Fear versus Possibility

So, first of all, let me assert my firm belief that ***the only thing we have to fear is … fear itself*** *— nameless, unreasoning, unjustified terror which paralyzes needed efforts to convert retreat into advance.*

In every dark hour of our national life a leadership of frankness and of vigor has met with that understanding and support of the people themselves which is essential to victory. And I am convinced that you will again give that support to leadership in these critical days.

Franklin D. Roosevelt, 1933

Fear of What?

- Fear that we are doomed
  - Therapists specializing in Climate Depression
- Fear that technofixes are the problem
- Fear that achieving NetZero is impossible
- Fear of nuclear anything
  - Had to change Nuclear Magnetic Imaging to MRI
  - Invisible poisons that last forever
  - Reactors exploding as A-bombs in our back yard

Neuroscience of Nuclear Fear
Total Immune system has two aspects

- Physical Immune System
  - T-cells and antibodies
    - Protects after a pathogen has gained entry
- Behavioral Immune System
    - From deep evolutionary ancestry
    - Searches environment for possible disease sources
      - Aims for very low “Missed Targets”
      - Necessarily has high “False Alarm Rate”
    - Bodily reactions
      - Disgust
      - Fear
      - Avoidance
    - Once triggered, it’s difficult to turn off

See Needle Points by Norman Doidge:
https://www.tabletmag.com/sections/science/articles/needle-points-vaccinations-chapter-one

Just the Facts…

- I grew up in a good liberal Democrat family
  - Just provide the facts, and
  - People will do the right thing
- But, world wide, many have developed deep immune response to nuclear anything
  - Guilt over bombing of Japan
  - Nuclear accidents creating invisible poisons
  - Deliberate stoking of fear by organizations
    - Ubiquitous photos of mushroom clouds
    - Claims of contaminating local dairies and milk supplies
    - Loss of trust in social systems
  - I was among the doubters, especially after Fukushima

My Turning Points

- Agreed to lead a TED TALK TUESDAY
- Chose Nuclear Power as topic
  – Stewart Brand & Mark Jacobson (2010)
    - **Debate: Does the world need nuclear energy?**
    - https://www.ted.com/talks/stewart_brand_mark_z_jacobson_debate_does_the_world_need_nuclear_energy?language=en
  – Bill Gates (2010)
    - Innovating to Zero
  – David McKay
    - A Reality Check on Renewables
  – Stewart Brand (2009)
    - Four Environmental Heresies
- I was persuaded by new facts—Stewart Brand converted

Just the Facts…

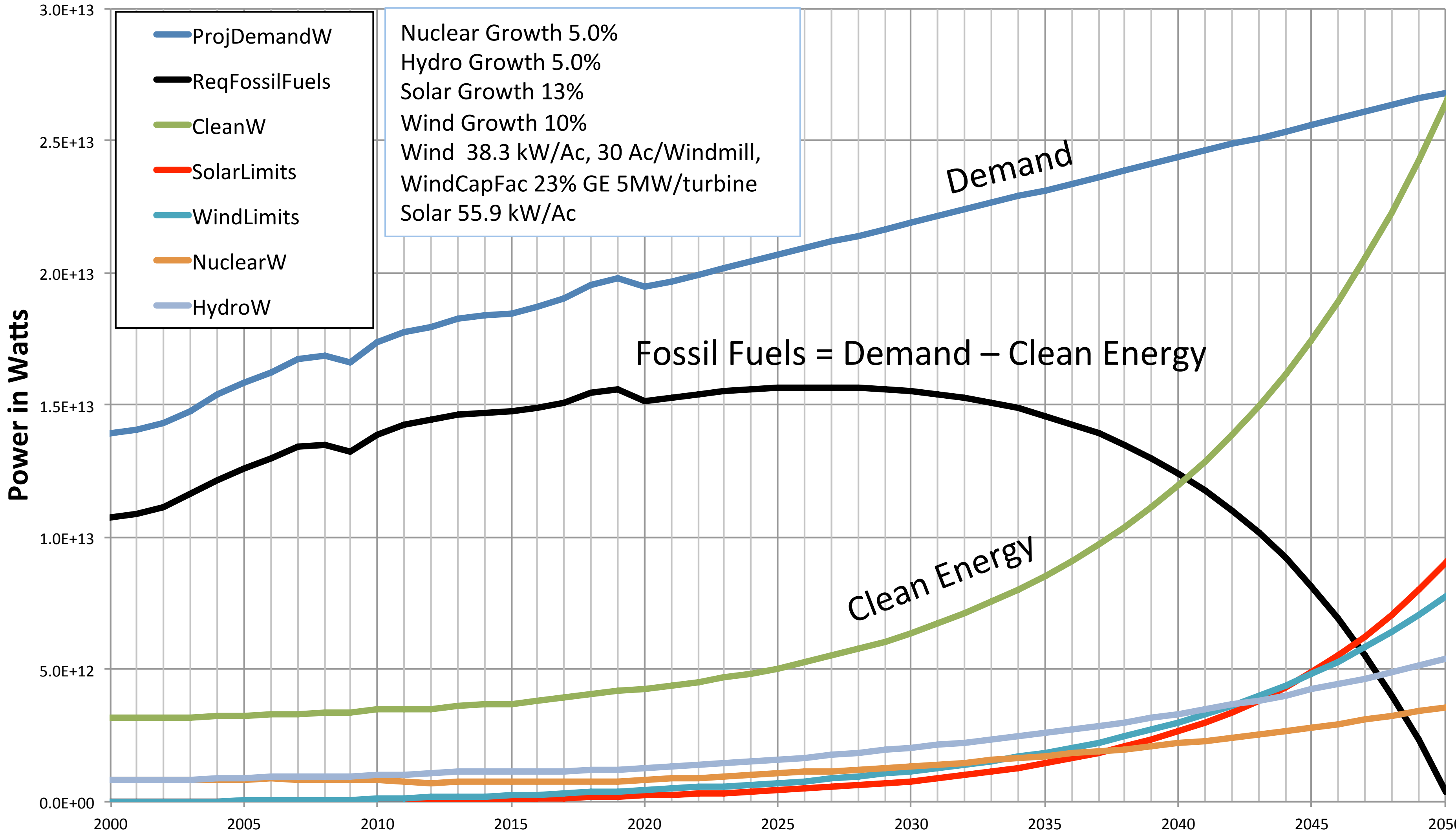
Fear 1: Is NetZero by 2050 Possible?

I showed a model with settable growth rates for all primary global energy sources

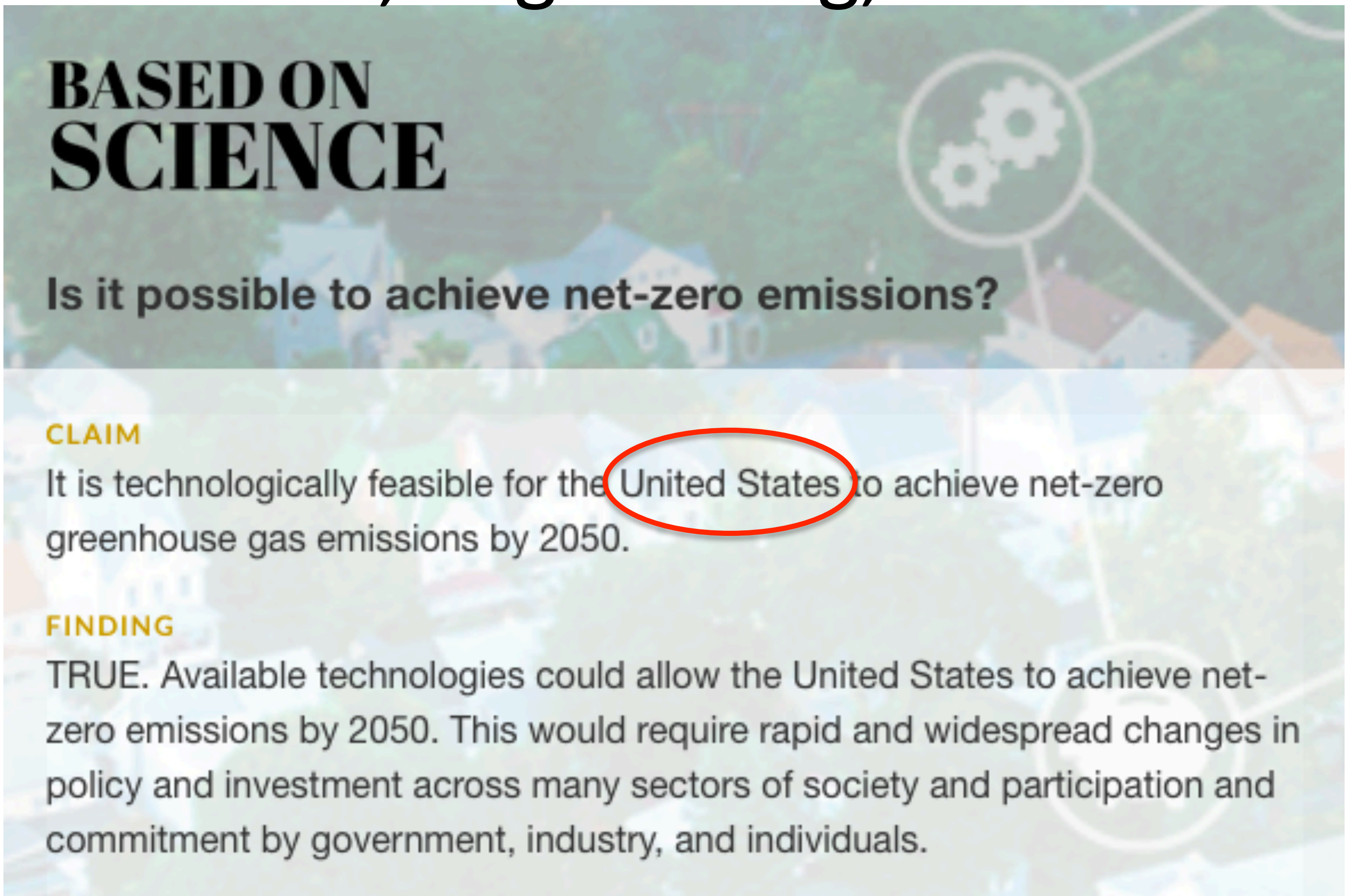
- Numerous scenarios where net zero is feasible
- Based on annualized averages
  - Necessary but not sufficient

- Challenge arises when we look at daily usage

Plausible to Eliminate Fossil Fuels by 2050:



National Academies of Science, Engineering, Medicine



BASED ON SCIENCE

Is it possible to achieve net-zero emissions?

CLAIM

It is technologically feasible for the United States to achieve net-zero greenhouse gas emissions by 2050.

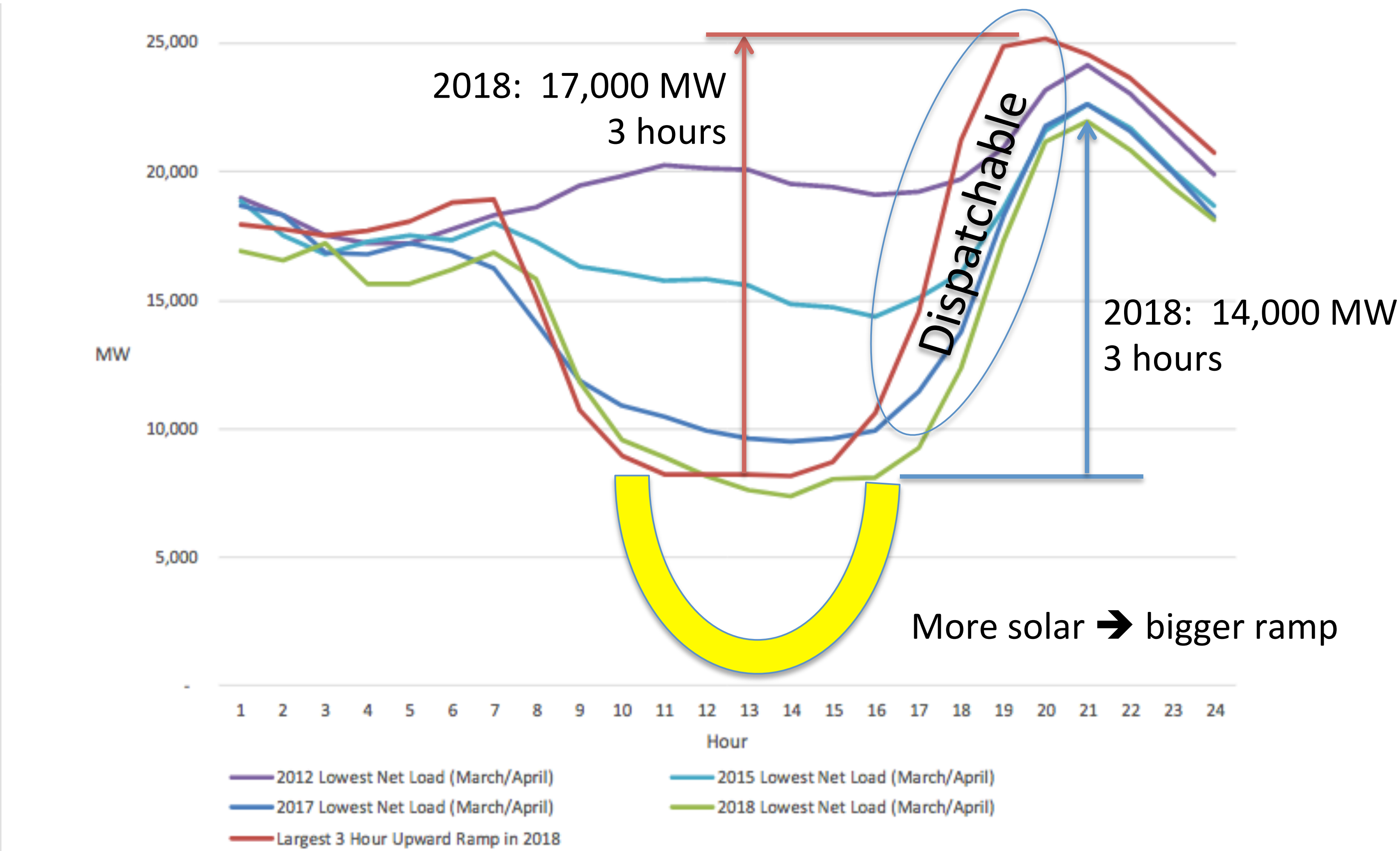
FINDING

TRUE. Available technologies could allow the United States to achieve net-zero emissions by 2050. This would require rapid and widespread changes in policy and investment across many sectors of society and participation and commitment by government, industry, and individuals.

https://www.nationalacademies.org/based-on-science/is-it-possible-to-achieve-net-zero-emissions

Daily Challenge

California (Solar) Duck Curve



Adding more solar → increases demand for **Dispatchable Clean Energy**

Source: Developed by Energy Commission staff using data from the California ISO

Dispatchable Clean Energy Sources

- Hydro
- Pumped Hydro
- Batteries
- Geothermal
- Nuclear

California's Duck Curves
Projected to 2030 including Demand Response

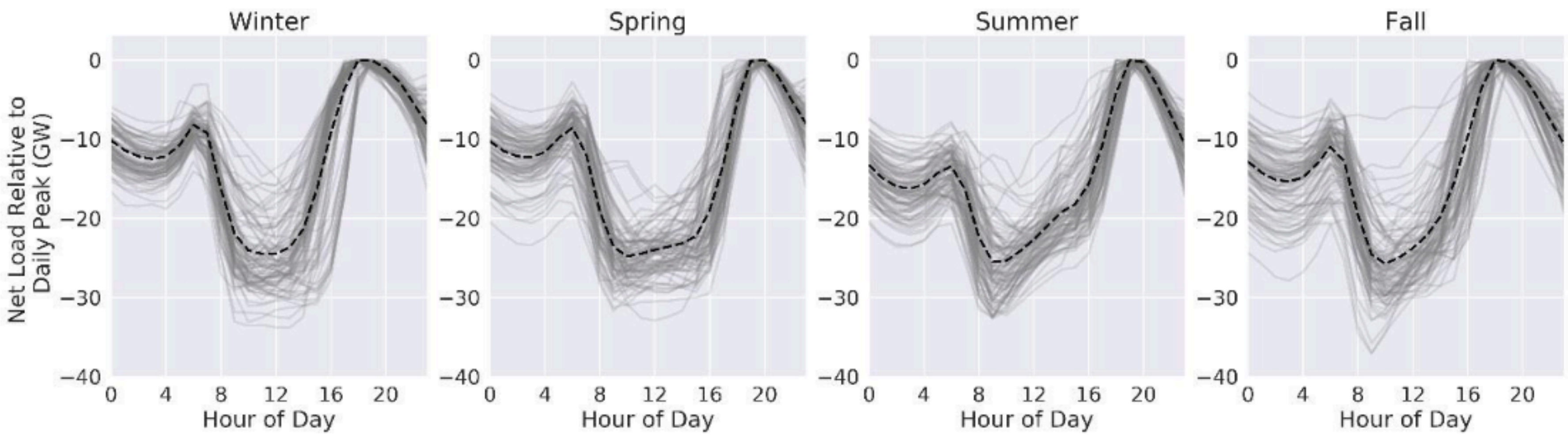


Figure 3-11. Forecasted system-level net load (gross demand less solar and wind generation) for 2030, normalized to each curve's peak value, in each day of the year (solid gray lines) and averaged by season (dashed black lines). There is evident variability in the size of the morning and evening ramps, both seasonally and from day to day within each season.

- Dispatchable Energy includes CO_2 emitting GAS
- Need Dispatchable Clean Energy (DCE) for ramps

https://eta-publications.lbl.gov/sites/default/files/ca_dr_potential_study_-_phase_3_-_shift_-_final_report.pdf

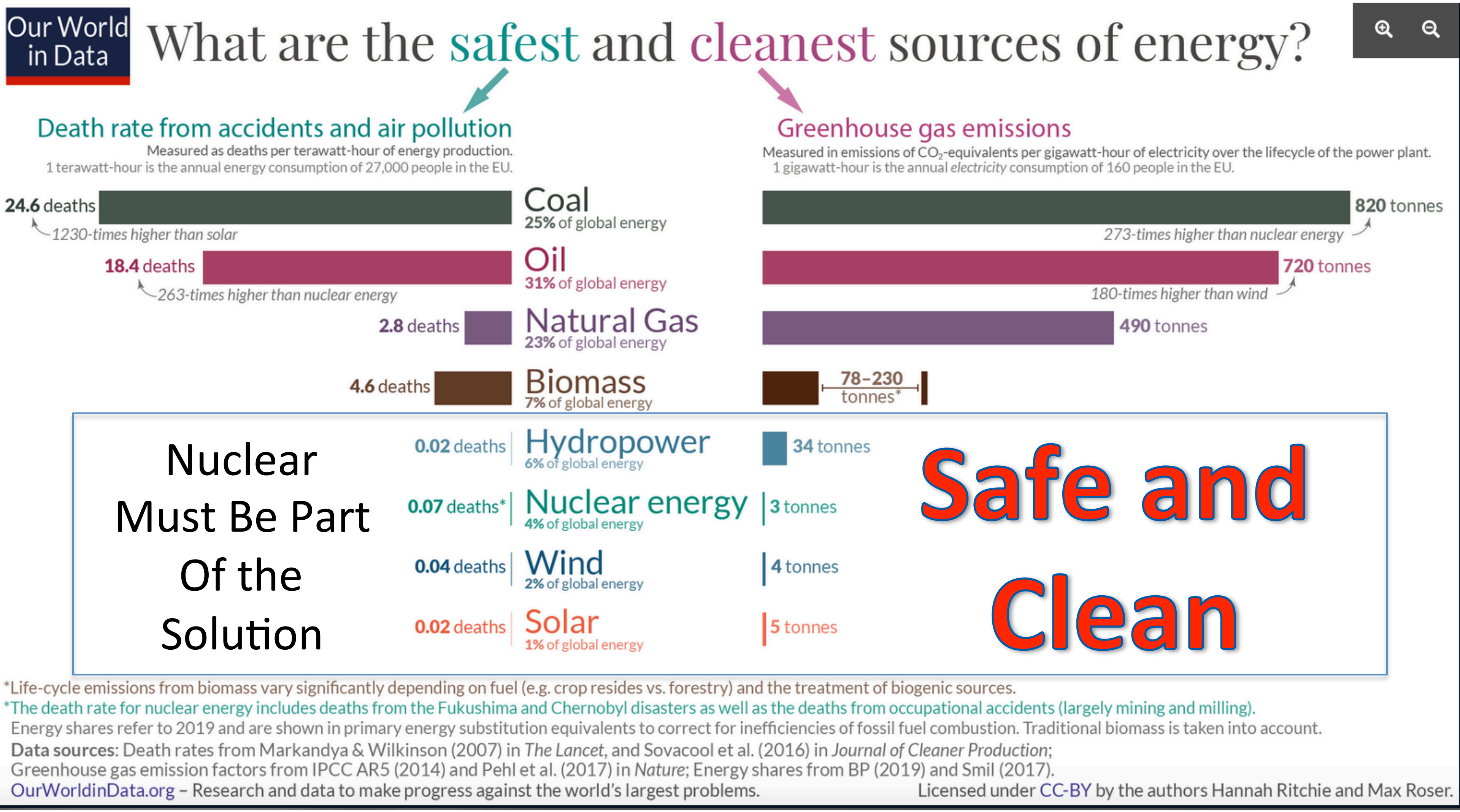
Nuclear Fear: The Main Issues

1. Safety
2. Waste
3. Proliferation
4. Cost
    a. Levelized Cost of Electricity (LCOE) in $/MW
    b. Installation
5. Deployment time

Safety

- All 3 reactor failures ➔ loss of cooling
  - And human blunders
  - AC power required to run cooling water pumps
  - Chernobyl released significant radioactive isotopes
  - Fukushima after effects are below safe limits
  - Three Mile Island released near zero
    - No measureable radiation above natural background
- All new reactors are passively cooled
  - Natural processes are sufficient to prevent any meltdowns
- And NO, it is impossible for a nuclear reactor to blow up
  - Bomb grade Uranium is 90% U235
  - LWRs use fuel enriched to 3%-5% U235
  - Advanced reactors will use High Assay Low Enriched Uranium fuel
    - Enriched to about 20%

Nothing to Fear but Fear Itself



Nuclear Must Be Part Of the Solution

Safe and Clean

Waste

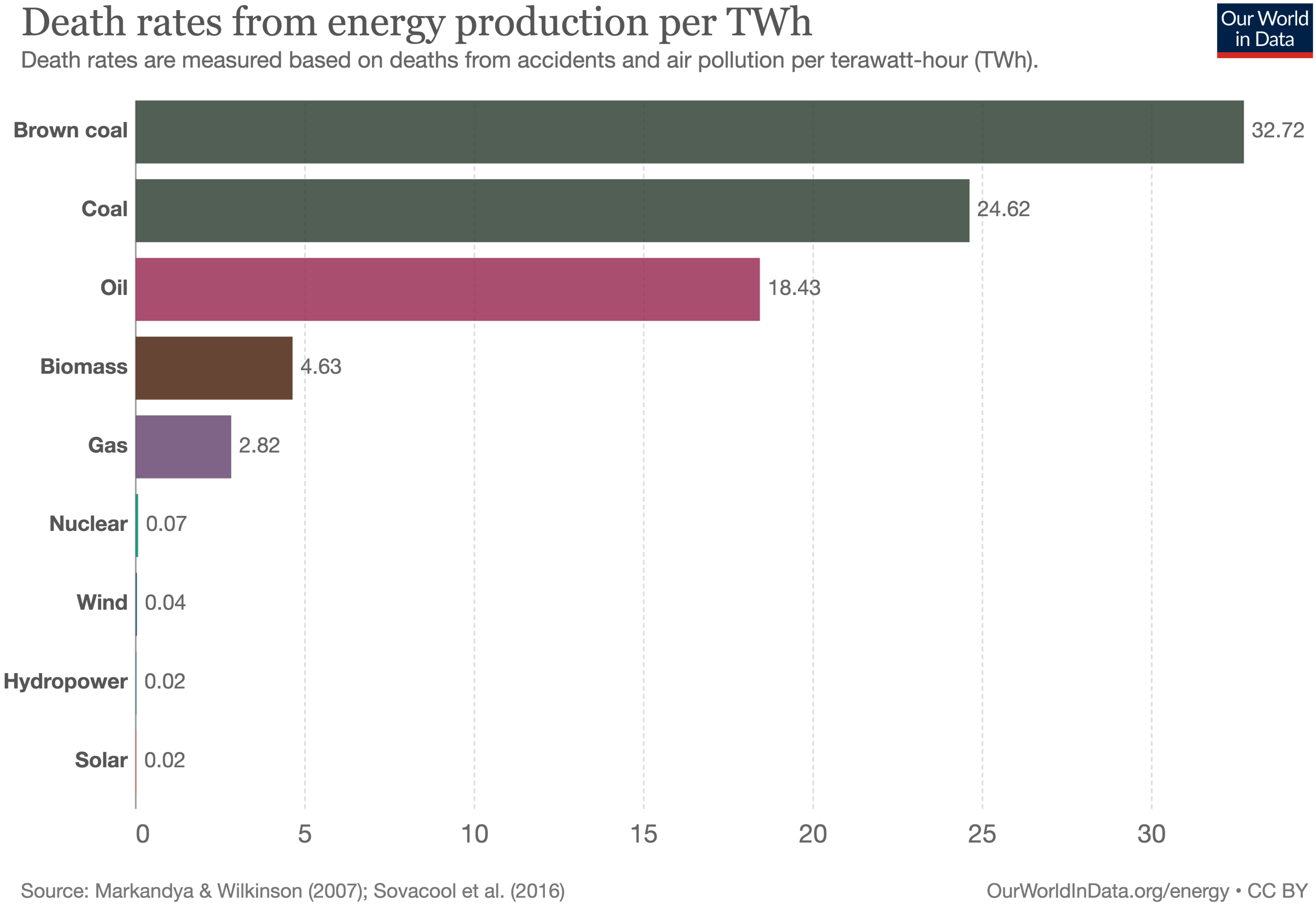
- Very little waste compared to coal
- Waste is safely stored on site awaiting
  - Burning as fuel in advanced reactors
  - Dry Cask Storage➔ casks are ≈indestructable
    - See Illinois Energy Professor https://www.youtube.com/watch?v=KnxksKmJa6U
- Zero waste has been released by commercial reactors

Dry Cask Storage

By Nuclear Regulatory Commission - http://www.nrc.gov/reading-rm/photo-gallery/index.cfm?&cat=Nuclear_Reactors, Public Domain, https://commons.wikimedia.org/w/index.php?curid=3429615

Coal: 10,000 tons/day @ 1 GW

Coal Ash Storage Problems



Death rates from energy production per TWh
Death rates are measured based on deaths from accidents and air pollution per terawatt-hour (TWh).
Our World in Data
Brown coal
32.72
Coal
24.62
Oil
18.43
Biomass
4.63
Gas
2.82
Nuclear
0.07
Wind
0.04
Hydropower
0.02
Solar
0.02
0
5
10
15
20
25
30
Source: Markandya & Wilkinson (2007); Sovacool et al. (2016)
OurWorldInData.org/energy • CC BY

https://www.nrdc.org/onearth/coal-ash-hazardous-coal-ash-waste-according-epa-coal-ash-not-hazardous-waste

PEACE, JUSTICE AND STRONG INSTITUTIONS

Proliferation

- nuclear proliferation, **the spread of nuclear weapons, nuclear weapons technology, or fissile material to countries that do not already possess them**. The term is also used to refer to the possible acquisition of nuclear weapons by terrorist organizations or other armed groups.
- Non Proliferation Treaty has worked
- FUSION is the long term answer

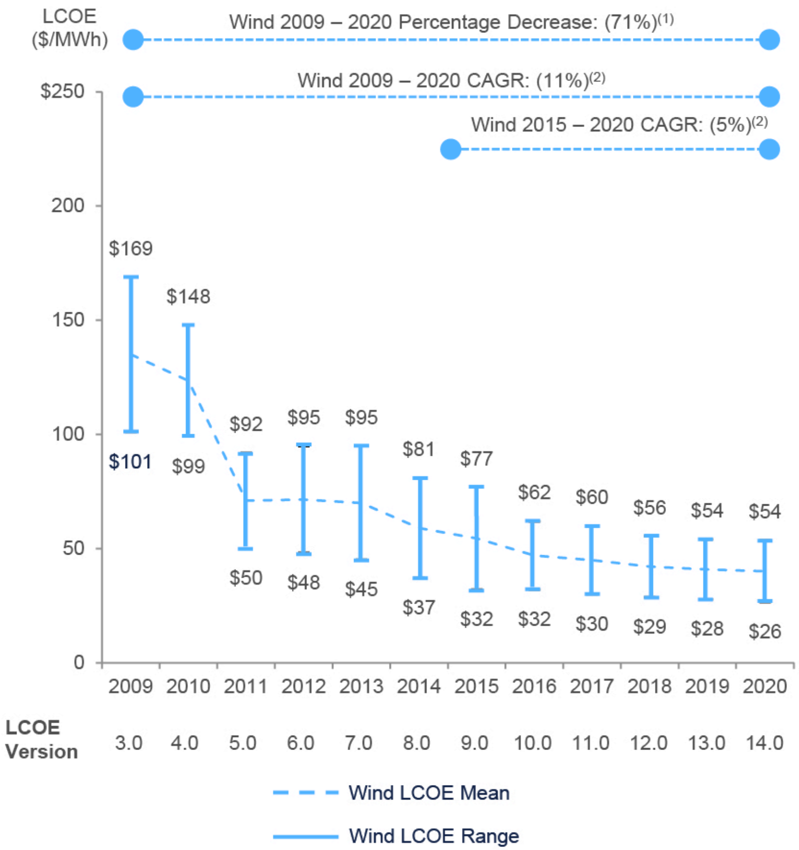
Cost of Nuclear Energy

- Capital cost to build the plant
- Cost per MWh compared with Wind and Solar

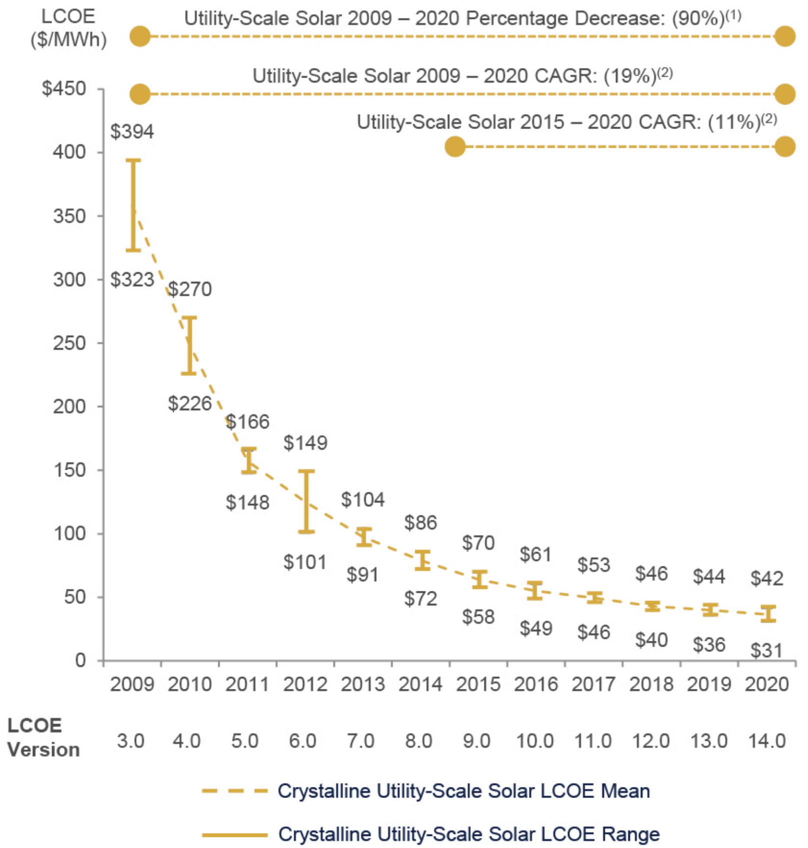
History of Renewable Costs

In light of material declines in the pricing of system components and improvements in efficiency, among other factors, wind and utility-scale solar PV have exhibited dramatic LCOE declines; however, as these industries have matured, the rates of decline have diminished

Unsubsidized Wind LCOE

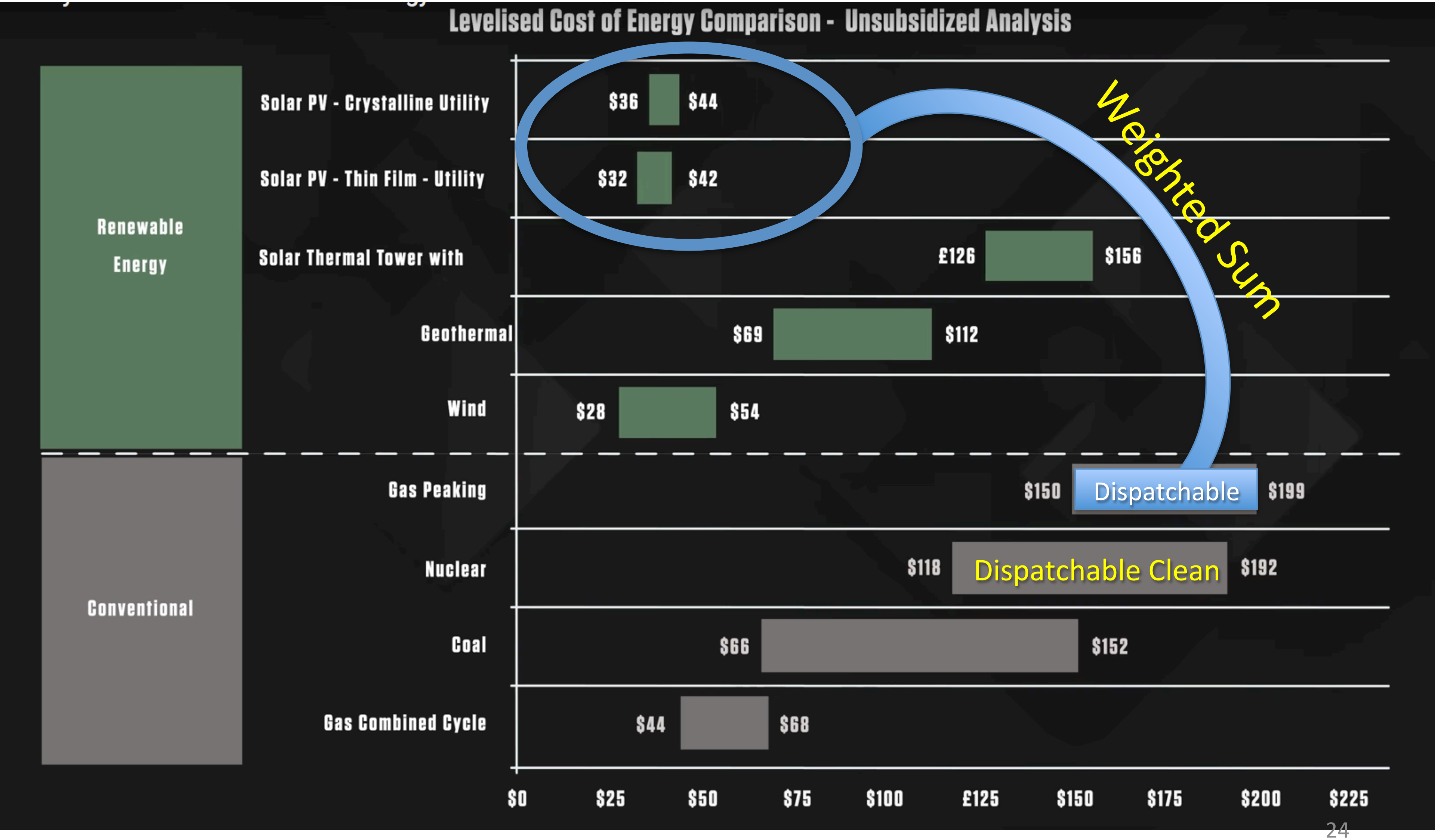


Unsubsidized Solar PV LCOE



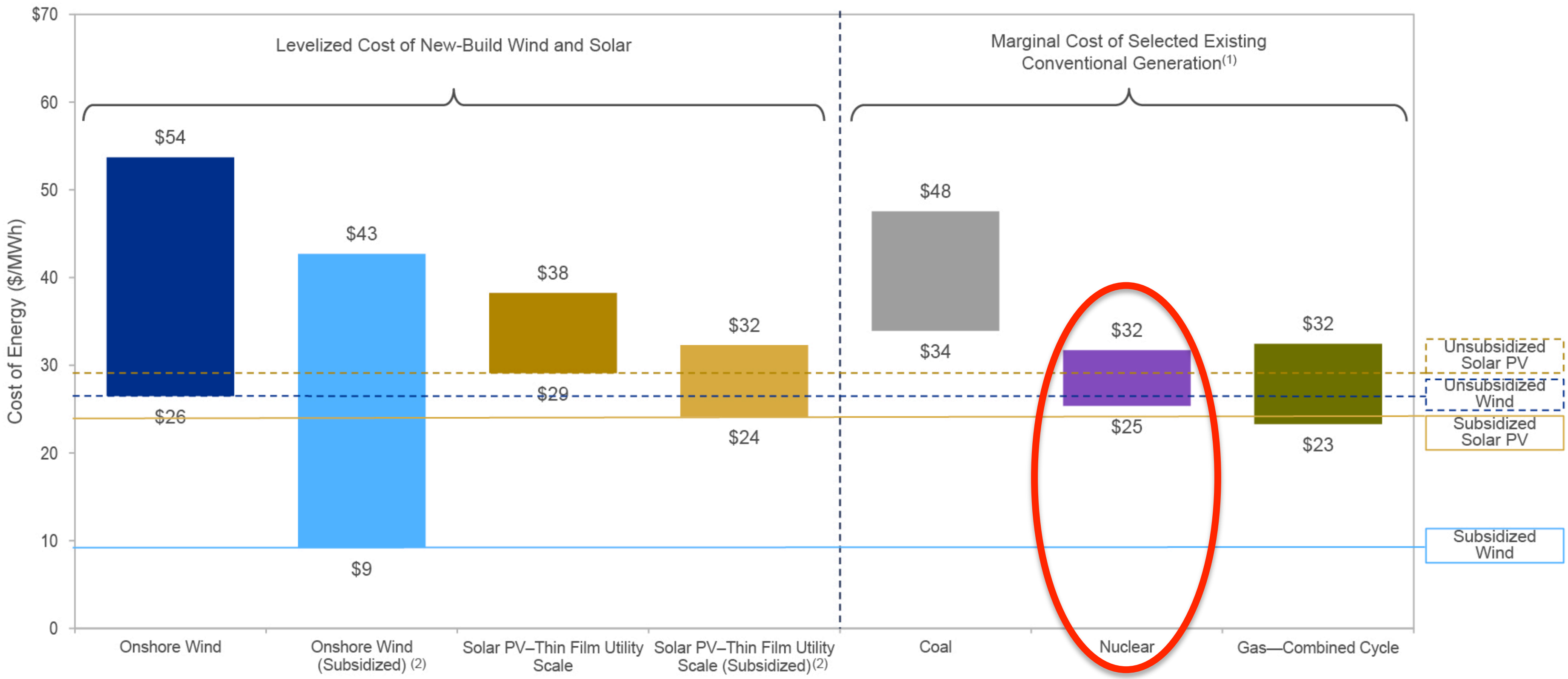
Source: Lazard estimates.
(1) Represents the average percentage decrease of the high end and low end of the LCOE range.
(2) Represents the average compounded annual rate of decline of the high end and low end of the LCOE range.

Cost in $/MWh


Levelised Cost of Energy Comparison - Unsubsidized Analysis
Renewable Energy
Solar PV - Crystalline Utility
$36
$44
Solar PV - Thin Film - Utility
$32
$42
Solar Thermal Tower with
£126
$156
Geothermal
$69
$112
Wind
$28
$54
Conventional
Gas Peaking
$150
$199
Dispatchable
Nuclear
$118
$192
Dispatchable Clean
Coal
$66
$152
Gas Combined Cycle
$44
$68
Weighted Sum
$0
$25
$50
$75
$100
£125
$150
$175
$200
$225

Levelized Cost of Energy Comparison

Certain renewable energy generation technologies have an LCOE that is competitive with the marginal cost of existing conventional generation



Source: Lazard estimates.

Note: Unless otherwise noted, the assumptions used in this sensitivity correspond to those used in the global, unsubsidized analysis as presented on the page titled "Levelized Cost of Energy Comparison—Unsubsidized Analysis".

(1) Represents the marginal cost of operating fully depreciated gas combined cycle, coal and nuclear facilities, inclusive of decommissioning costs for nuclear facilities. Analysis assumes that the salvage value for a decommissioned gas combined cycle or coal asset is equivalent to its decommissioning and site restoration costs. Inputs are derived from a benchmark of operating gas combined cycle, coal and nuclear assets across the U.S. Capacity factors, fuel, variable and fixed operating expenses are based on upper and lower quartile estimates derived from Lazard's research.

(2) The subsidized analysis includes sensitivities related to the TCJA and U.S. federal tax subsidies. Please see page titled "Levelized Cost of Energy Comparison—Sensitivity to U.S. Federal Tax Subsidies" for additional details.

https://www.lazard.com/perspective/lcoe2020

Time Until Deployment

- Cost overruns usually due to delays
  - Construction loan interest can doom a project
  - Design changes during construction
- NuScale first of kind goal—2029-2030
- Other new designs after 2030
- Fear not—we will need lots of clean energy from 2030 to 2050
- After Net Zero we still need to reduce CO2 in the atmosphere and oceans

https://www.carbonbrief.org/explainer-will-global-warming-stop-as-soon-as-net-zero-emissions-are-reached

Nuclear has a Vital Role: Dispatchable Clean Energy

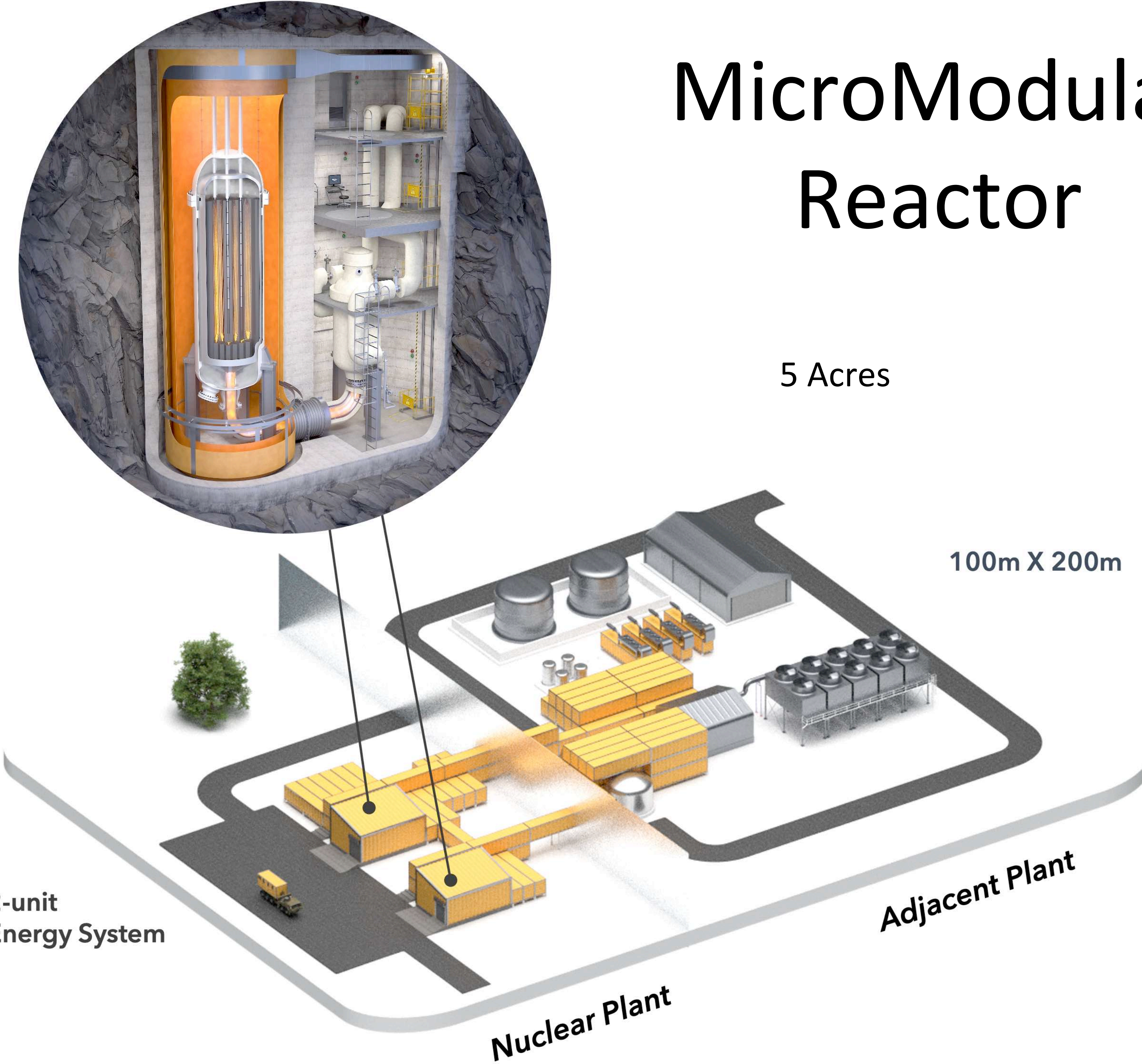
- All Advanced Reactors can *Load Follow*
  - Respond to Dispatch Commands from grid operator
    - Generation UP, Generation DOWN
- Baseload is a special case of **Dispatchable**
  - Follow Seasonal Variations in Baseload Demand
- California imports energy to match Duck Ramp
  - Ramp get bigger with more solar penetration
- Nuclear has an essential role in decarbonization
  - Fission and then FUSION

Waste--

- Water cooled reactors use Low Enriched fuel
  - Natural Uranium ore is 99.3% U_{238} & .7% U_{235}
  - Low Enrichment increases U_{235} to 3%-5%
  - Light Water Reactor (LWR) "spent fuel"
    - 95% U238
    - 3% fission products
    - 1% unburned U235
    - 1% Plutonium (Pu239 half life 24,100 years)
    - Trace levels of long lived "Transuranics"
- Advanced Reactor Waste is Fission Products
  - All U238 converts to Plutonium and is burned
  - Transuranics are burned as fuel
  - Thorium fuel makes no Transuranics
  - Much less total volume (≈ .1%)
  - Decays to safe levels in under 500 years
- Manageable Problems

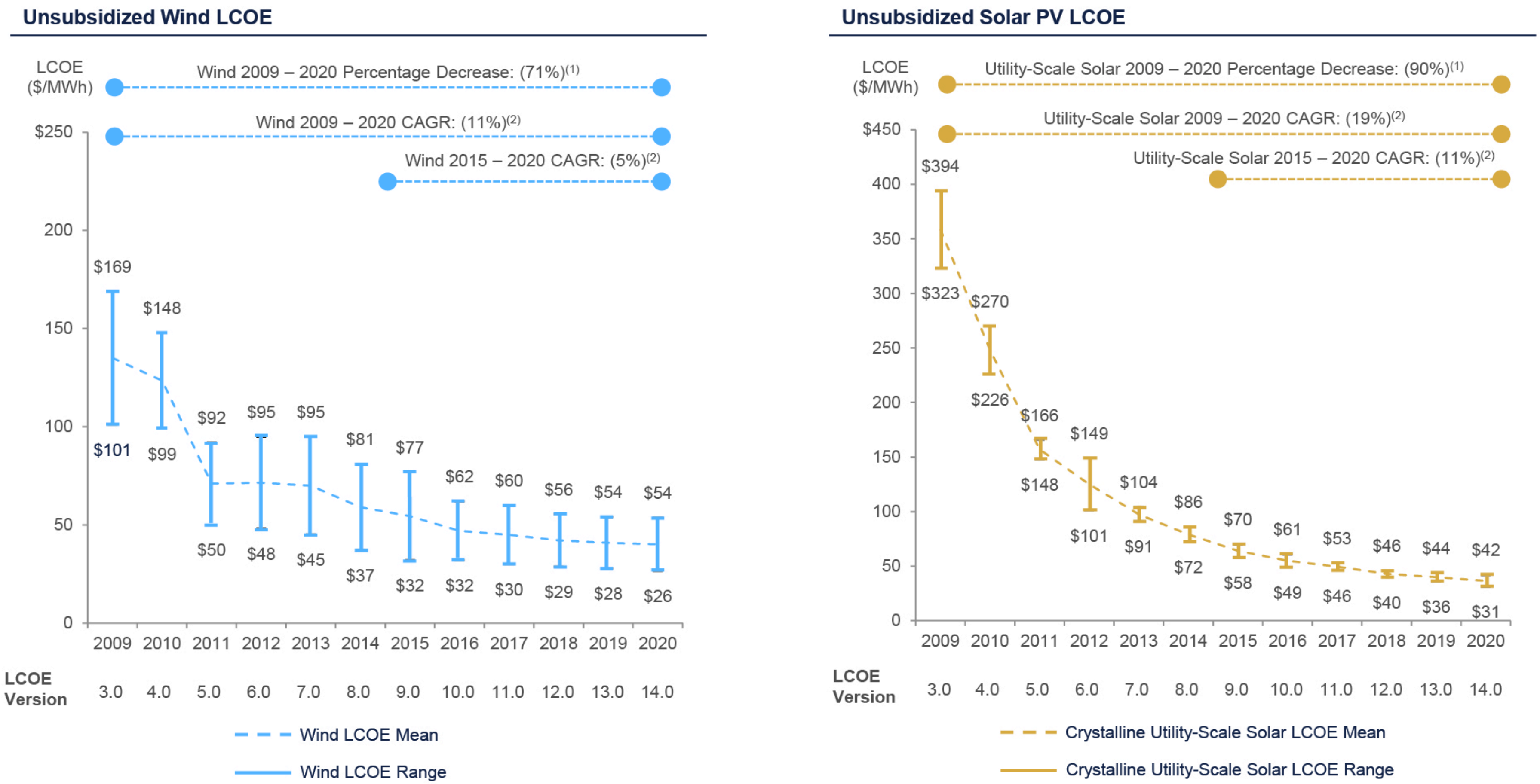
MicroModular Reactor

5 Acres



Unsubsidized Costs of Renewables

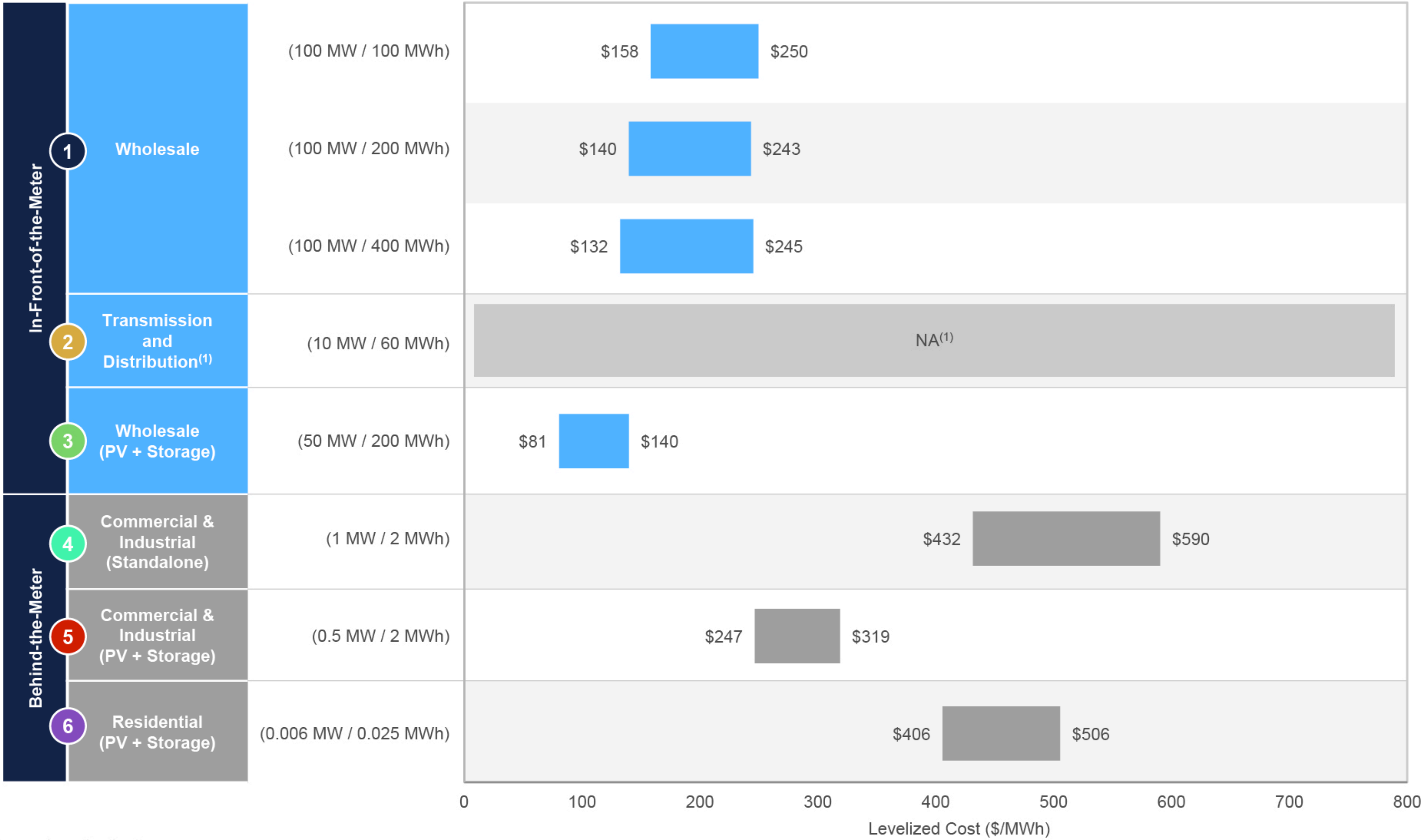
In light of material declines in the pricing of system components and improvements in efficiency, among other factors, wind and utility-scale solar PV have exhibited dramatic LCOE declines; however, as these industries have matured, the rates of decline have diminished



Source: Lazard estimates.
(1) Represents the average percentage decrease of the high end and low end of the LCOE range.
(2) Represents the average compounded annual rate of decline of the high end and low end of the LCOE range.

https://www.lazard.com/perspective/lcoe2020

Unsubsidized Levelized Cost of Storage

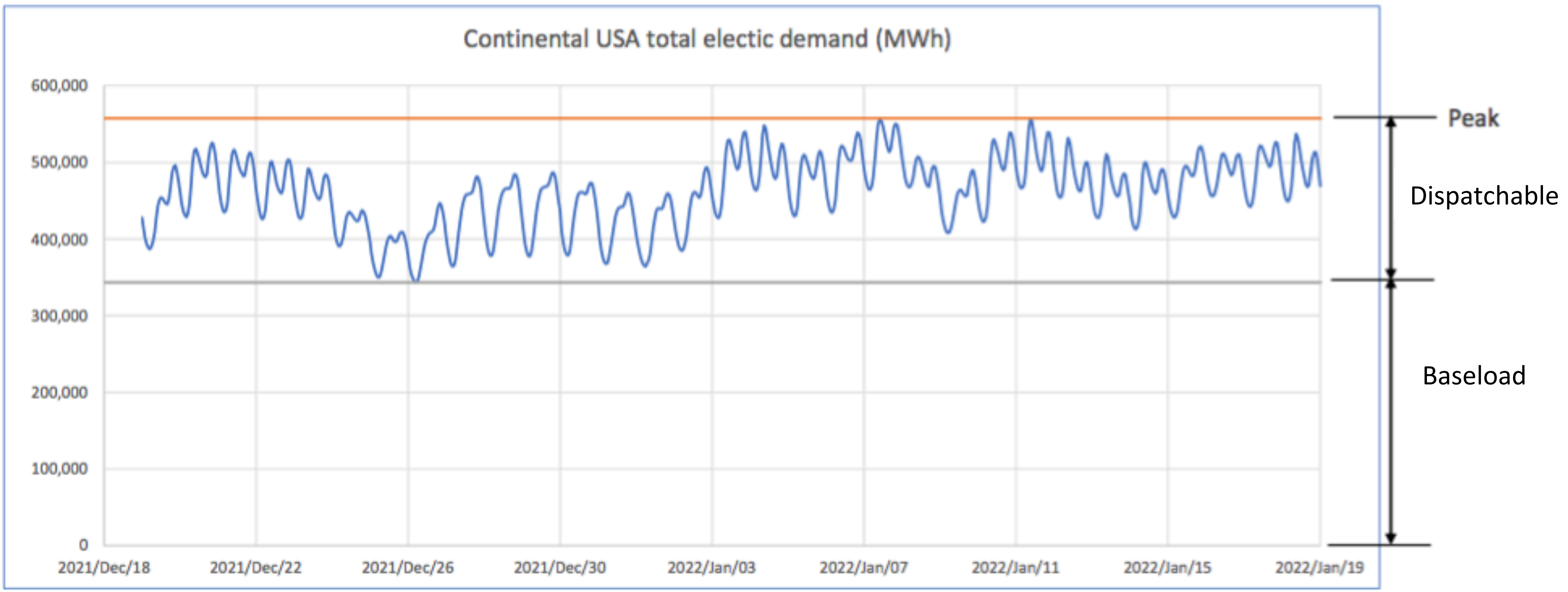


Source: Lazard estimates.

(1) Given the operational parameters for the Transmission and Distribution use case (i.e., 25 cycles per year), certain levelized metrics are not comparable between this and other use cases presented in Lazard's Levelized Cost of Storage report. The corresponding levelized cost of storage for this case would be $2,025/MWh – $2,771/MWh.

https://www.lazard.com/perspective/lcoe2020

Coal Waste


Continental USA total electic demand (MWh)
600,000
500,000
400,000
300,000
200,000
100,000
0
2021/Dec/18
2021/Dec/22
2021/Dec/26
2021/Dec/30
2022/Jan/03
2022/Jan/07
2022/Jan/11
2022/Jan/15
2022/Jan/19
Peak
Dispatchable
Baseload

Fission Reactor Requirements

- Safe
  - No radiation leaks
  - No possibility of melt down
- Minimum Waste
  - Quantity (.1% to .01% of LWR waste volume)
  - Storage-life (300-500 years)
- No possibility of weapons grade materials
  - Burn process does not produce Pu239