



Variable Renewables and Nuclear: A Match Made in Heaven or Hell



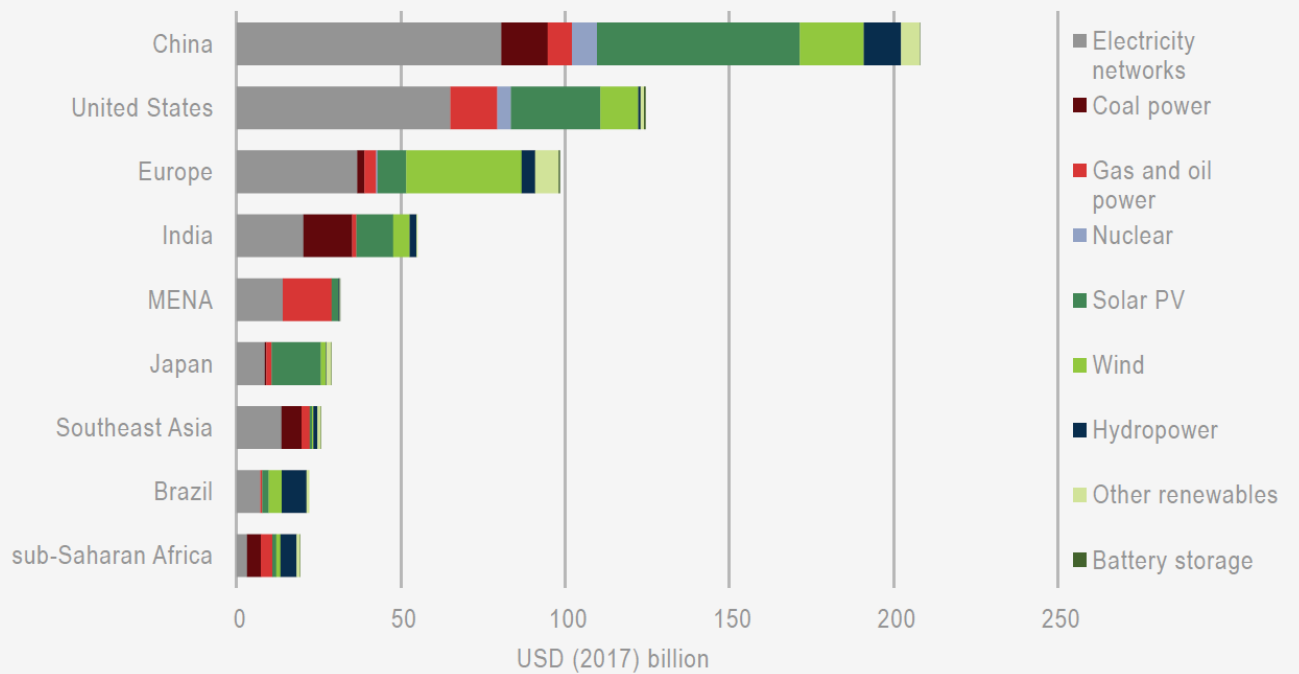
MIT*ei*
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generation across the world in recent years and costs continue to fall



But what happens when intermittent resources become a substantial percentage of power production?

The share of low-carbon sources in power generation investment maintained a high level at 70% globally, exceeding that in fossil fuel based power in most major countries and regions.

Note: MENA = Middle East and North Africa.

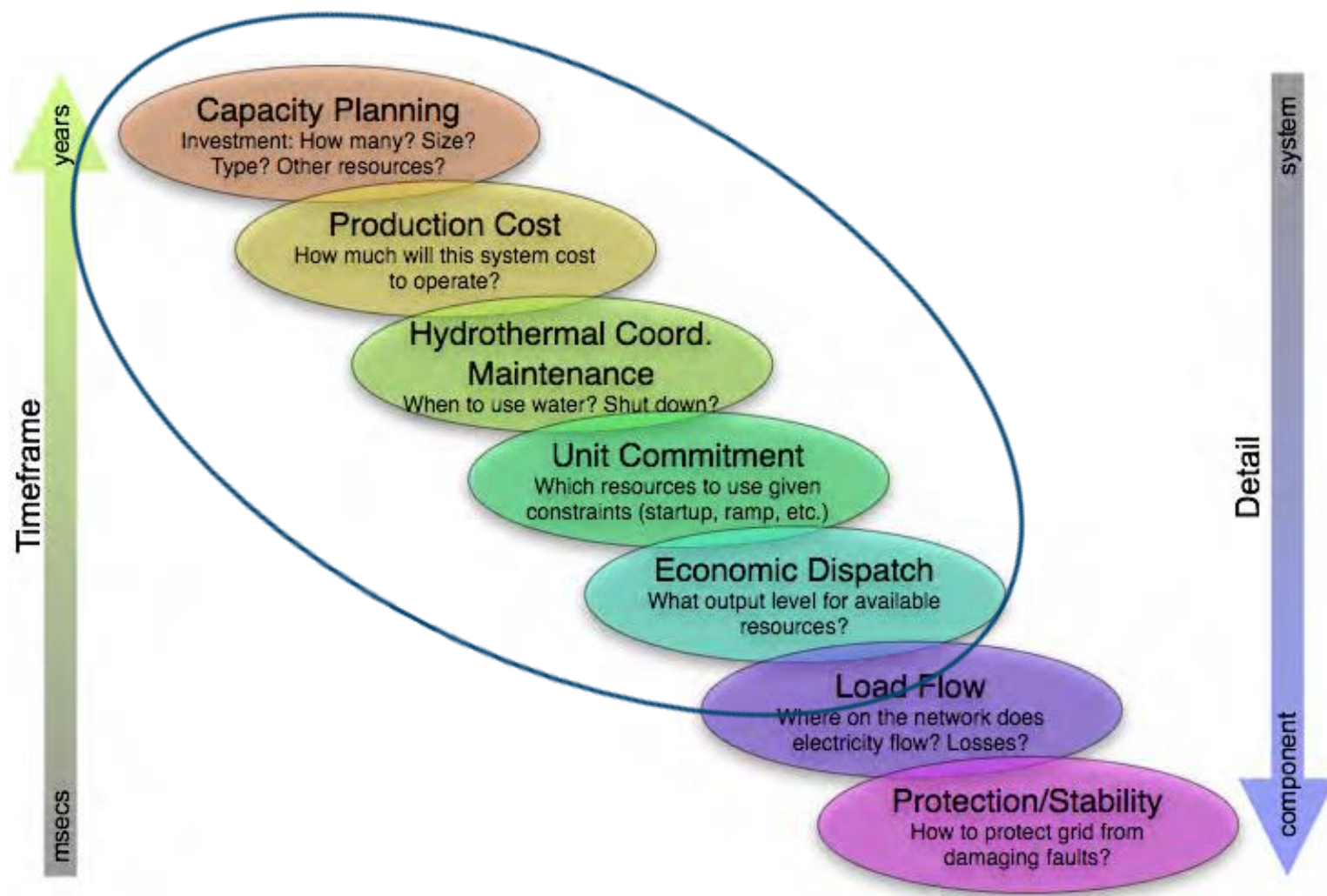
Source: IEA (2018)

EIA: Wind (\$0.05) and solar (\$0.053) cents per kWh are nearly competitive with natural gas even without tax subsidies

Advanced Nuclear at \$0.076-0.084/kWh seems out of the picture



Needed: an electricity sector modeling tool that covers capacity planning and at least down to economic dispatch as demand varies over hours of the day

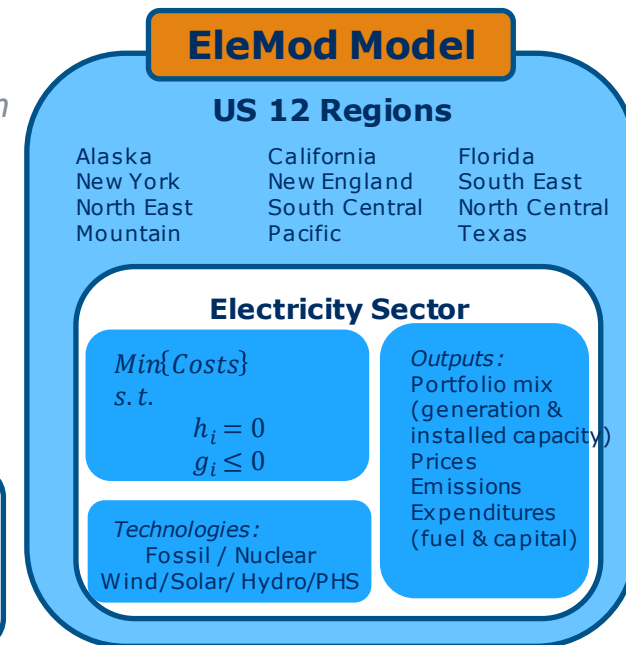
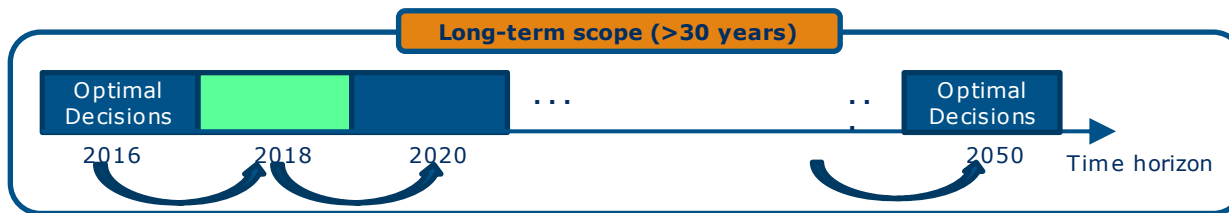


Source: Palmintier, 2013

EleMod: A capacity planning-hourly dispatch model

■ U.S. regional generation expansion power system model (Tapia-Ahumada and Perez-Arriaga^{**}; Perez-Arriaga and Meseguer, 1997)

- Designed to determine the cost-effective electric generation expansion and operation subject to technical and policy constraints
- LP model that minimizes the total cost of producing electricity
- Deterministic | Recursive-dynamic structure
 - Optimal solutions computed for every two year periods*
- Three time ranges in the decision making process:
 - Capacity expansion planning | Operation planning | Operation dispatch*
- Hourly details:
 - Regional load demands | Regional wind, solar, hydro profiles estimates*
- Several technology categories | Technical and environmental constraints



Scenarios

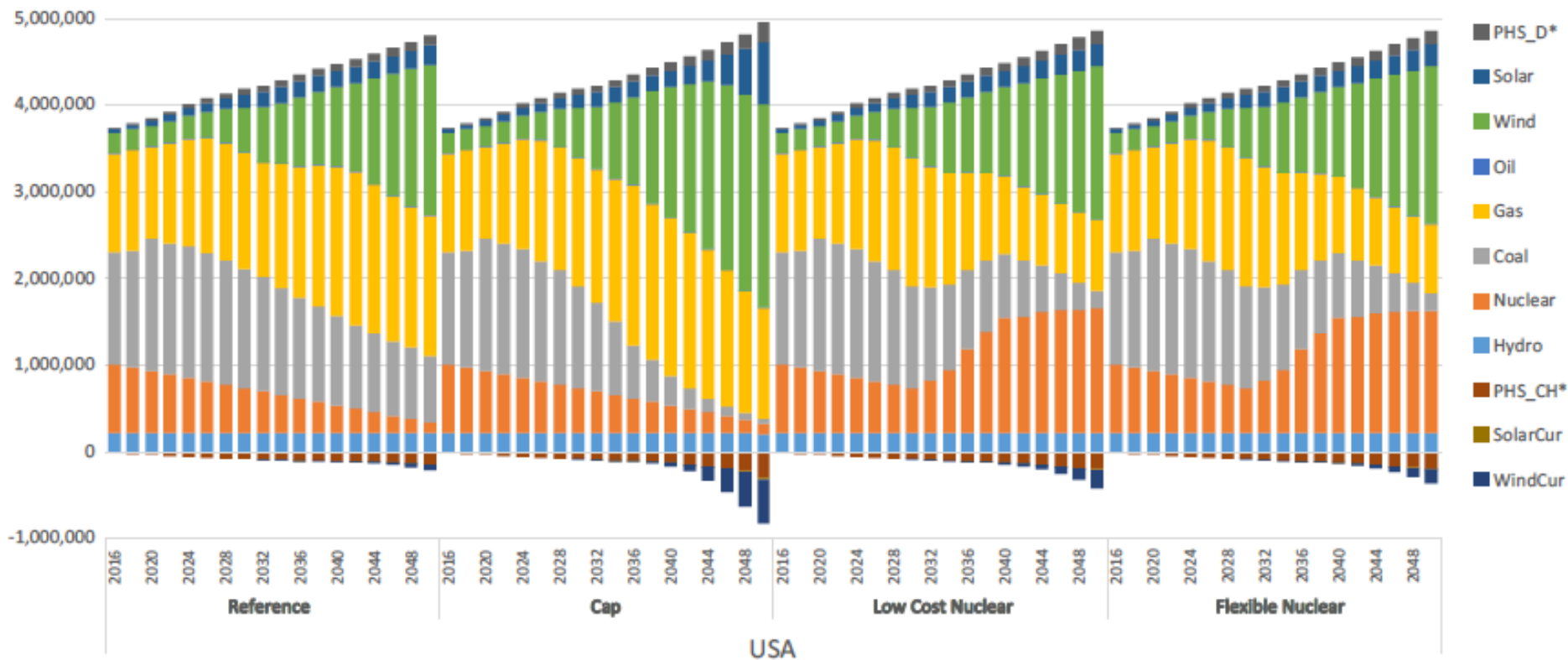
Reference: Technology costs starting at EIA levels, and solar PV and Wind declining at 3% per year to \$30 and \$50/MWh by 2050, Nuclear at \$94/MWh (2018\$)

CAP: CO₂ Reduction of 90% from 2005 , w/ base technology costs

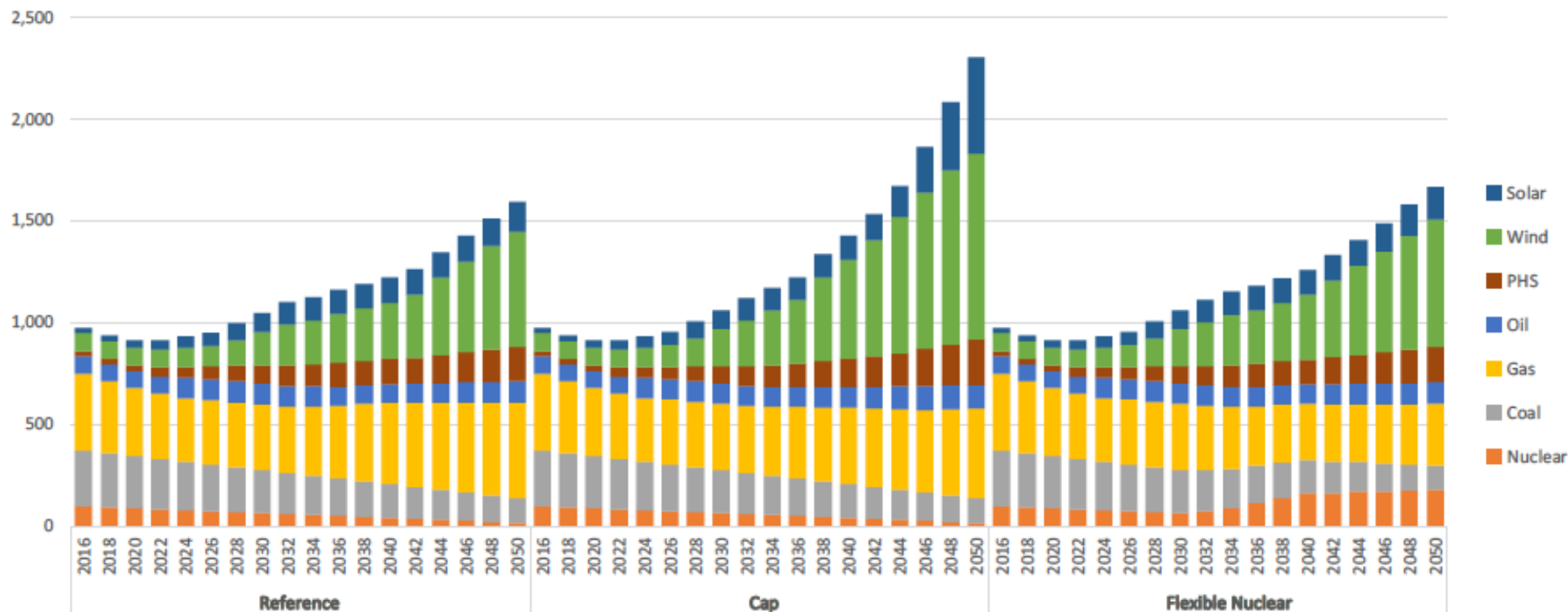
Low Cost Nuclear: w/90% CO₂ reduction and nuclear at \$55-\$60/MWh (2018\$)

Flexible Nuclear: Low Cost Nuclear plus able to ramp and shut down easily

More Details: National generation by fuel—total generation prescribed to meet EIA projected demand.

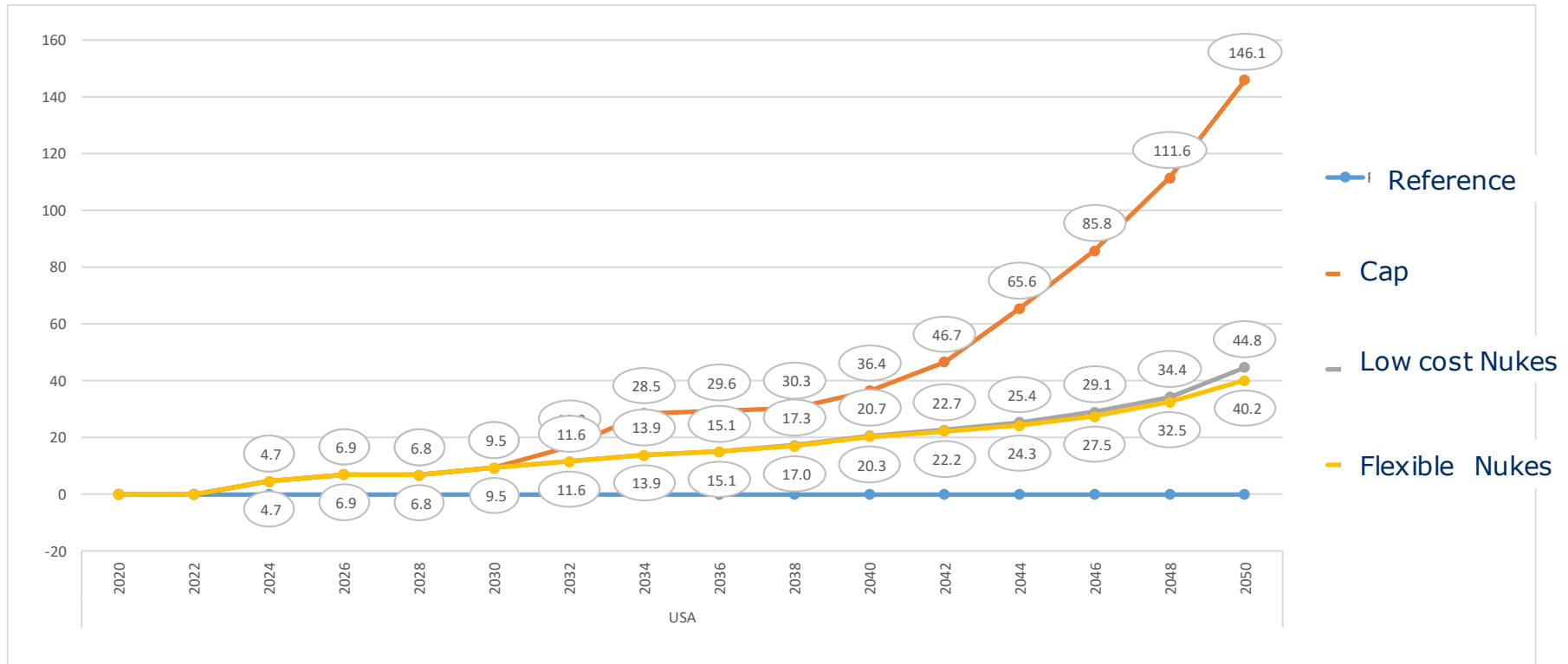


More Details: National installed capacity.



- Low capacity utilization for renewables and curtailments--much more installed capacity in the **Cap** scenario.
- Decline in coal capacity is less than the decline in generation from coal, indicative of low operating level, stranded coal generation assets.

Bottom line: The 90% CAP is achieved with wind, solar and gas, but lower cost nuclear significantly reduces the needed CO2 Price



- By 2050 the CO2 price is nearly \$150/ton (2018\$), but drops by 70% with lower cost nuclear.
- Flexible nuclear doesn't add much.
- Once renewables get above 40% of power, matching load and supply a problem.

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- There is no match—they are mostly substitutes.
- Nuclear technical flexibility is largely irrelevant, you would never want to build nuclear on the idea that you would operate it less than full capacity—economics does not make sense.
- There 3 possibilities
 1. Nuclear to expensive and completely out of the picture.
 2. Nuclear more expensive than renewables, but less costly than adding storage or spilling renewables.
 3. Nuclear less expensive than renewables.
- Caveats
 - Where the boundaries are depend on relative costs.
 - We haven't pushed this near 100%--need for peaking.
 - Optimal planning model-if capacities and demands don't turn out as planned, more value to nuclear flex?

Thank you



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