Where Nuclear Fits into the Clean Energy Future

State Considerations about the Future Role of Nuclear Energy
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The Scale of the Problem
The States

Notes:
- **Colorado.** Legislation applies only to non-municipal utilities that serve >500,000 customers, i.e. Xcel Energy (Public Service Company of Colorado). Target subject to later study or action.
- **Nevada.** Legislation excludes co-ops, which account for about 6 percent of electricity sales. Target subject to later study or action.
Options

Variable Weather-Dependent

Firm Dispatchable
Challenges

Review of 40 studies: having firm zero carbon power available reduces costs and risks in achieving a zero carbon grid especially as reductions move > 50%
In California, as in most of the Northern Hemisphere, wind and solar varies substantially not just daily but weekly-monthly, in a way that does not always match load. At high levels of wind and solar energy (> 50-60% of system energy), “filling the gap” begins to pose serious cost challenges.
2018 Smoothed Daily Average Wind Production in California Independent System Operator (CAISO)
2018 Smoothed Daily Average Solar Production in CAISO
Smoothed Daily Load & Renewable Energy Generation, Mixed Renewable Scenario

2018 wind and solar generation scaled to meet portion of CAISO Load

Seasonal surplus

Seasonal deficit

Smoothed Daily CAISO Load (MW)

Smoothed Daily Renewable Generation (MW)
Percent of Hourly Load Served, Mixed Renewable Scenario

2018 wind and solar generation scaled to meet portion of CAISO Load

73% of annual load covered by wind and solar
Can we solve this problem with batteries or other energy storage to capture the seasonal surplus and use it in deficit periods?
Daily Renewable Energy Generation Surpluses and Deficits, Mixed Renewable Scenario

2018 wind and solar generation scaled to meet portion of CAISO Load

35,946,633 MWh cumulative surplus
The storage solution

Surplus to store and use = 35,946,633 MWh or 18% of annual CAISO load

Assume $100/kwh for storage capacity (~ 60-80% drop from today’s costs)

Capital cost = $3.59 Trillion

Utilization factor < 1%

Total cost of wind + solar+ storage = $1,612/MWH (vs current average generation cost of $50/MWH)
CAISO Energy Costs with Full Storage versus Renewable Penetration Level

Energy Cost (Billions of Dollars)

Current $45.0
50% Renewables $49.0
80% Renewables $452.0
100% Renewables $1,612.0

$/MWH

$/MWH
Same conclusions at national scale (copper plate trans-continental HVDC grid, demand response, storage)

Source: Jenkins et al., Getting to Zero Carbon Emissions in the Electric Power Sector, Joule (2018)
Challenges of Low Carbon Energy Sources

Renewables
- Cost Challenges at high penetration
- Transmission Siting
- Land Use

Nuclear
- Cost
- Waste Concerns

Hydro
- Availability
- Environmental Concerns
- Siting

Biomass
- Land Use
- Crop Competition
- Other Emissions

Gas with Carbon Capture
- Commercialization
- Upstream Emissions
- Pipelines
Challenges of Low Carbon Energy Sources
Historical Decarbonization Efforts

Average annual increase of carbon-free net electricity generation in kilowatt-hours per capita-year during decade of peak scale-up

Author’s revision of Cao et al.’s Fig. S2. Their same nine nuclear and eight renewable cases are shown; seven nuclear (Scotland, Spain, California, United Kingdom, Italy, China, and India) and seven renewable (Scotland, Sweden, Ireland, Portugal, United Kingdom, Costa Rica, and India) cases are added and marked by an asterisk. BP nuclear outputs are divided by 1,0546 to convert gross to net. BP data are added for the missing category of “Geothermal, Biomass, and Other” renewables. All data shown are from BP, no later than the last year Cao et al.’s Science article used (2015), though later renewable data would promote some countries to higher rankings.
“To this day, approximately 12% of the gas in our pipeline on Oahu is hydrogen — this is the highest concentration of hydrogen reported by any gas utility in the U.S.”
Nuclear and Hydrogen
Future Nuclear
Clean Air Task Force using proven US EPA modeling tools has determined that loss of zero emission generation from the retirement of four nuclear power plants in Illinois would result in the following cumulative health-related impacts and costs over a ten-year period:

- Between 1,200 to almost 2,700 premature deaths;
- Over 30,000 additional asthma attacks and other respiratory symptoms leading to limited daily activities;
- Almost 140,000 work loss days;
- $10 to $24 billion ($1 to $2.4 billion per year) in monetized damages due to increased air pollution.

Thank You

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New nuclear cost: room for improvement!

- US (Vogtle 3&4)
- France (Flamanville 3)
- Finland (Olkiluoto 3)
- UK (Seabank B)
- UAE (Barakah 1-4)
- Japan (3 units)
- Russia (2 units)
- Korea (10 units)
- China (4 units)

Total Capital Cost
Waste: not an unsolvable problem

Finland’s consent-sited waste repository under construction
Policy Flow

1. Pass technology-inclusive CES and multi-sector mandates
2. Enact supporting state policies (e.g. innovation demos, tax credits, infrastructure investment)
3. Work with leading utilities on implementation plans
4. Lock down utility implementation plans through IRPs