# Hurry or Wait?

## Pacing the Renewable Transition

BU Institute for Sustainable Energy


Dean Murphy
Jurgen Weiss


April 13, 2017

THE Brattle GROUP

# The basic question we are trying to answer

**The costs of long-lived renewable energy assets continue to decline quickly**

- Most renewable projects (wind, solar PV) have life spans of 20-30 years or longer
  - Building a renewable energy facility at a given site today means foregoing the option of building a cheaper/more efficient facility in that location in the future
  - While some cost reductions may be due partly to "learning" and experience (i.e., depend on deployment), some cost reductions will occur just from waiting
- This suggests WAITING to deploy may enable more renewables for the same investment

**But delayed renewable investment means higher cumulative GHGs in the meantime**

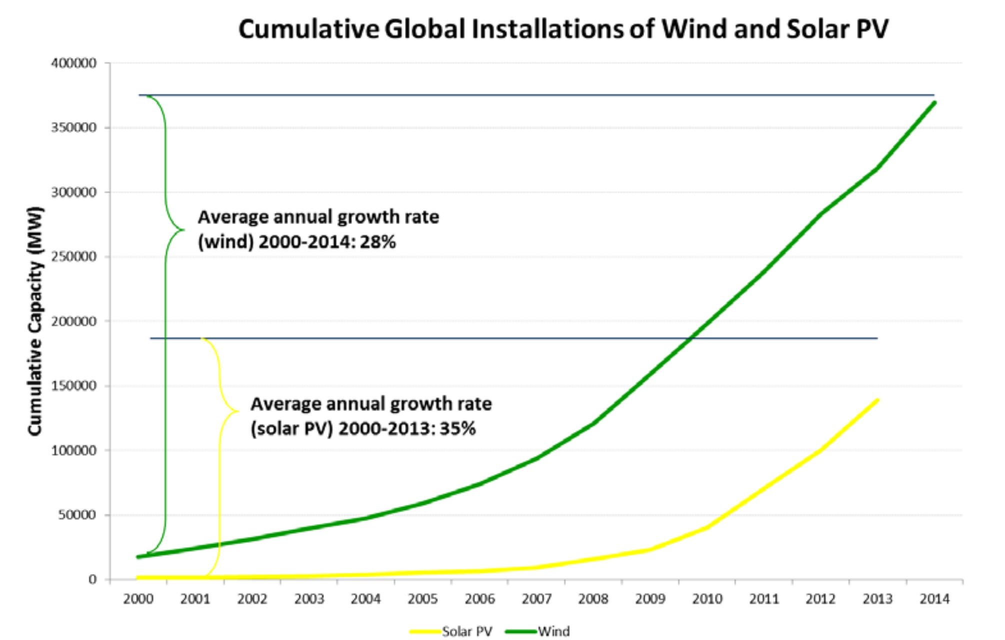
  - And higher social costs:  higher (expected) damages due to climate change
  - Also, potentially larger risks of extreme (fat tail) outcomes

**We developed a simple model that illustrates the trade-off between rapid (HURRY) and delayed (WAIT) renewable development**

# A simple model to understand the trade-offs

- US electricity sector modeled (very simply) through 2050
  - Start with 2015 generation sources and production (as per EIA)
  - Assume no increase in coal-fired generation, so incremental demand met by existing gas fired generation (increased utilization of existing plants) and/or renewables

- Assume ultimate full decarbonization of the power sector
  - Base line growth rates of wind/solar based on lower end of historic growth until acceleration kicks in – which is either now (HURRY) or in 2030 (WAIT)
    - Annual post-kick-off growth rates based on recent global growth rates of wind (30%) and solar PV (40%), assumed to be sustainable until full decarbonization achieved
    - Includes $5/MWh integration cost (more on this later)



Sources: EPIA, Global Market Outlook for Photovoltaics 2014-2018, Figure 1, GWEC, Global Status of Wind Power in 2014

# Renewable cost declines driven by time and deployment (2-factor learning model)

- Learning models often don't differentiate between learning by research (LBR) vs learning by doing (LBD)
  - Some two factor learning models estimate roughly half the progress due to LBR, half due to LBD
- Decomposed overall observed learning rates into time trend and learning-by doing trend (assumption)
  - Time: Costs fall 1.5% per year, for wind and PV
  - Learning:
    - Wind costs fall 7% with each additional doubling of installed capacity
    - PV falls 12% with each doubling
- More conservative than historical experience
  - Rubin, et. al show average learning rates of 12% for onshore wind, 23% for PV
  - Our base case assumptions correspond to slightly lower overall learning rates for wind and significantly lower rates for solar PV

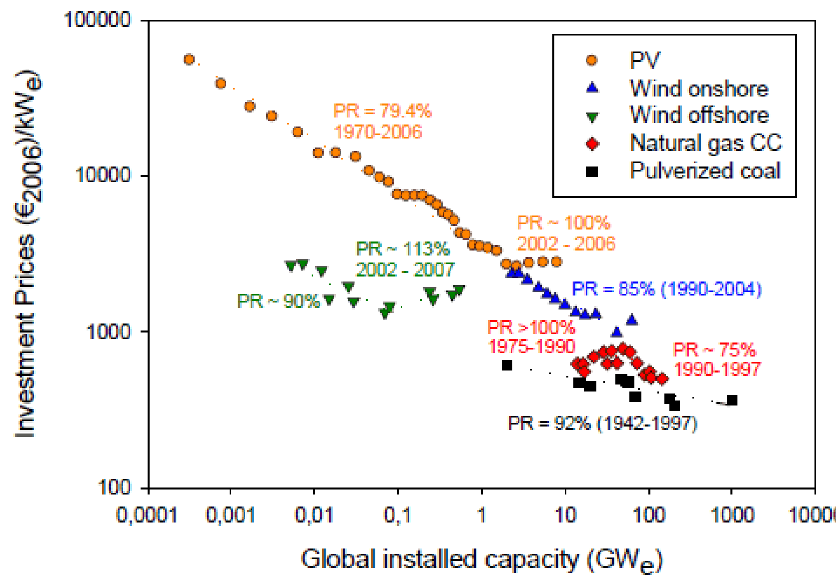
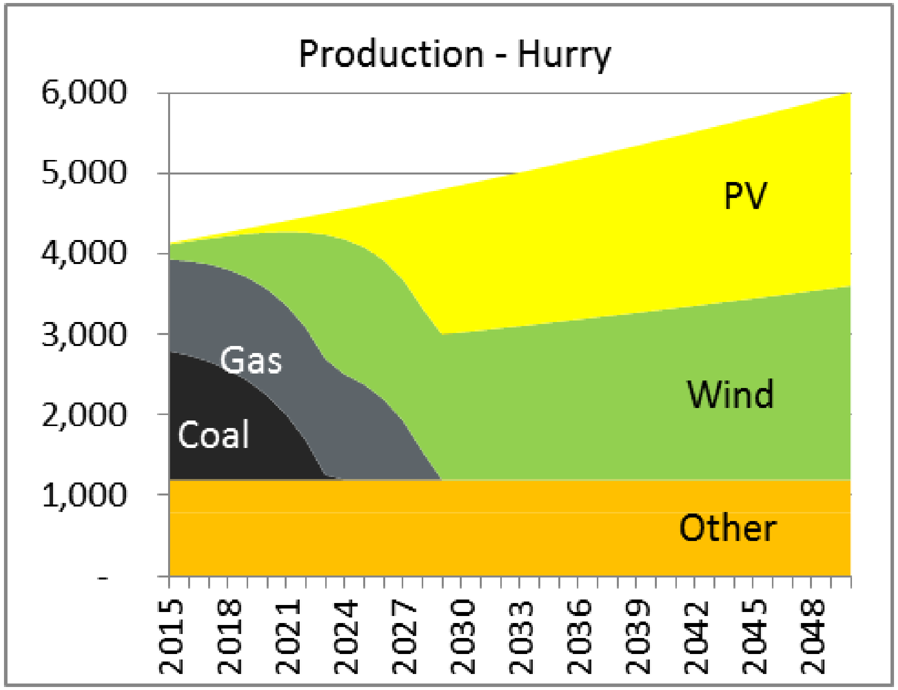


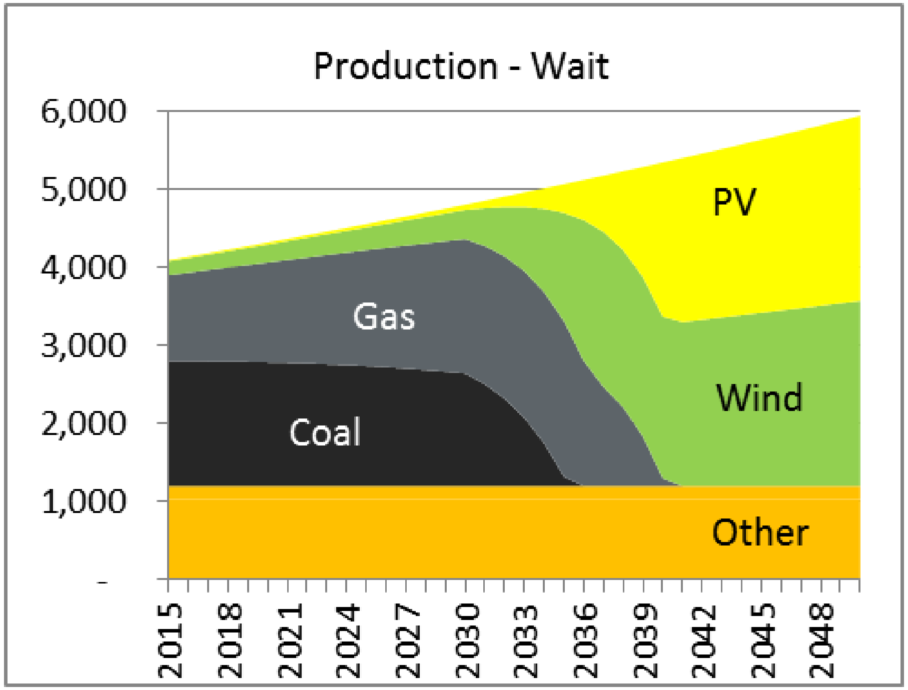

**Table 1**
Range of reported one-factor and two-factor learning rates for electric power generation technologies.

| Technology and energy source | No. of studies with one factor[a] | No. of studies with two factors | One-factor models[b] | | Two-factor models[c] | | | | Years covered across all studies |
|---|---|---|---|---|---|---|---|---|---|
| | | | Range of learning rates | Mean LR | Range of rates for LBD | Mean LBD rate | Range of rates for LBR | Mean LBR rate | |
| Coal | | | | | | | | | |
| PC | 4 | 0 | 5.6–12% | 8.3% | – | – | – | – | 1902–2006 |
| *PC+CCS*[d] | *2* | *0* | *1.1–9.9%*[d] | | – | – | – | – | *Projections* |
| *IGCC*[d] | *2* | *0* | *2.5–16%*[d] | | – | – | – | – | *Projections* |
| *IGCC+CCS*[d] | *2* | *0* | *2.5–20%*[d] | | – | – | – | – | *Projections* |
| Natural gas | | | | | | | | | |
| NGCC | 5 | 1 | −11 to 34% | 14% | 0.7–2.2% | 1.4% | 2.4–17.7% | 10% | 1980–1998 |
| Gas turbine | 11 | 0 | 10–22% | 15% | – | – | – | – | 1958–1990 |
| *NGCC+CCS*[d] | *1* | *0* | *2–7%*[d] | | – | – | – | – | *Projections* |
| Nuclear | 4 | 0 | Negative to 6% | – | – | – | – | – | 1972–1996 |
| Wind | | | | | | | | | |
| Onshore | 12 | 6 | −11 to 32% | 12% | 3.1–13.1% | 9.6% | 10–26.8% | 16.5% | 1979–2010 |
| Offshore | 2 | 1 | 5–19% | 12% | 1% | 1% | 4.9% | 4.9% | 1985–2001 |
| Solar PV | 13 | 3 | 10–47% | 23% | 14–32% | 18% | 10–14.3% | 12% | 1959–2011 |
| Biomass | | | | | | | | | |
| Power generation[e] | 2 | 0 | 0–24% | 11% | – | – | – | – | 1976–2005 |
| Biomass production | 3 | 0 | 20–45% | 32% | | | | | 1971–2006 |
| Geothermal[f] | 0 | 0 | – | – | – | – | – | – | |
| Hydroelectric | 1 | 1 | 1.4% | 1.4% | 0.5–11.4% | 6% | 2.6–20.6% | 11.6% | 1980–2001 |

[a] Some studies report multiple values based on different datasets, regions, or assumptions.
[b] LR=learning rate. Values in italics reflect model estimates, not empirical data.
[c] LBD=learning by doing; LBR=learning by researching.
[d] No historical data for this technology. Values are projected learning rates based on different assumptions.
[e] Includes combined heat and power (CHP) systems and biodigesters.
[f] Several studies reviewed presented data on cost reductions but did not report learning rates.

# HURRY achieves full decarbonization by 2030; WAIT a decade later



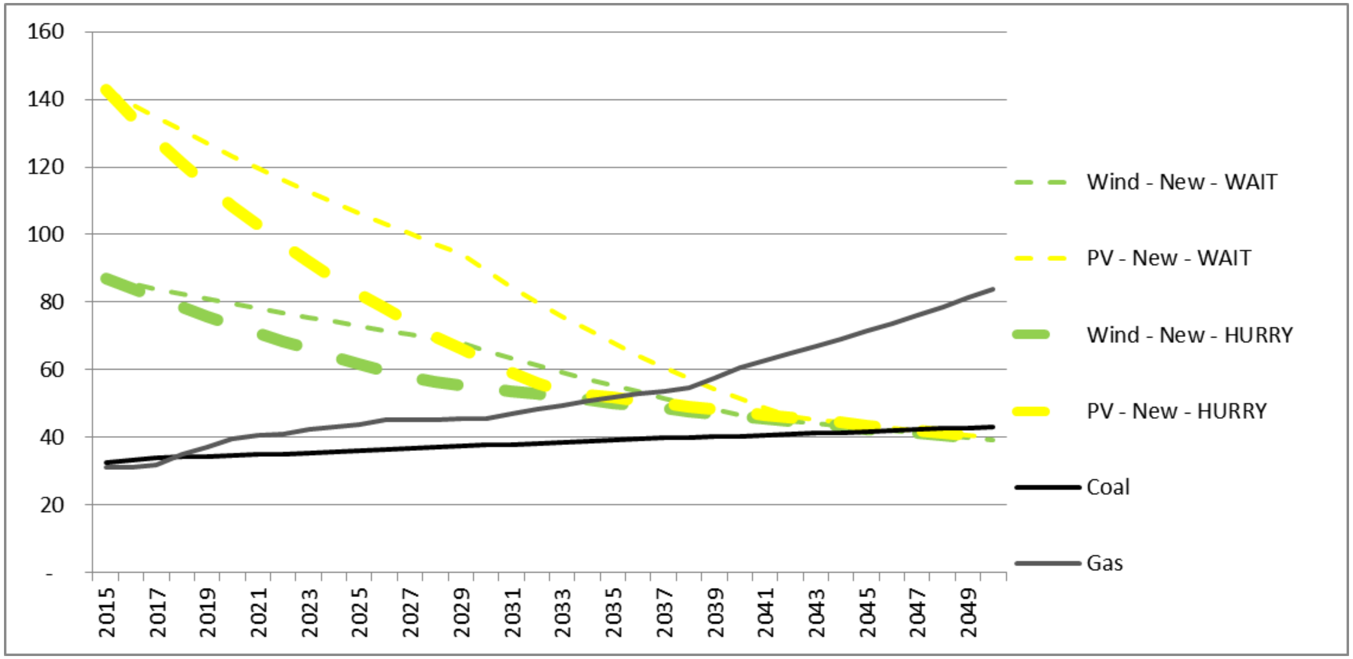

**<u>Both</u> of these may be viewed as aggressive timetables**

- The relative <u>difference</u> between them, rather than any particular deployment trajectory, is most important

**Model calculates, for HURRY and WAIT paths (i.e., accelerate renewables in 2016 vs in 2030):**

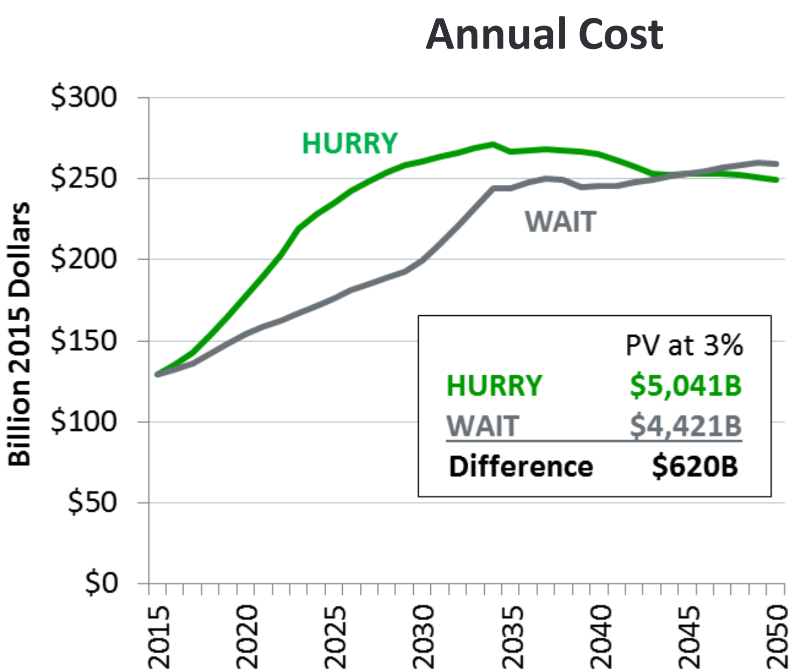
- Total cost of electricity production through 2050
  - Capital investment cost of renewables, plus To-Go costs only for fossil (fuel, fixed and variable O&M)
- Total GHG emissions

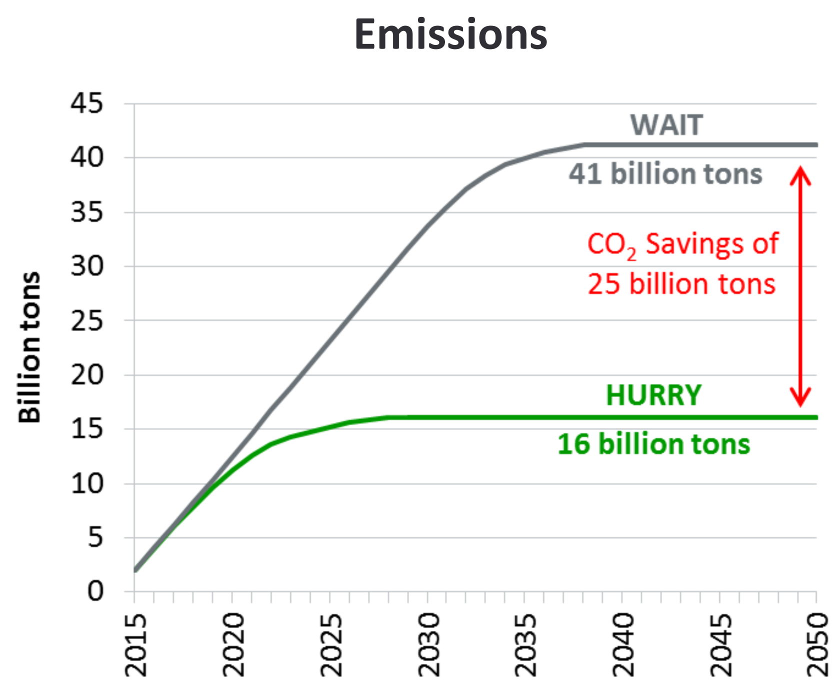
# HURRY leads to earlier cost reductions (LBD), but higher total costs (invest sooner)




- Renewable costs for **new resources** match gas in 2035 (HURRY)/2038 (WAIT)
  - Once full deployment is reached in both cases, HURRY and WAIT costs converge again (same total time, same total deployment)
  - Coincidentally, wind and PV costs converge in the long run
- HURRY costs more: though unit costs are lower at any point, investment occurs early, before costs fall (plus discounting: HURRY costs occur earlier)

# Hurry has higher NPV costs than Wait, but also has __significantly__ lower $CO_2$ emissions




- $620 billion NPV difference translates into an average of 0.4 cents/kWh (or **roughly 5% of average retail rates of 10 cents/kWh**) **– not a lot**
- 25 billion tons lower GHG emissons in Hurry case
- Implies cost of $25/ton of avoided GHG emissions

# Sensitivity analyses show surprising robustness in these results

| Scenario | Discount Rate | Time Trend: Wind (%/yr) | Time Trend: Solar (%/yr) | Learning Rate: Wind (%/dbl) | Learning Rate: Solar (%/dbl) | Gas Price | Decarb. Level (%) | Avoided CO2 (B tons) | Incremental Cost ($B, NPV) | **Avoided CO2 Cost ($/ton)** |
|---|---|---|---|---|---|---|---|---|---|---|
| Base Case | 3.0% | 1.5% | 1.5% | 7.0% | 12.0% | EIA Ref. | 100% | 25.2 | $ 620 | **$ 24.63** |
| EIA Low Gas | 3.0% | 1.5% | 1.5% | 7.0% | 12.0% | EIA Low | 100% | 25.2 | $ 806 | **$ 32.03** |
| $3 Gas | 3.0% | 1.5% | 1.5% | 7.0% | 12.0% | $3 gas | 100% | 25.2 | $ 880 | **$ 35.01** |
| Half Learning Rates | 3.0% | 0.8% | 0.8% | 3.5% | 6.0% | EIA Ref. | 100% | 25.2 | $ 1,105 | **$ 43.95** |
| Low LBD/Hi Time | 3.0% | 3.5% | 5.0% | 3.5% | 6.0% | EIA Ref. | 100% | 25.2 | $ 794 | **$ 31.58** |
| No LBD/All Time | 3.0% | 4.0% | 7.0% | 0.0% | 0.0% | EIA Ref. | 100% | 25.2 | $ 1,041 | **$ 41.40** |
| All LBD/No Time | 3.0% | 0.0% | 0.0% | 11.0% | 15.0% | EIA Ref. | 100% | 25.2 | $ 437 | **$ 17.38** |
| No Learning (LBD or time) | 3.0% | 0.0% | 0.0% | 0.0% | 0.0% | EIA Ref. | 100% | 25.2 | $ 1,753 | **$ 69.71** |
| 2.5% Discounting | 2.5% | 1.5% | 1.5% | 7.0% | 12.0% | EIA Ref. | 100% | 25.2 | $ 658 | **$ 26.15** |
| 5% Discounting | 5.0% | 1.5% | 1.5% | 7.0% | 12.0% | EIA Ref. | 100% | 25.2 | $ 491 | **$ 19.54** |
| Wait = 2050 | 3.0% | 1.5% | 1.5% | 7.0% | 12.0% | EIA Ref. | 100% | 54.6 | $ 423 | **$ 7.75** |
| Delay Hurry 1 year | 3.0% | 1.5% | 1.5% | 7.0% | 12.0% | EIA Ref. | 100% | 23.4 | $ 553 | **$ 23.66** |
| Delay Wait 1 year | 3.0% | 1.5% | 1.5% | 7.0% | 12.0% | EIA Ref. | 100% | 26.9 | $ 639 | **$ 23.77** |
| Half Decarbonization | 3.0% | 1.5% | 1.5% | 7.0% | 12.0% | EIA Ref. | 50% | 15.7 | $ 436 | **$ 27.85** |
| Pessimistic ($3 Gas, Half Learn) | 3.0% | 0.8% | 0.8% | 3.5% | 6.0% | $3 gas | 100% | 25.2 | $ 1,366 | **$ 54.33** |
| Ex Pessimistic ($3 Gas, No Learn) | 3.0% | 0.0% | 0.0% | 0.0% | 0.0% | $3 gas | 100% | 25.2 | $ 2,014 | **$ 80.09** |

**The range of costs/ton is low compared to estimated damages (SCC) and the rate impact likely moderate compared to typical rate fluctuations.**

# Conclusions

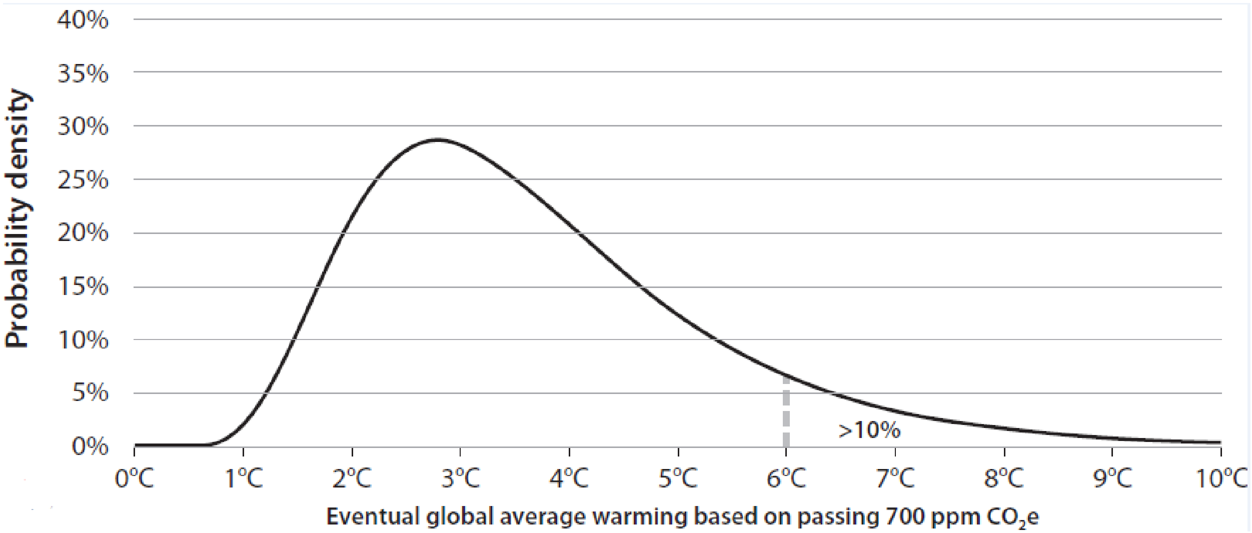
- The simple notion that we can save money by waiting to decarbonize ignores the significant costs of waiting
  - This principle holds elsewhere, though the benefits may be more obvious
    - Cars get better/cheaper all the time, but we don’t wait forever to buy
    - How about computers or cell phones?
- Compared to what we pay for electricity and normal cost fluctuations, the extra cost to HURRY is moderate
  - It is also small compared to typical estimates of GHG abatement costs
- Most cost/benefit comparisons don’t represent the insurance value of more rapid decarbonization (the “fat tails”), which provides further support for rapid and early decarbonization
- Rapid decarbonization of power creates a more immediate rationale for electrification of other sectors, to help economy-wide decarbonization

# Critical assumptions and further research

- Integration cost is likely the most unrealistic assumption in this analysis
  - $5/MWh may be reasonable (even generous) at low penetration rates, but costs could be higher – perhaps significantly higher – at high penetration levels
  - This could underestimate the total costs of decarbonization (and thus the incremental cost of hurrying, due to discounting)
    - But our starting cost assumptions are pretty high
    - Renewable costs in our model estimated reach levels by 2050 already observed today
  - Currently working on applying same 2-factor learning model to integration costs
  - Same conclusion (Hurry is a "relatively good deal" based on cost of abatement) applies to partial decarbonization (to the point where integration costs rise sharply)
- Can assumed growth rates be maintained?
  - Work on more realistic technology diffusion model (taking into account supply chain build-up)

# Appendix

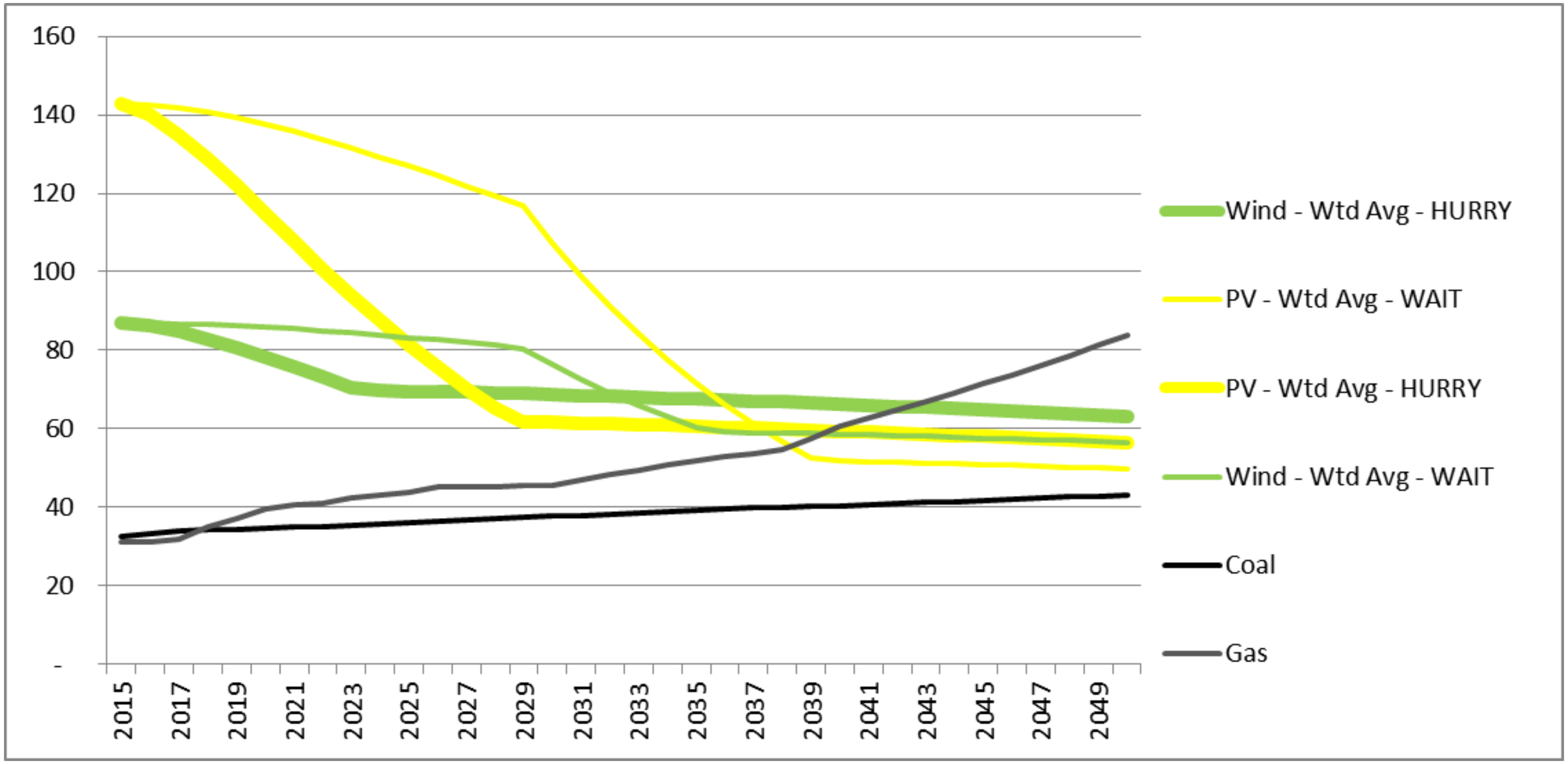
# Avoided $CO_2$ costs below SCC imply Hurry offers "free" insurance against fat tails




*An estimate of the likelihood of warming due to a doubling of greenhouse gas concentrations (Source: Wagner & Weitzman "Climate Shock"*

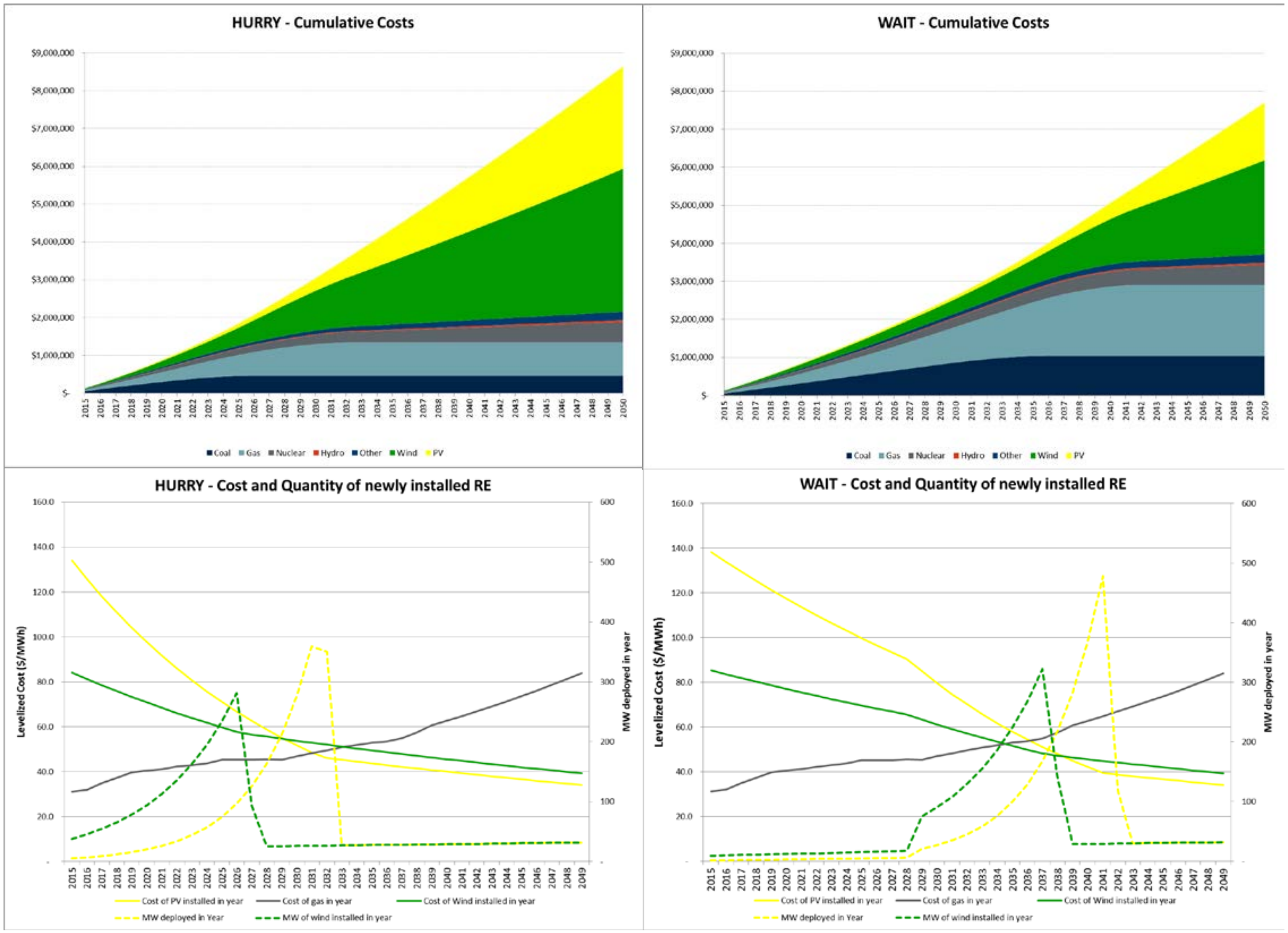
- Doubling of $CO_2$ leads to expected increases in global mean temperatures of about 3 degrees Celsius
- But: 10% chance that doubling leads to temperature increase of 6 degrees Celsius or higher (about 11 degrees F)
  - We don't know what impact that has; we likely don't want to find out

# New renewables are always less costly than the existing renewables portfolio




- Weighted average at any point is above new resource cost (new costs declining)
  - Portfolio contains older vintages with higher costs
  - New renewables ultimately have same cost in long run, but Wait has lower average cost, due to later deployment that benefits from time-based cost reductions
    - Long-run cost is overestimated (levelized based on 20yrs, but paid up to 35 yrs)

# Deployment paths and avoided fuel costs provide some intuition behind these results



# Rubin, et al., 2015, A review of learning rates for electricity supply technologies, Energy Policy

**Table 1**
Range of reported one-factor and two-factor learning rates for electric power generation technologies.

| Technology and energy source | No. of studies with one factor[a] | No. of studies with two factors | One-factor models[b] | | Two-factor models[c] | | | | Years covered across all studies |
|---|---|---|---|---|---|---|---|---|---|
| | | | Range of learning rates | Mean LR | Range of rates for LBD | Mean LBD rate | Range of rates for LBR | Mean LBR rate | |
| Coal | | | | | | | | | |
| PC | 4 | 0 | 5.6–12% | 8.3% | – | – | – | – | 1902–2006 |
| *PC+CCS*[d] | *2* | *0* | *1.1–9.9%*[d] | | – | – | – | – | *Projections* |
| *IGCC*[d] | *2* | *0* | *2.5–16%*[d] | | – | – | – | – | *Projections* |
| *IGCC+CCS*[d] | *2* | *0* | *2.5–20%*[d] | | – | – | – | – | *Projections* |
| Natural gas | | | | | | | | | |
| NGCC | 5 | 1 | −11 to 34% | 14% | 0.7–2.2% | 1.4% | 2.4–17.7% | 10% | 1980–1998 |
| Gas turbine | 11 | 0 | 10–22% | 15% | – | – | – | – | 1958–1990 |
| *NGCC+CCS*[d] | *1* | *0* | *2–7%*[d] | | – | – | – | – | *Projections* |
| Nuclear | 4 | 0 | Negative to 6% | – | – | – | – | – | 1972–1996 |
| Wind | | | | | | | | | |
| Onshore | 12 | 6 | −11 to 32% | 12% | 3.1–13.1% | 9.6% | 10–26.8% | 16.5% | 1979–2010 |
| Offshore | 2 | 1 | 5–19% | 12% | 1% | 1% | 4.9% | 4.9% | 1985–2001 |
| Solar PV | 13 | 3 | 10–47% | 23% | 14–32% | 18% | 10–14.3% | 12% | 1959–2011 |
| Biomass | | | | | | | | | |
| Power generation[e] | 2 | 0 | 0–24% | 11% | – | – | – | – | 1976–2005 |
| Biomass production | 3 | 0 | 20–45% | 32% | | | | | 1971–2006 |
| Geothermal[f] | 0 | 0 | – | – | – | – | – | – | |
| Hydroelectric | 1 | 1 | 1.4% | 1.4% | 0.5–11.4% | 6% | 2.6–20.6% | 11.6% | 1980–2001 |

[a] Some studies report multiple values based on different datasets, regions, or assumptions.
[b] LR = learning rate. Values in italics reflect model estimates, not empirical data.
[c] LBD = learning by doing; LBR = learning by researching.
[d] No historical data for this technology. Values are projected learning rates based on different assumptions.
[e] Includes combined heat and power (CHP) systems and biodigesters.
[f] Several studies reviewed presented data on cost reductions but did not report learning rates.