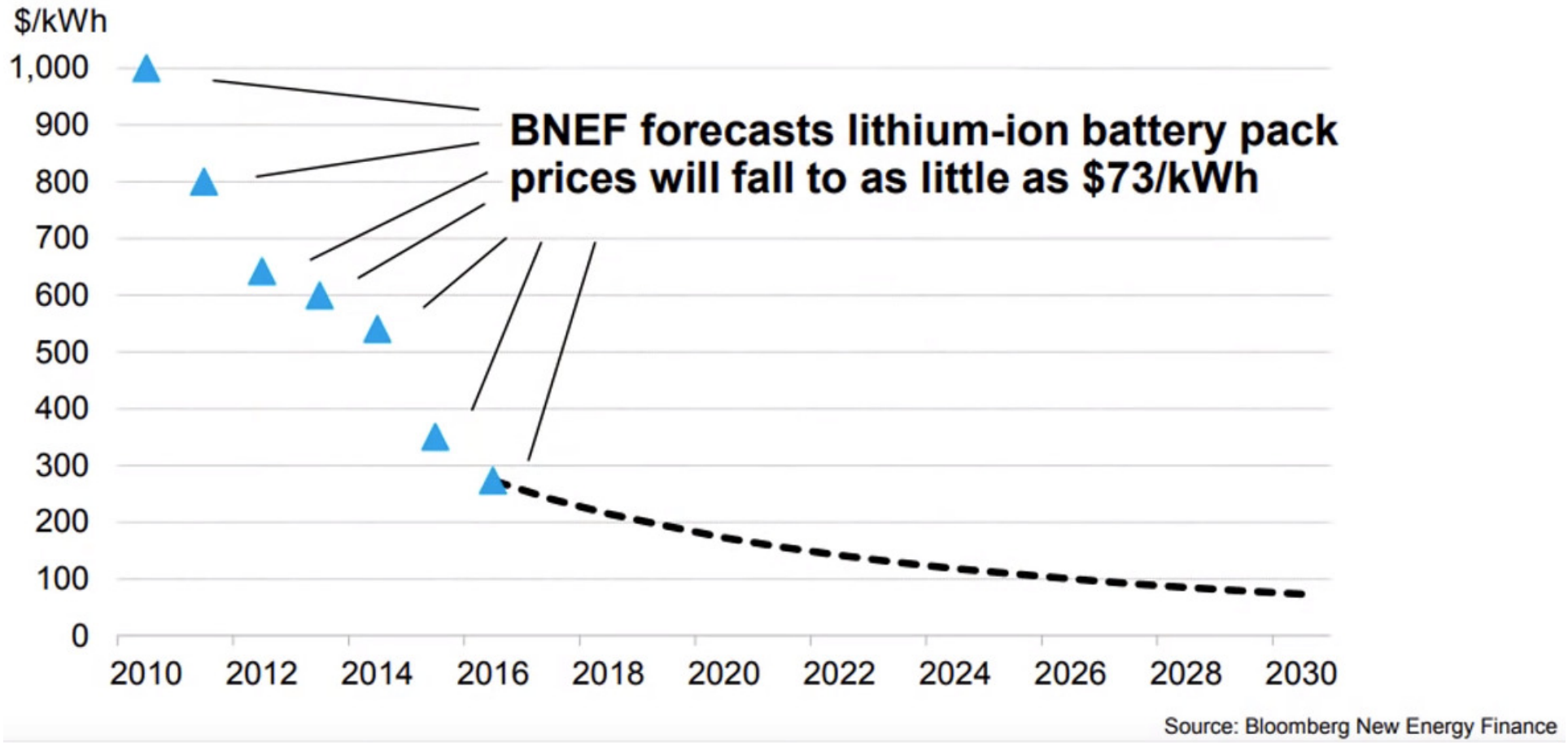
Compressed Air	Pumped Hydro	Thermal	Lithium-Ion (2017)
$159/KWH	$263/KWH	$331/KWH	$652/KWH

Lithium-Ion (2018)
$200/KWH

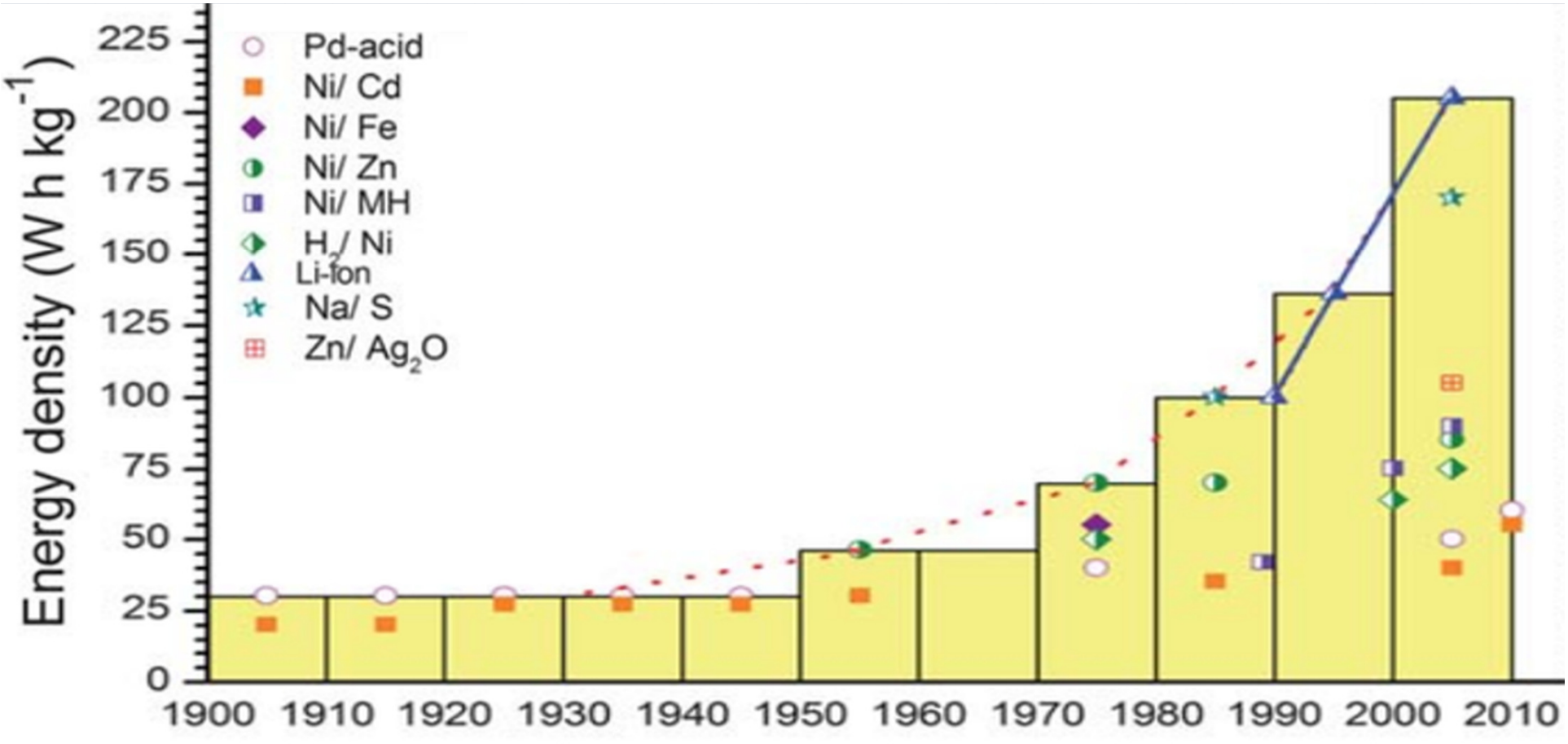


- Most scalable solution at present is pumped hydro
- Lithium-Ion advancements are helping batteries win!
- Batteries are now competitive with natural gas peak-shaving costs

($200/KWH to burn natural gas at peak load
vs $200/KWH with battery bank)



New technology has driven down the price of batteries



Moore's Law for Batteries

More improvements on the way

- Adding Silicon
  - Yields 25% higher energy density
  - Improves recharge rate by 8X
  - Low cost material

  - However, even adding as little as 1% silicon causes swelling and shrinking upon recharge and discharge

Supercapacitor Development

- Can provide Megawatts to the grid in a matter of seconds
- Technology is only 10 years old
- Saving companies thousands by reclaiming otherwise wasted energy

Batteries	Supercaps
- Long-term storage	- Rapid charge and discharge
- Can hold 90% of energy over a year	- Losing energy the moment it receives it
- Charging may take several hours	- Can charge kilowatts in seconds
- Used to maintain power for hours or days	- Used to provide large amounts of power in seconds

Tesla Powerwalls could shake up the grid

Scalable, Efficient, Effective.

- Stores 13.5 kWh each
  - Up to 10 per household
- New source for baseload needs
  - Decentralizes current energy grid

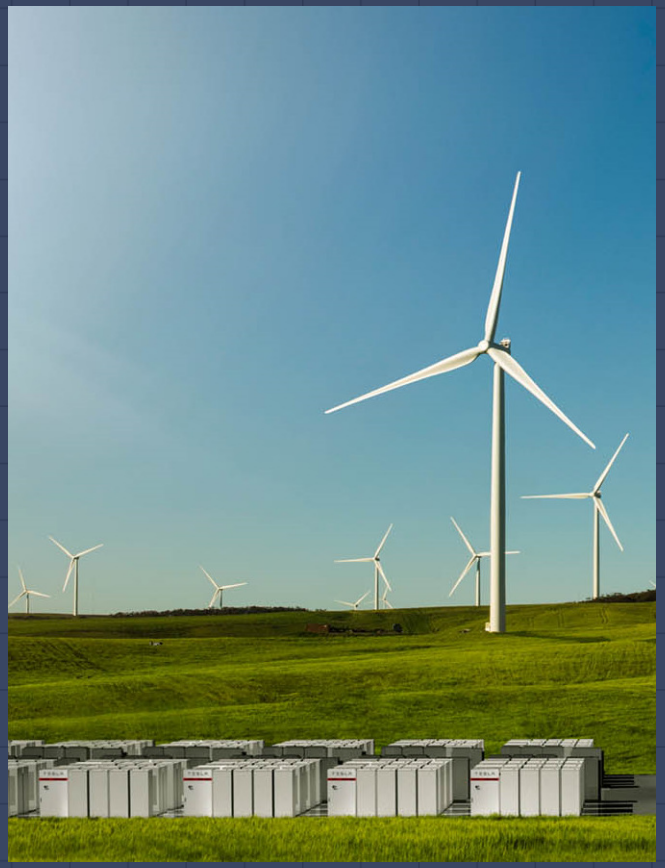
Tesla Powerpacks are making batteries a reality

The addition of a 100MWh Battery pack cut back power outages by 90% in South Australia

Reduced prices at peak demand by 90%, saved $24 million in first quarter ROI = 6 months!!

200 of these systems could support the whole of Australia

Root cause: gov't mandated over-reliance on renewables and retirement of dispachables.



Conclusions

- We can probably be carbon neutral for electric power in 30 years by doing wind and solar combined with massive amounts of storage
  - It could completely decentralize the grid as we know it
  - Who will maintain the transmission lines?
- It might be short sighted to abandon Nuclear technologies
  - So many additional benefits by using safer technologies
  - Can also utilize most of what we were going to bury at yucca mountain
- Your car and house might be part of your local micro grid
- Continue to hope for new advances in Storage, Batteries, and Solar
- … and maybe even have a bit of hope for MSR's or LFTR's