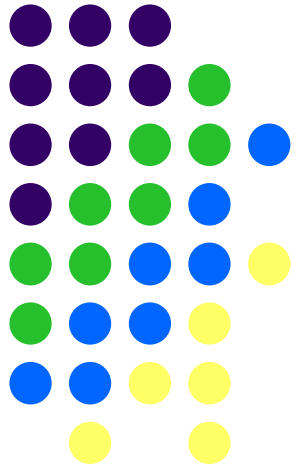
Energy Economics: What Does 100% Renewable Look Like?

American Renewable Energy Day
15 August 2019
Snowmass, Colorado

Lori Smith Schell, Ph.D., ERP
Empowered Energy

174 N. Elk Run, Durango, CO 81303 USA
Tel: (970) 247-8181 • Fax: (970) 247-3761
E-Mail: LSchell@EmpoweredEnergy.com



Empowered™ Energy

Short Answer: It Depends. Policy & Cost Drive Renewables

Identify Technology-Specific Attributes

↓

Quantify Technology-Specific Value Proposition

↓

Rank Emerging Technologies by Value Proposition and Suitability for Achieving Policy Mandates

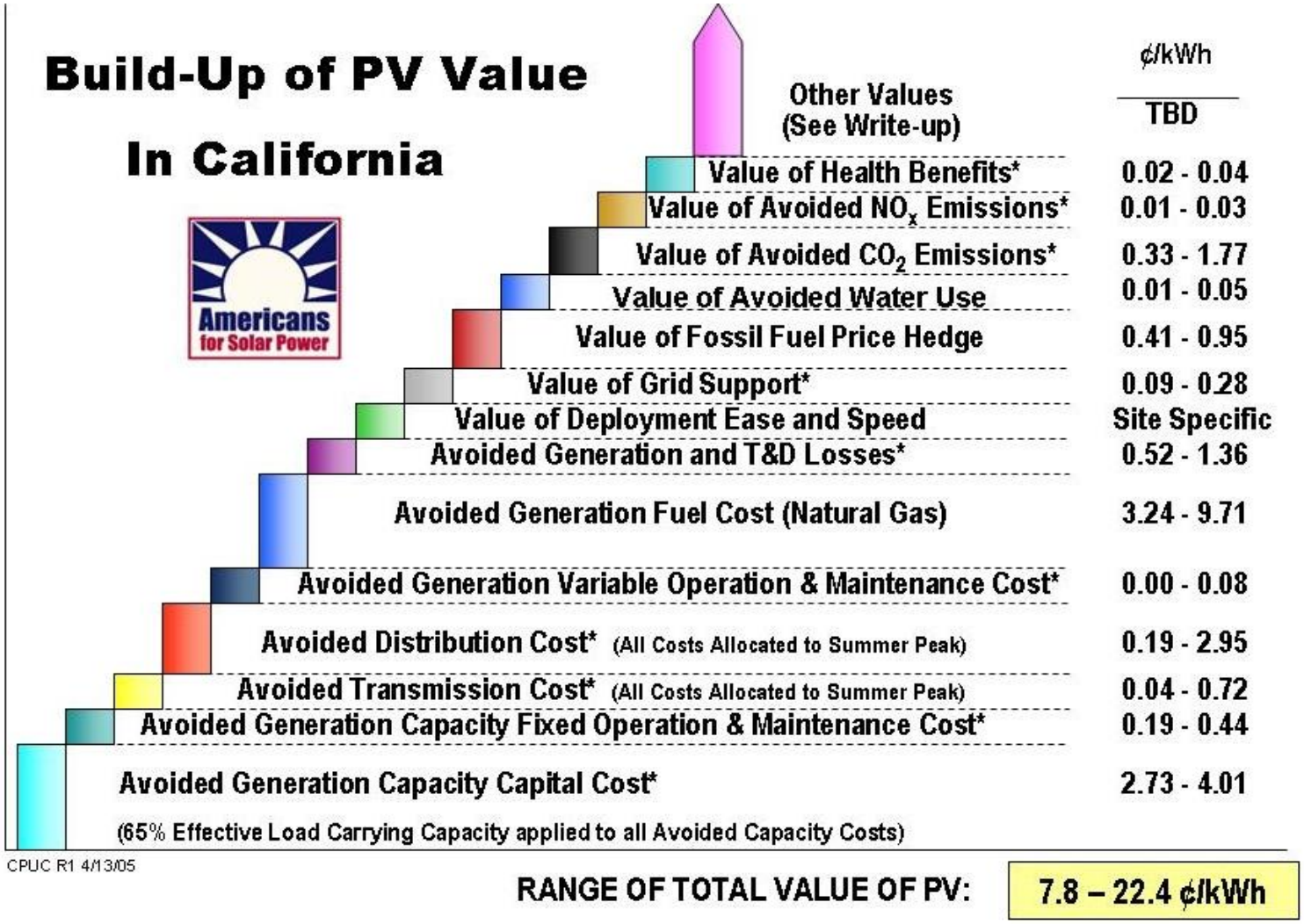
↓

Contribute to the Efficient Achievement of Policy Mandates at Minimum Cost

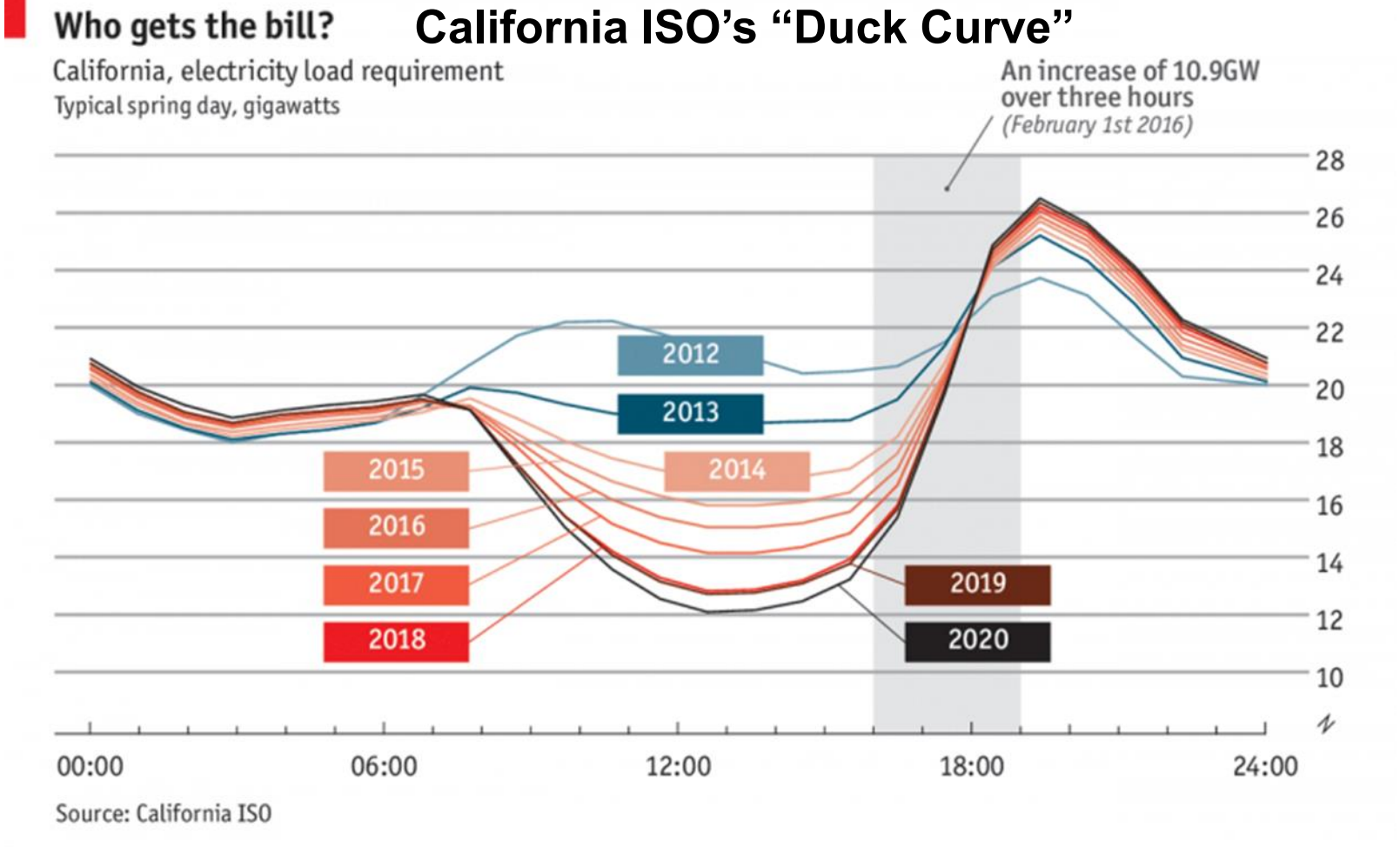
↓

Enable Evolution of Next Generation Technologies

PV "Waterfall" Informed Debate on the California Solar Initiative

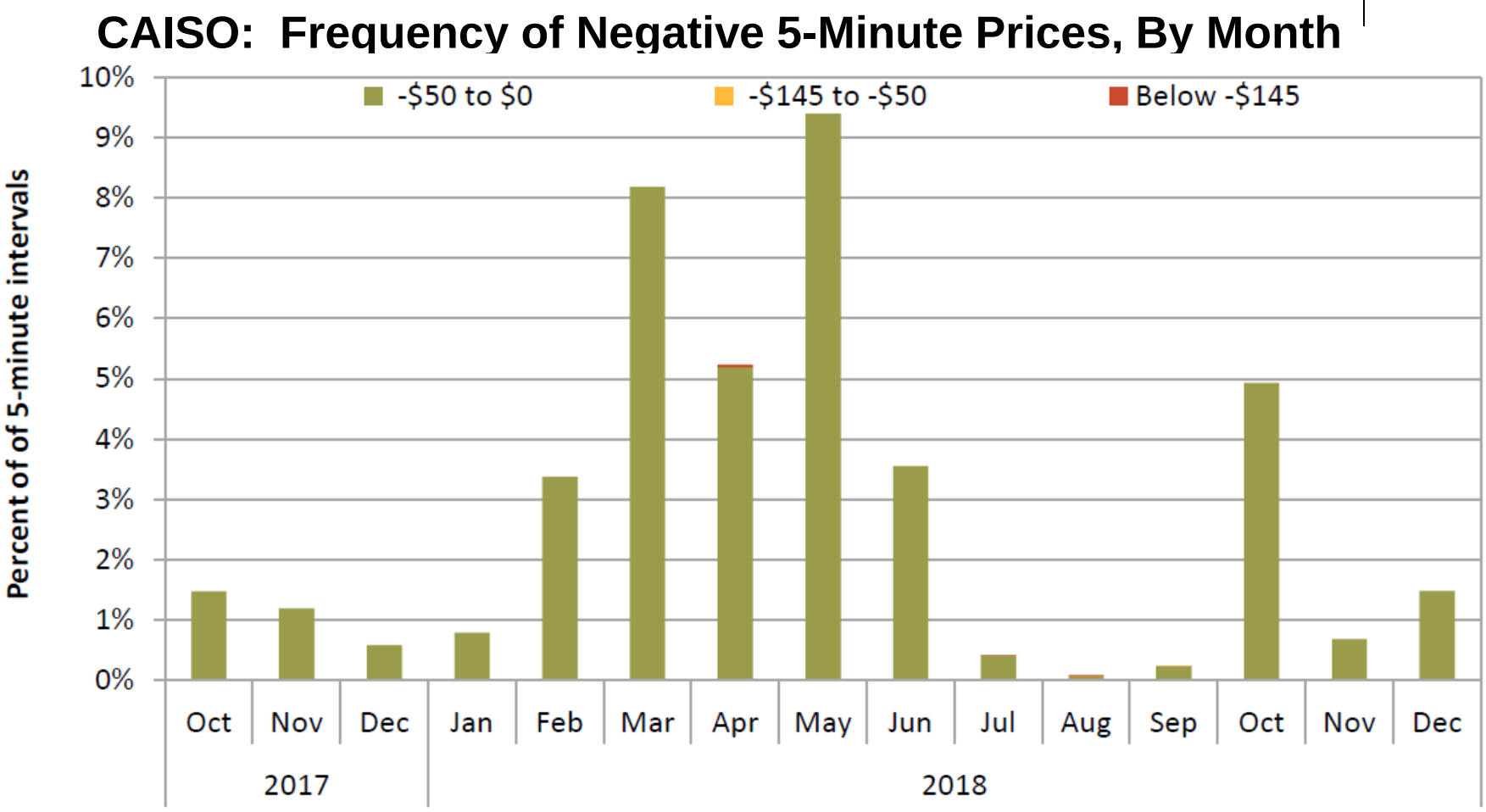


Renewables Impact Net Load & Require Periodic Curtailment



Source: The Economist, 3/28/2018, *What a ten-year-old duck can teach us about electricity demand*.
https://www.economist.com/graphic-detail/2018/03/28/what-a-ten-year-old-duck-can-teach-us-about-electricity-demand

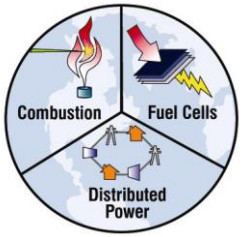
Required Curtailment Impacts Wholesale Electricity Pricing



Source: California Independent System Operator, February 13, 2019, *Q4 2018 Report on Market Issues and Performance*. http://www.caiso.com/Documents/2018FourthQuarterReportonMarketIssuesandPerformance.pdf#search=negative%205%2Dminute%20prices

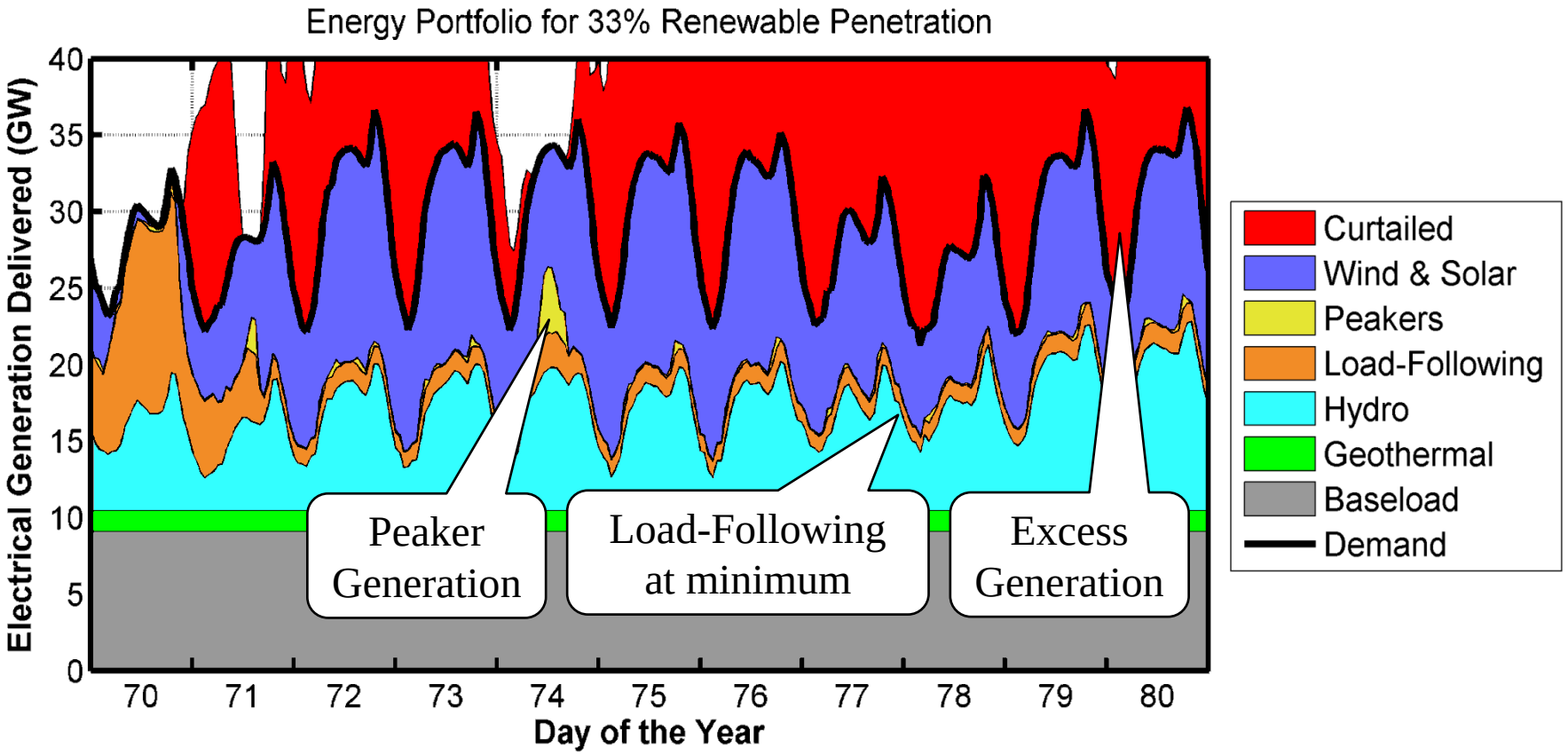
HiGRID Results: Renewables Integration

- **Task 4.1: Perform spanning analysis for different resources in California**
  - **Installation of renewables affects how other generators operate**



Advanced Power and Energy Program

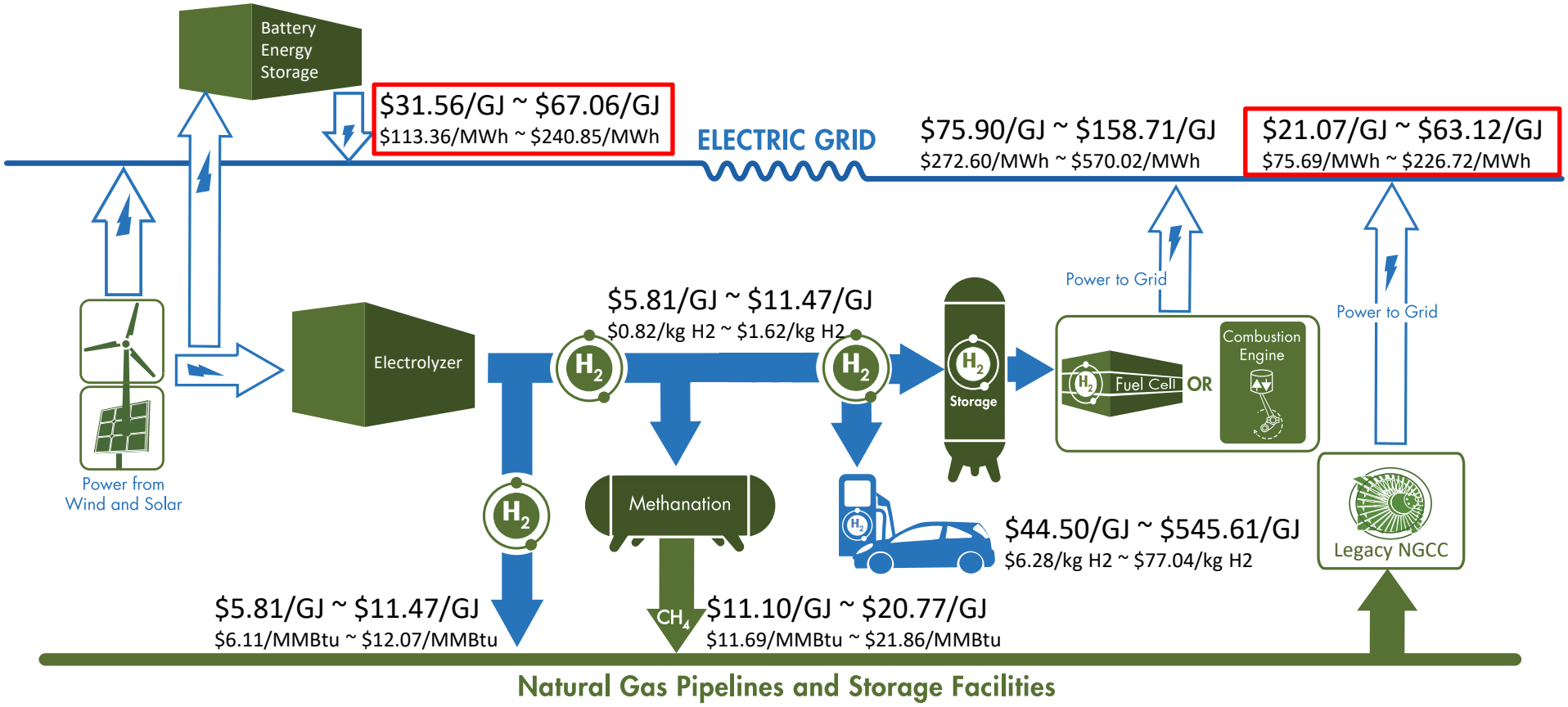
UCIrvine | University of California



LCORE* Results

CURRENT COSTS & EFFICIENCIES

45% Capacity Factor for Batteries;
90% Capacity Factor for All Other Equipment



* LCORE = Levelized Cost of Returned Energy = Levelized Cost of Energy with Zero-Cost Electricity Input

LCORE* Results

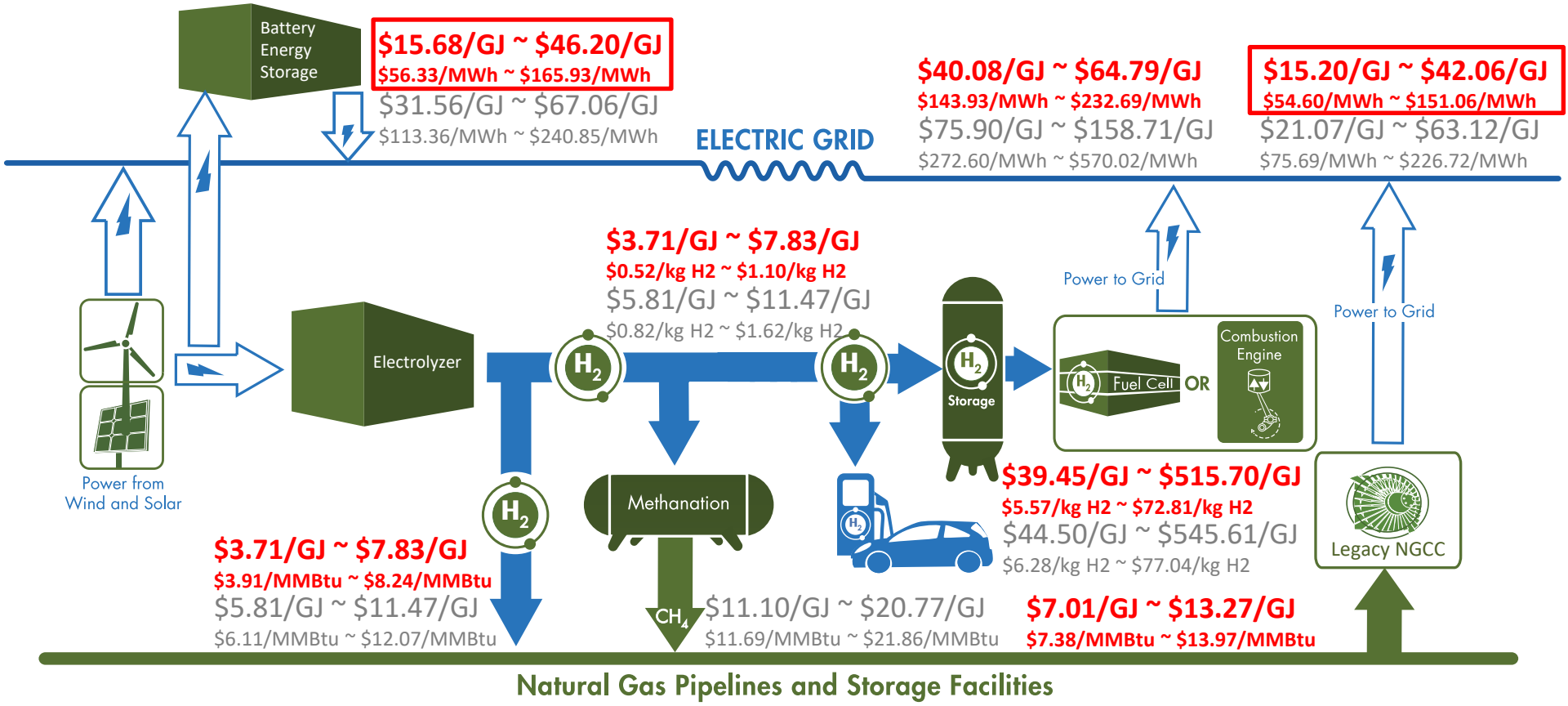
LCORE* Results

CURRENT COSTS & EFFICIENCIES

45% Capacity Factor for Batteries;
90% Capacity Factor for All Other Equipment

FUTURE COSTS & EFFICIENCIES

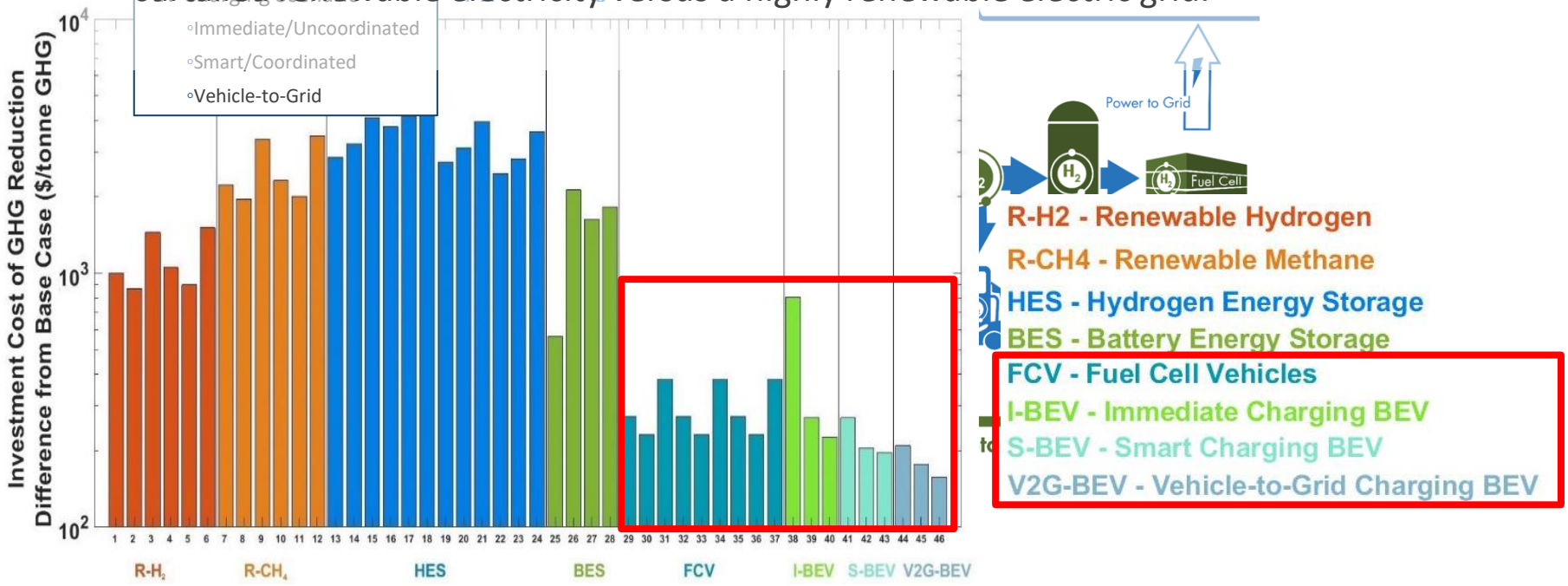
45% Capacity Factor for Batteries;
90% Capacity Factor for All Other Equipment



* LCORE = Levelized Cost of Returned Energy = Levelized Cost of Energy with Zero-Cost Electricity Input

Reduce Curtailment, Reduce Cost of Emissions Reductions

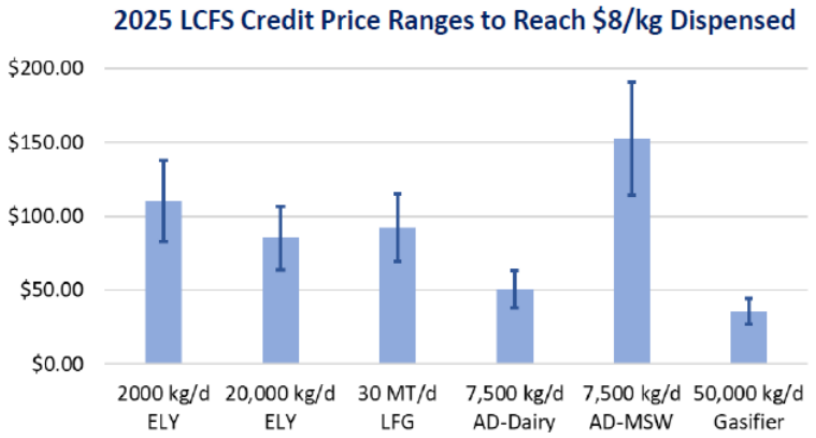
- Vehicle pathways yielded lowest cost GHG emission reductions
  - Higher GHG emissions from gasoline than natural gas
  - Higher potential to replace conventional technologies utilizing otherwise curtailed renewable electricity versus a highly renewable electric grid.

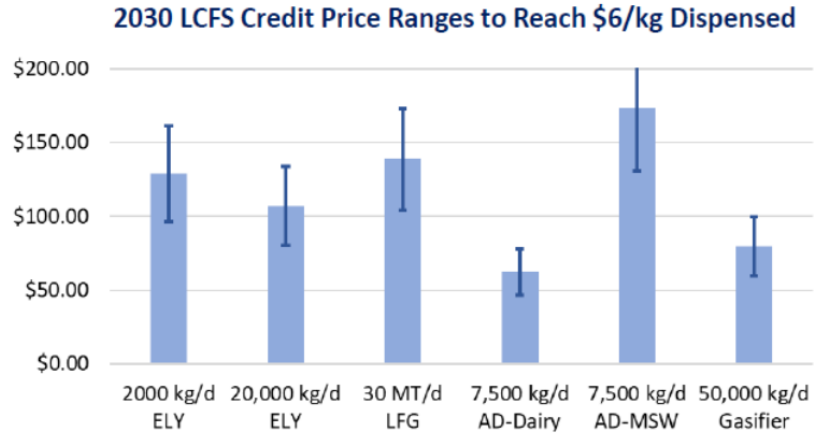


Source: Wang, Sarah M., et al., 1 February 2019, *Prioritizing among the end uses of excess renewable energy for cost-effective greenhouse gas emission reductions*, Applied Energy, Vol. 235, pp. 284-298. https://doi.org/10.1016/j.apenergy.2018.10.071

Current Analysis Doing Same for Renewable H2 Fueling

Credit Prices Needed to Achieve Pump Price Benchmarks



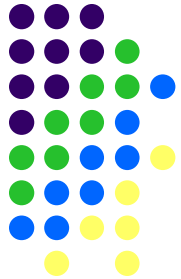


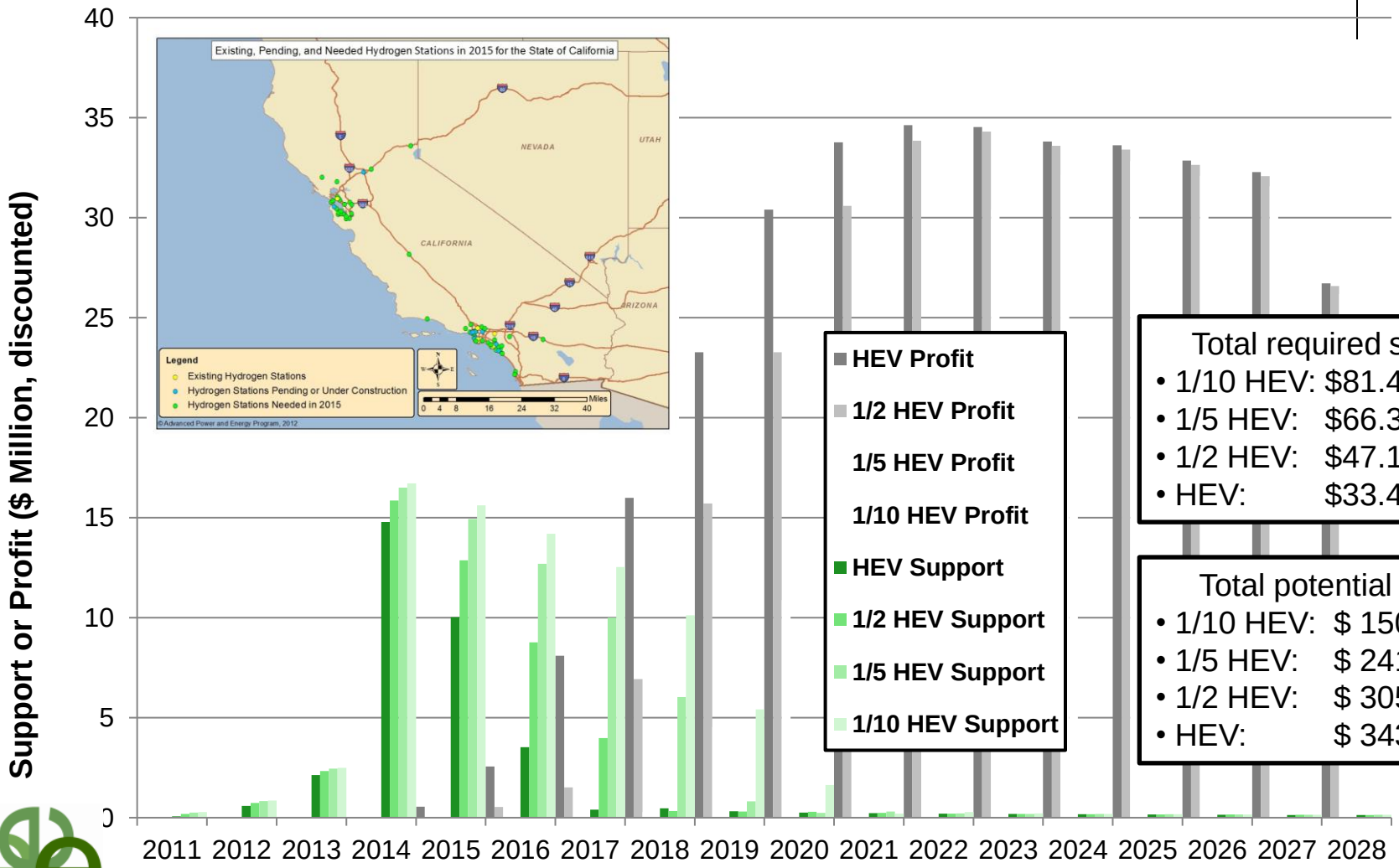
Commentary:

- All pathways likely to be financially viable when tipping fees and environmental credits are considered
- Biomass recovery mandates likely to cause tipping fees to adjust to meet market price
- Over the long term, electrolytic hydrogen is likely to be the "price setter" for RH2 as biomass resource constraints come into play and eRH2 becomes the marginal supply
- Timing depends on policy on and access to out-of-state biomass

Interim Results

Upfront Support Required: 68 H2 Fueling Station Network

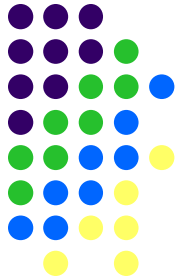




Total required support:
- 1/10 HEV: $81.4 MM
- 1/5 HEV: $66.3 MM
- 1/2 HEV: $47.1 MM
- HEV: $33.4 MM

Total potential profits:
- 1/10 HEV: $ 150 MM
- 1/5 HEV: $ 241 MM
- 1/2 HEV: $ 305 MM
- HEV: $ 343 MM

100% Renewable Depends on Well-Informed Public Policy



Identify Technology-Specific Attributes

↓

Quantify Technology-Specific Value Proposition

↓

Rank Emerging Technologies by Value Proposition and Suitability for Achieving Policy Mandates

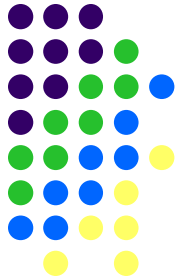
↓

Contribute to the Efficient Achievement of Policy Mandates at Minimum Cost

↓

Enable Evolution of Next Generation Technologies

100% Renewable Depends on Well-Informed Public Policy



Identify Technology-Specific Attributes

↓

Quantify Technology-Specific Value Pr

↓

Rank Emerging Technologi sition and
Suitability for mandates

Contribut hievement of Policy Mandates at
Minimum Cost

↓

lable Evolution of Next Generation Technologies

Whatever It Looks Like!

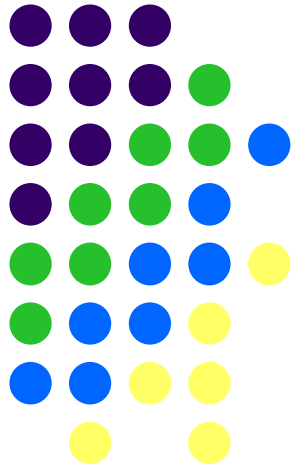
Energy Economics: What Does 100% Renewable Look Like?

THANK YOU!

QUESTIONS?

Lori Smith Schell, Ph.D., ERP
Empowered Energy

174 N. Elk Run, Durango, CO 81303 USA
Tel: (970) 247-8181 • Fax: (970) 247-3761
E-Mail: LSchell@EmpoweredEnergy.com



Empowered™ Energy