Increased Renewables in California: Impact on Fossil Fuel Generation, Levelized Costs, and CO_2 Emissions

Lori Smith Schell, Ph.D., Empowered Energy
Joshua D. Eichman, UC-Irvine
G. Scott Samuelsen, Ph.D. UC-Irvine

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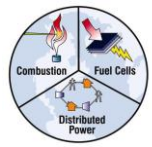

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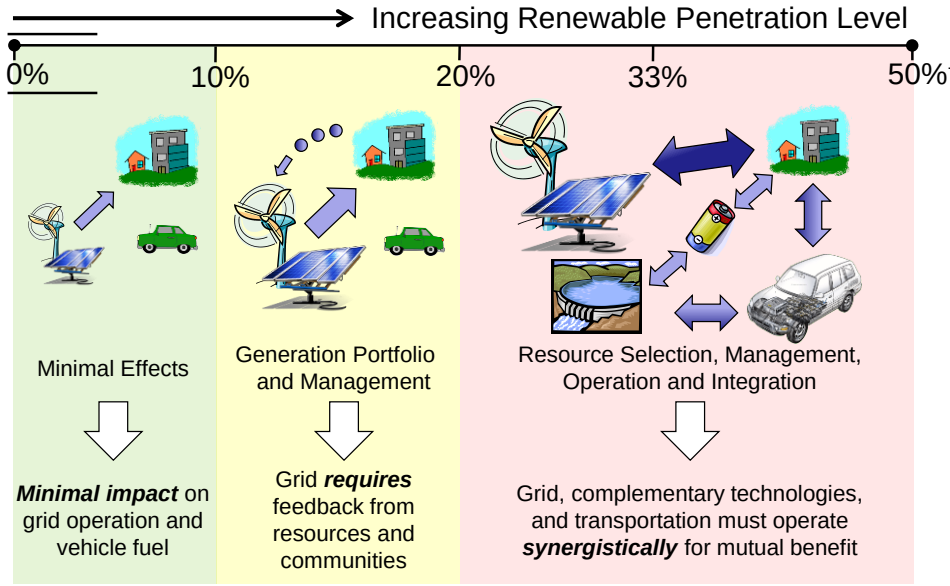
Motivation

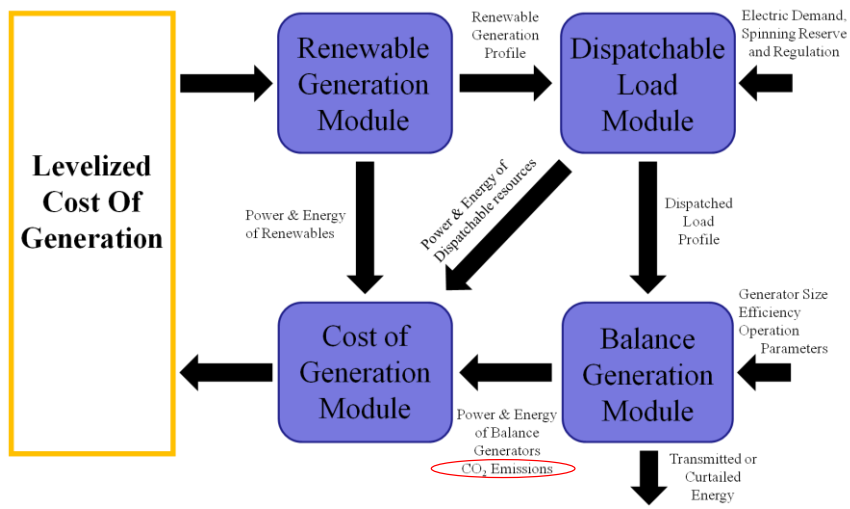
- **California has the most aggressive Renewable Portfolio Standard ("RPS") in the United States**
  - **Legislative mandate for 33% of retail sales by 2020**
    - **California Senate Bill X1 2, 4/12/2011**
- **Legislative mandate for GHG reductions**
  - **Achieve 1990 CO_2 levels by 2020**
    - **Executive Order S-14-08, 11/17/2008**
  - **CO_2 cap-and-trade program; compliance starts in 2013**
- **How to achieve both mandates at least cost?**
  - **Assess grid-wide impact of renewables penetration on other generation and on complementary technologies**
  - **Assess impact of CO_2 cost assumptions on levelized cost of electricity ("LCOE") for various portfolios**

More Renewables, More Challenges

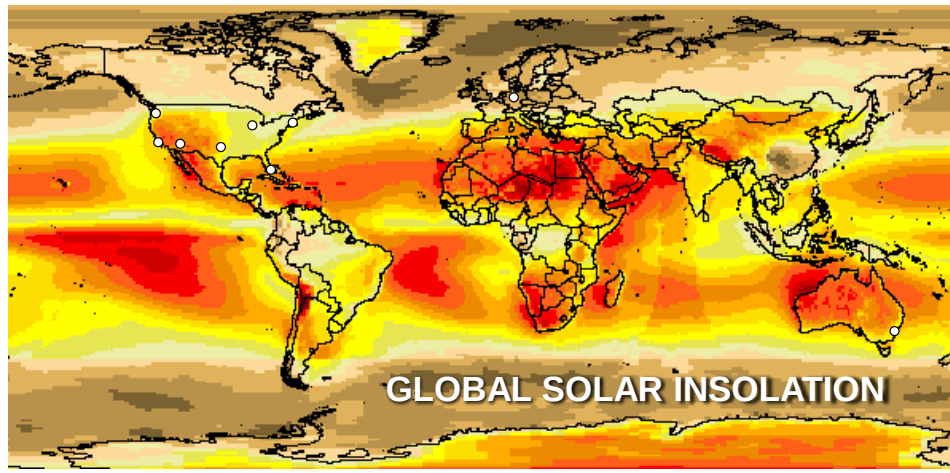


Impact of CO_2 Cost on Portfolio LCOE

- **Earlier GRID results did not consider CO_2 cost**



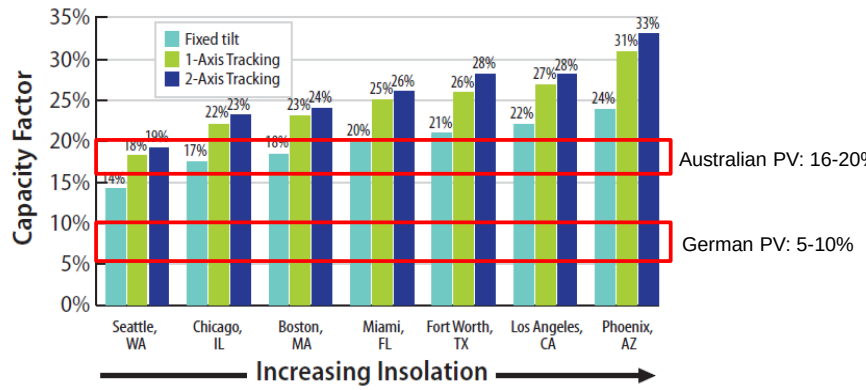
70 minutes = 1 Year of Global Energy Use



Source: *United Nations Environment Programme, Solar and Wind Resource Assessment, http://na.unep.net/swera_ims/map/.*

Compare Wind vs. Solar vs. 50/50 Mix

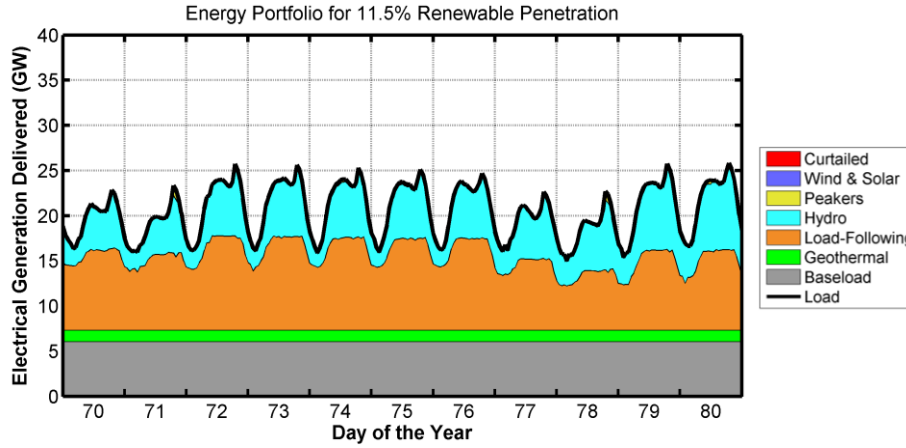
- **Renewables penetration is energy-based**
- **Capacity factor varies by location and technology**
  - **Annual kWh produced / (installed capacity x 8760 hr/yr)**



Source: *National Renewable Energy Laboratory, "2010 Solar Technologies Market Report", p. 55,* http://www.nrel.gov/docs/fy12osti/51847.pdf

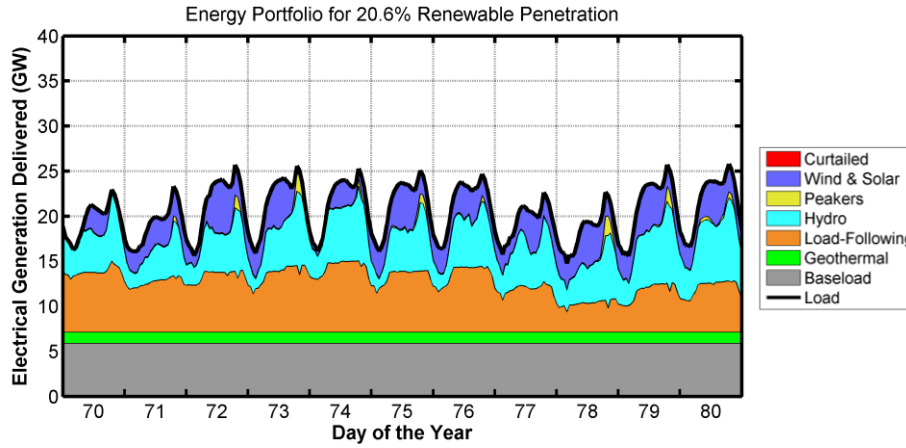
Actual California Generation Mix 2005

- Impact of wind and solar generation imperceptible
- 11.5% includes geothermal, biomass, small hydro



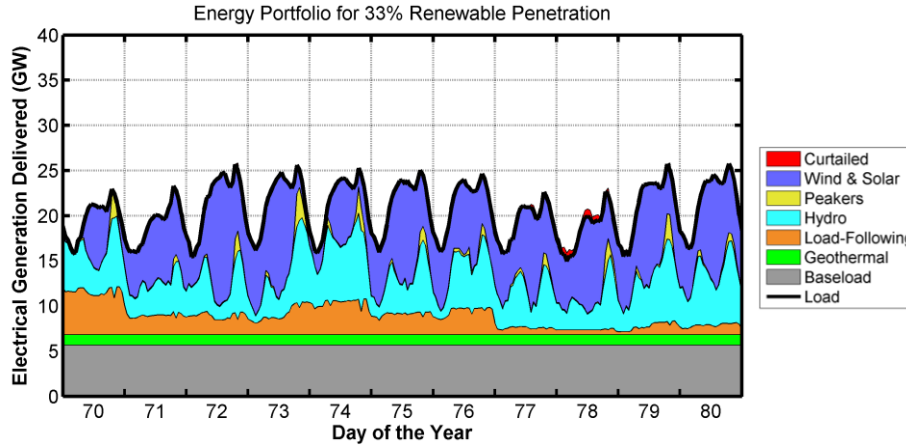
50/50 Wind/Solar Added to Achieve 20.6%

- Load-following more dynamic
- Peakers must provide increased balancing



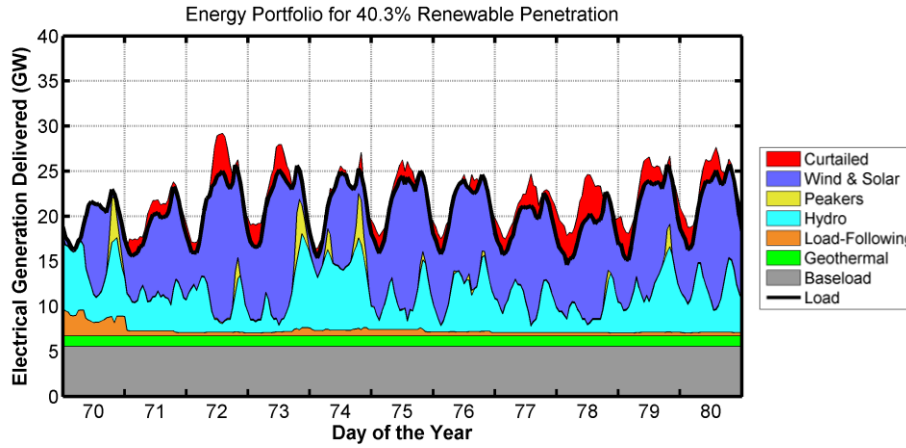
By 33% Renewables, Limited Curtailment

- Impact similar to 20.6% renewables, only more so
- All but baseload operate even *more* dynamically



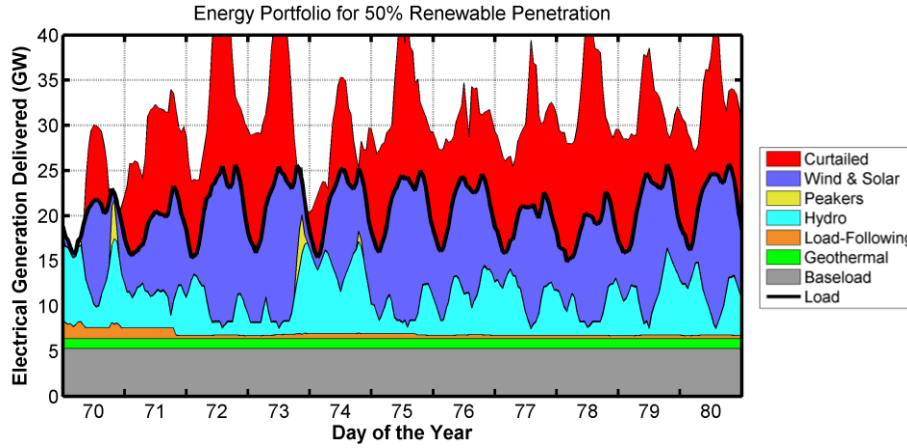
At 40%, More Significant Curtailment

- Load-following capacity is completely reduced and hydro is operating as dynamically as possible

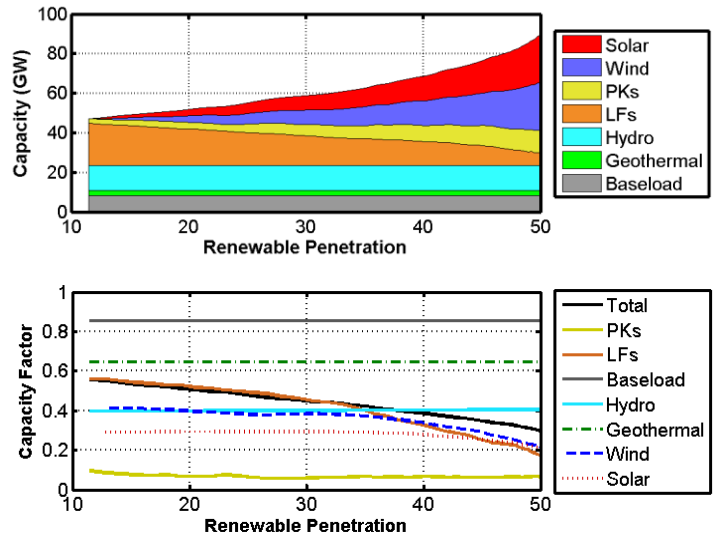


Complementary Technologies Required

- **Else renewables curtailment becomes extreme**

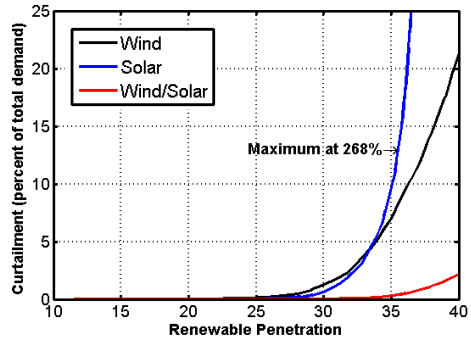


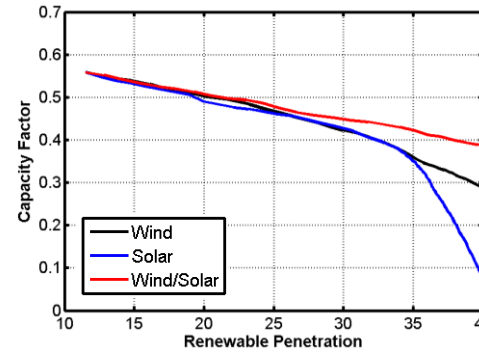
Adding Renewables Impacts Grid *Operation*



More Renewables = More Curtailment

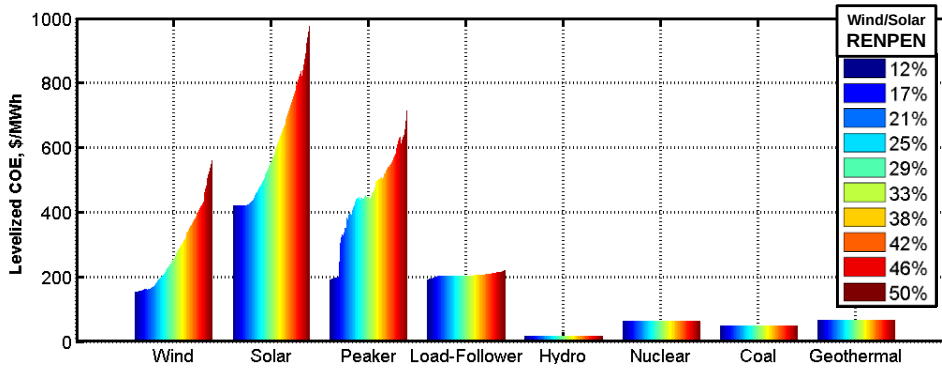
- **Absent complementary technologies, solar & wind intermittency leads to increasing curtailment levels**
- **Capacity factor is inversely related to curtailment**



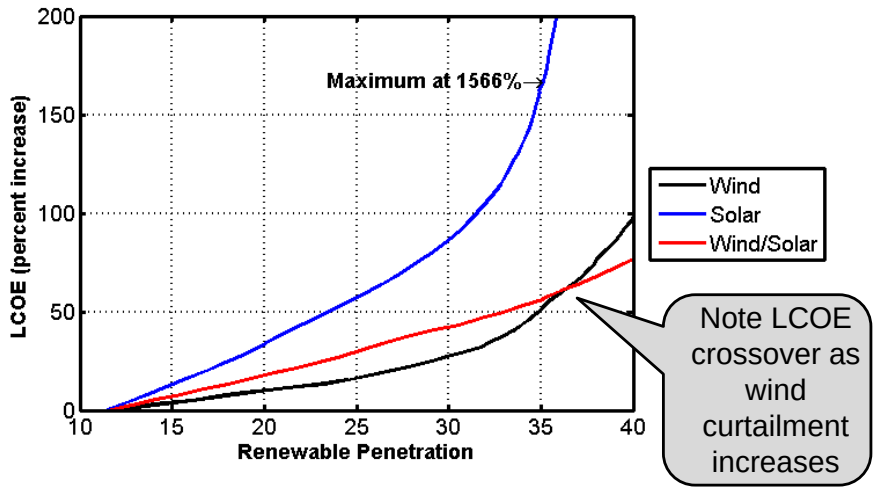


Adding Renewables Impacts Grid *Costs*

- **Declining load factors increase LCOE of wind, solar, peakers, and load-followers**
  - **Increasing curtailment of wind and solar**
  - **Increased use and cycling of peakers**
  - **Load-followers must back down as wind/solar increases**

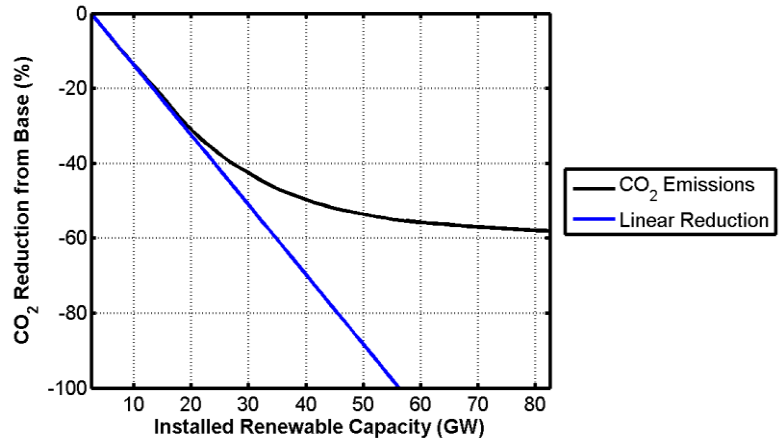


More Curtailment = Higher LCOE



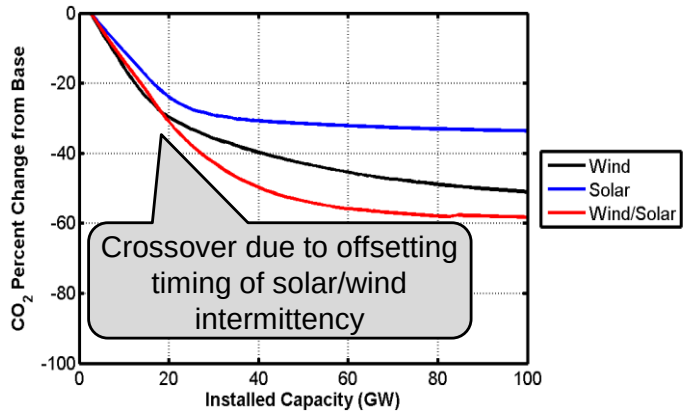
Curtailment ➔ Nonlinear CO_2 Reductions

- **Dispatchable power for balancing intermittency of solar/wind offsets some renewables CO_2 reductions**



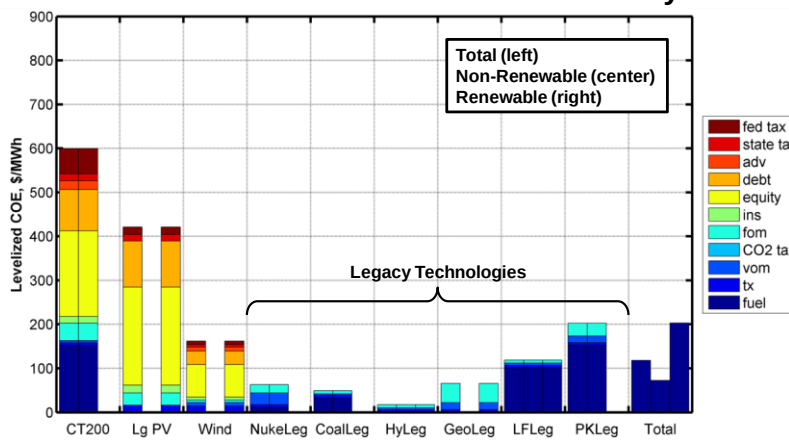
Diverse Renewables Best at Reducing CO_2

- **50/50 combination better for reducing CO_2**
  - **Base represents 11.5% renewables penetration in 2005 for California (from geothermal, biomass and small hydro)**



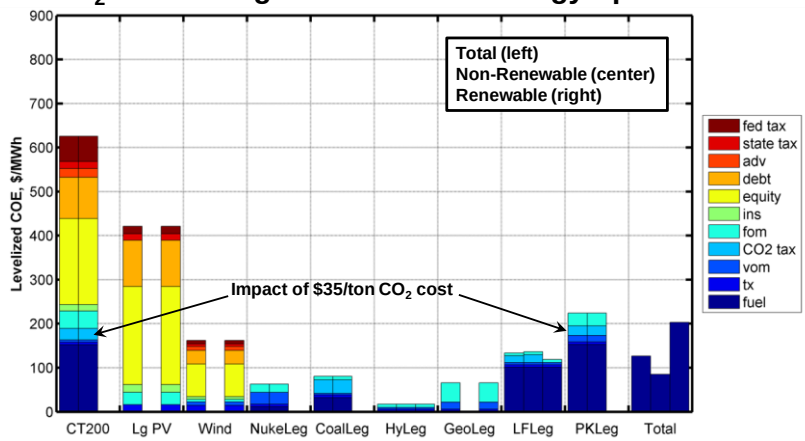
LCOE Components by Technology (1 of 3)

- **33% renewables penetration; no CO_2 cost**
  - **40% debt at 7.49% interest; 14.47% equity return**
  - **Calculate renewable/nonrenewable LCOE by technology**



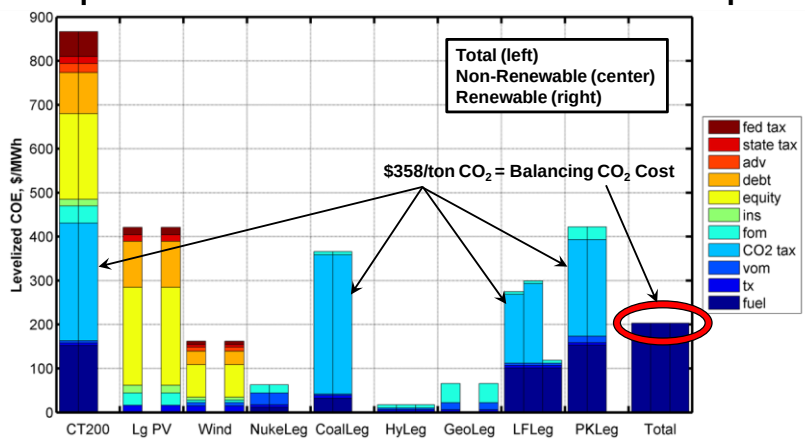
LCOE Components by Technology (2 of 3)

- **33% renewables penetration; $35/ton flat CO_2 cost**
  - **40% debt at 7.49% interest; 14.47% equity return**
  - **CO_2 cost changes relative technology-specific LCOE**



LCOE Components by Technology (3 of 3)

- **33% renewables penetration; "balancing" CO_2 cost**
  - **40% debt at 7.49% interest; 14.47% equity return**
  - **Equalizes LCOE of renewable & non-renewable portfolio**



Future Work

- **Determine required CO_2 tax to reduce California's 2020 CO_2 emissions to 1990 levels**
  - **Must calibrate load signal to available emissions data**
    - **California Independent System Operator ("CAISO")**
    - **California Air Resources Board ("CARB")**
    - **California Energy Commission ("CEC")**
    - **California Public Utilities Commission ("CPUC")**
  - **Model calibrated to 2005 load demand data from CAISO**
    - **Verified using Federal Energy Regulatory Commission generator data for 2000 and 2001 (released following the Western Energy Crisis)**