Evaluating energy technologies against climate targets

Jessika E. Trancik
Institute for Data, Systems, and Society, MIT
Santa Fe Institute

July 29, 2016
Global Sustainability Summer School
Santa Fe Institute

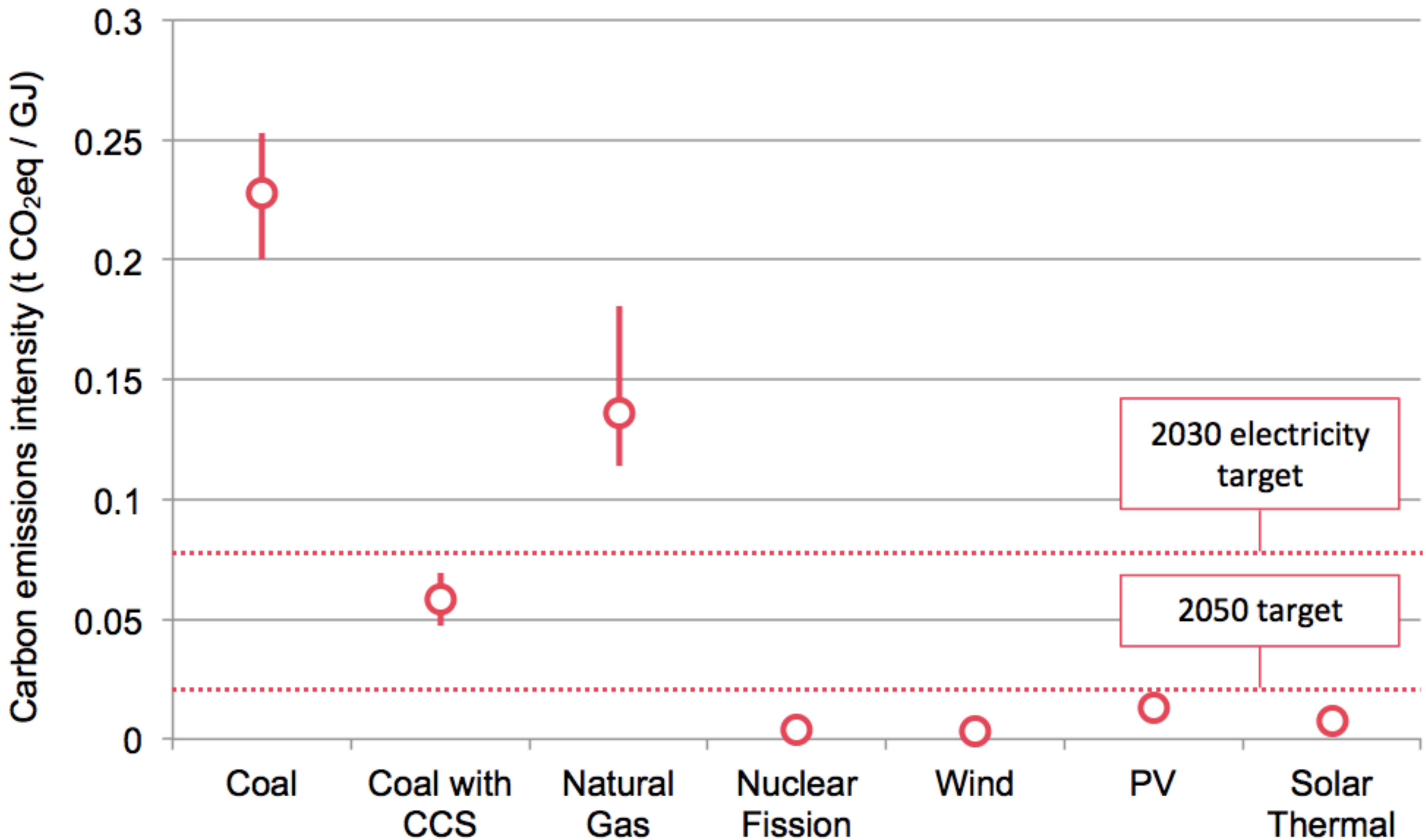
Today’s agenda

- Role of energy systems in climate change mitigation
- Evaluating energy technologies against climate targets

Lecture 2 outline: evaluating energy technologies

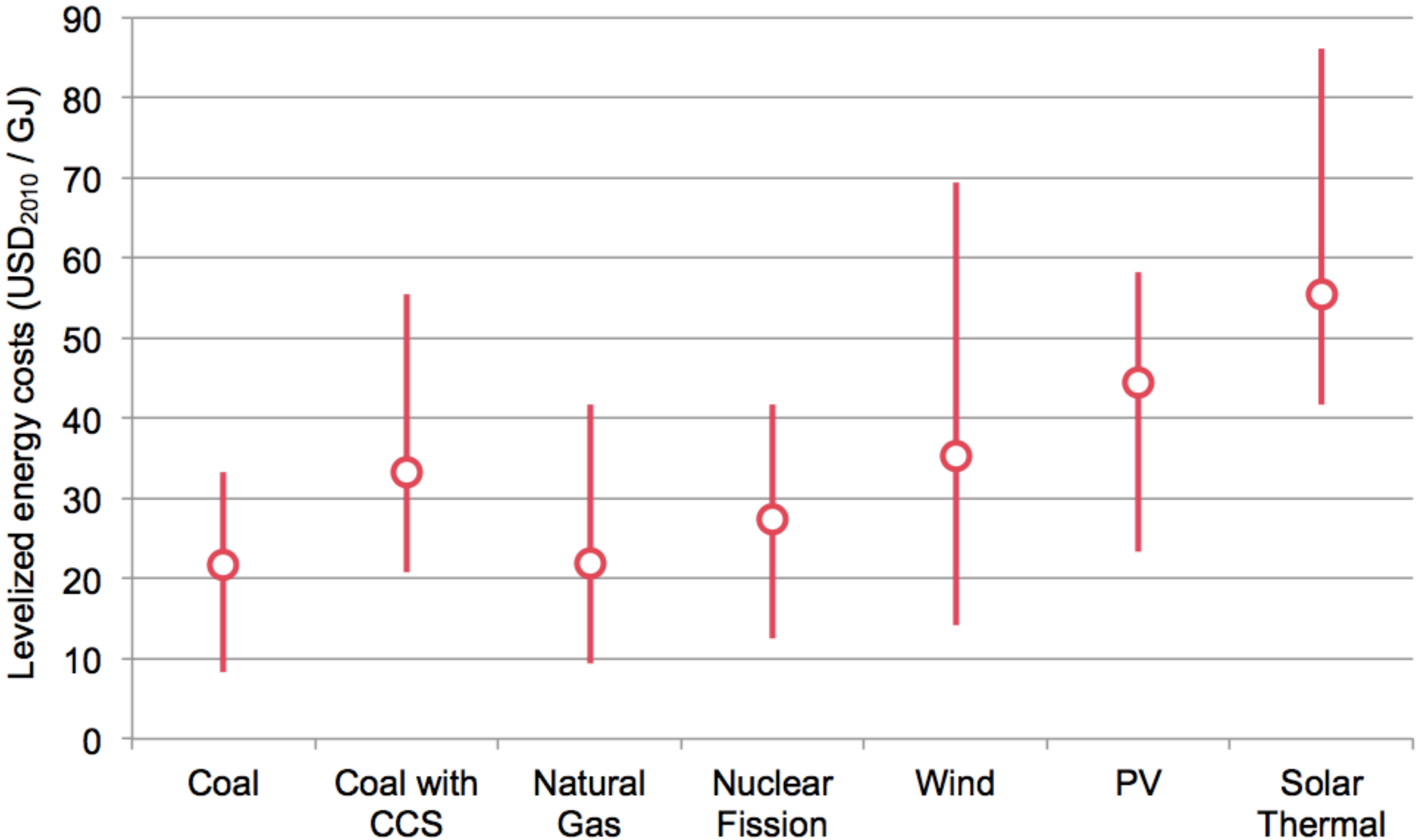
- Technology innovation dynamics
- Evaluating technologies against demand patterns

U.S. carbon intensity target



Trancik, *Nature*, 2014

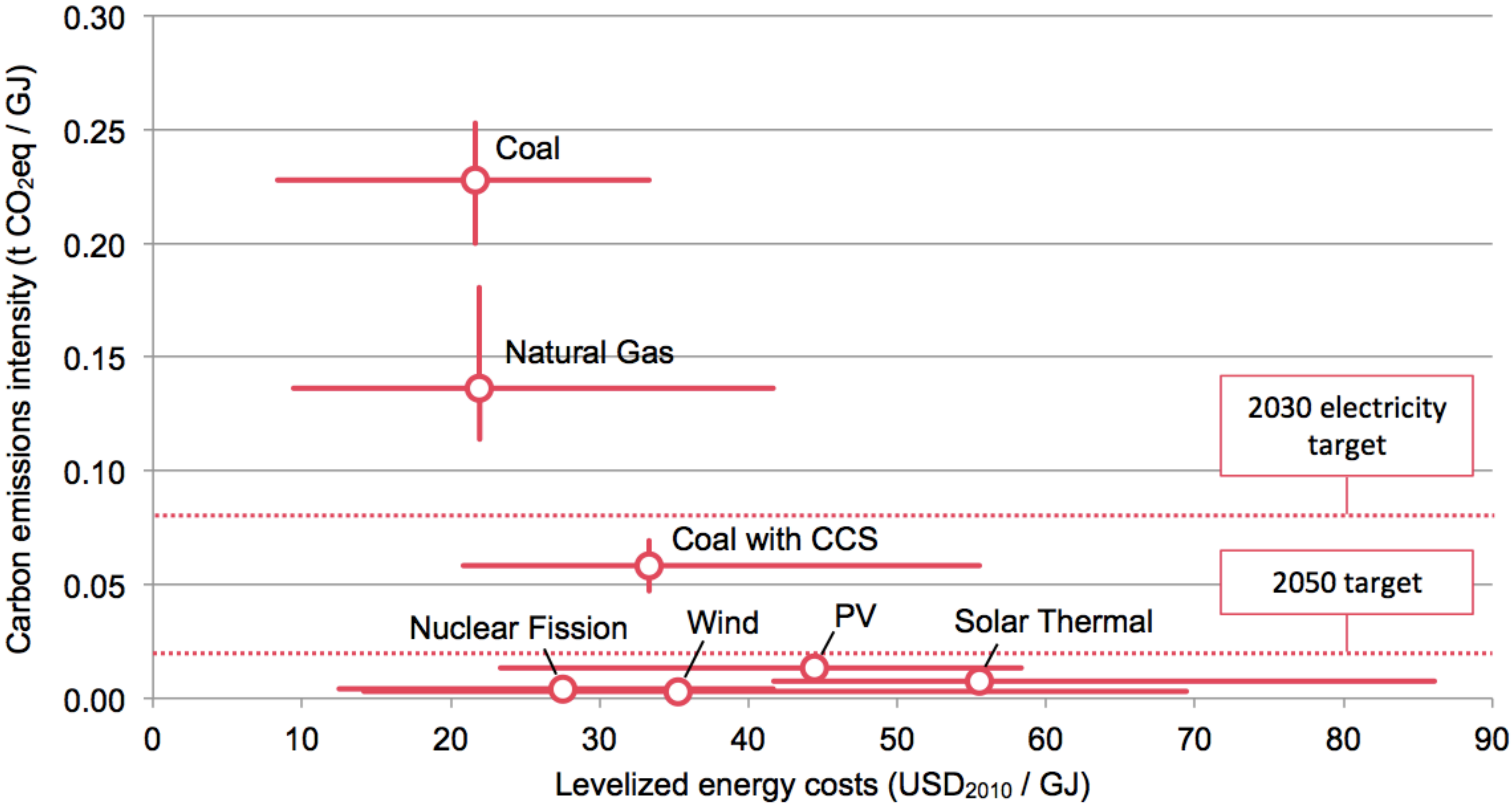
Trancik,Cross-Call, *ES&T*, 2013



Trancik, *Nature*, 2014

Trancik,Cross-Call, *ES&T*, 2013

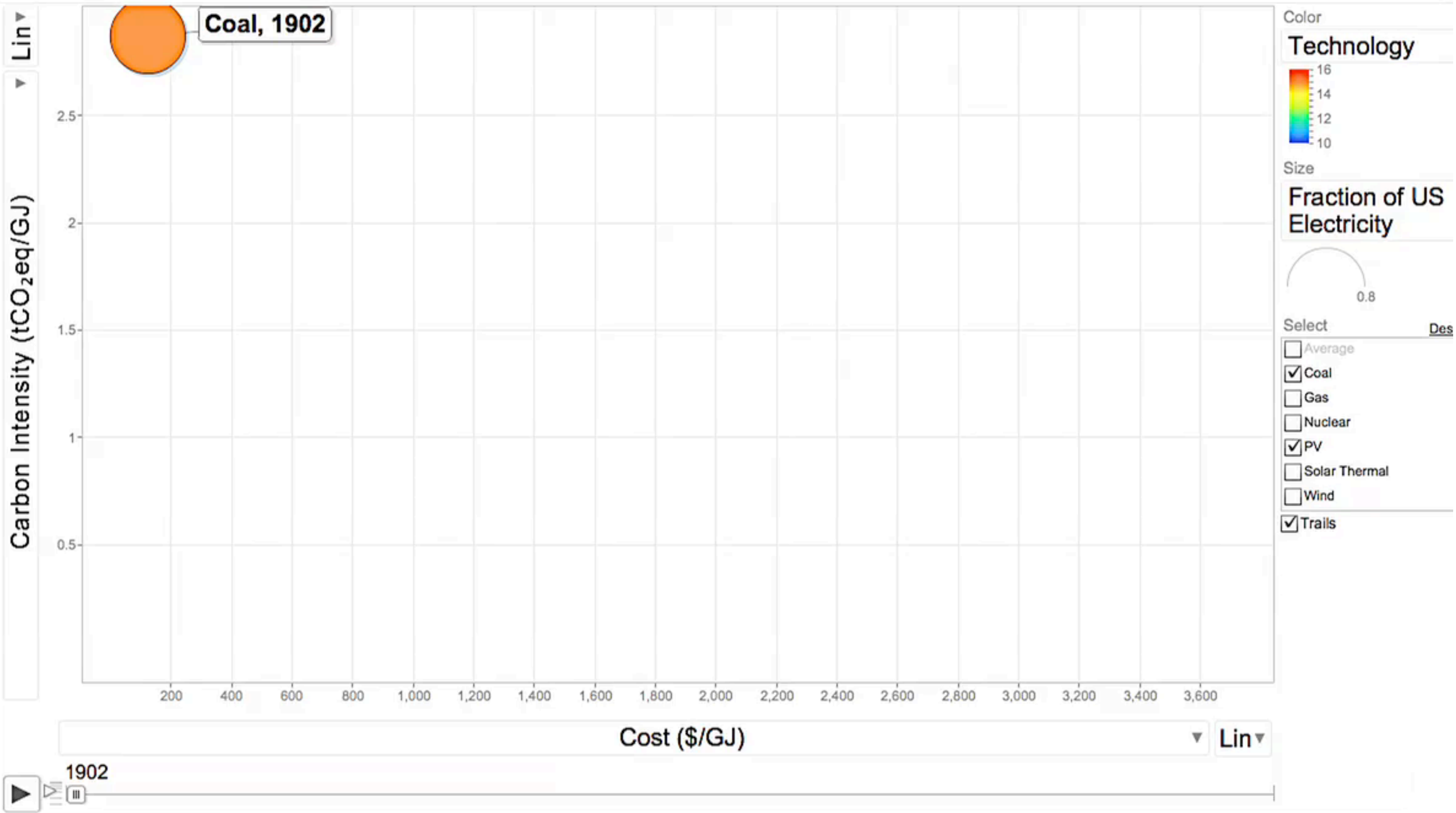
Cost-carbon curve



Trancik, *Nature*, 2014

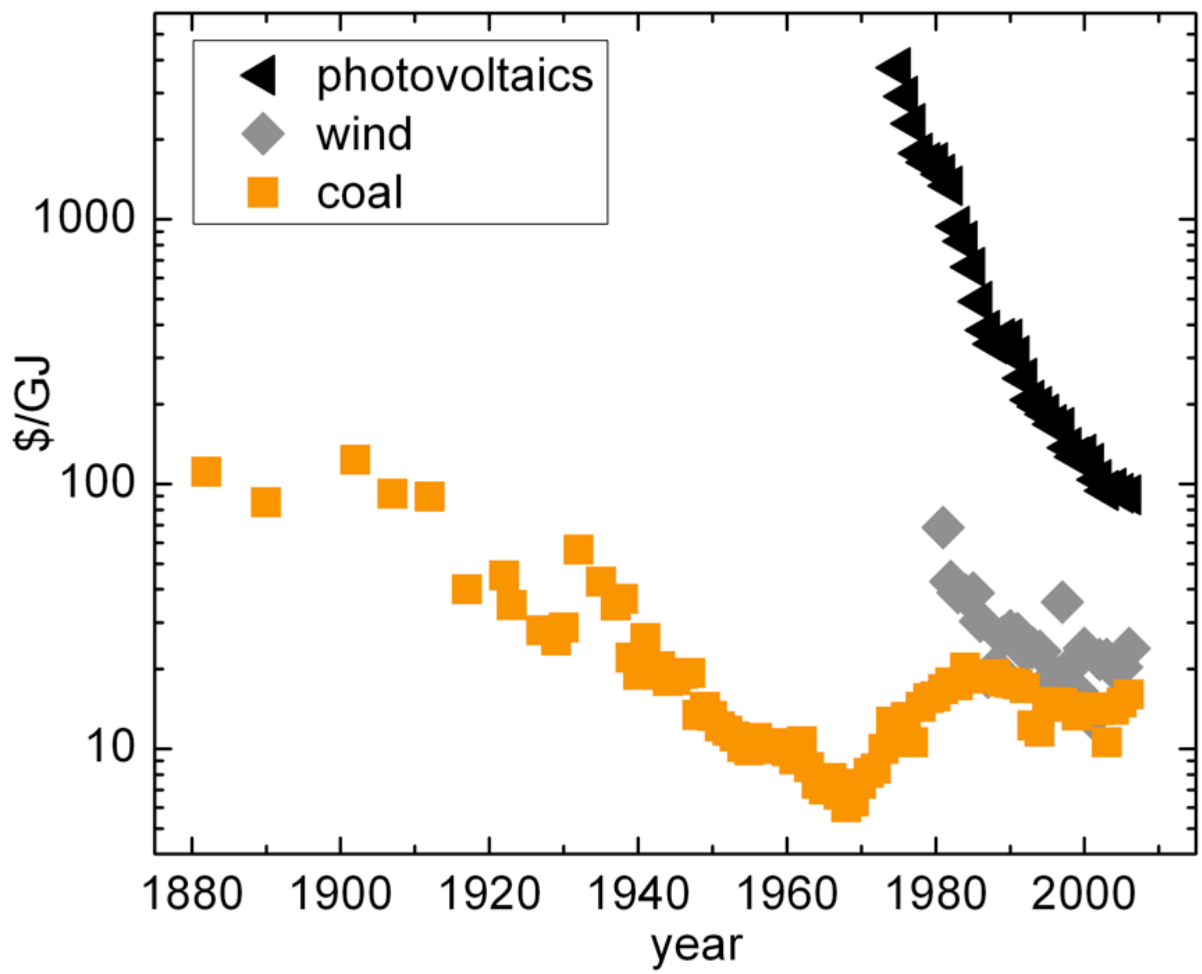
Trancik,Cross-Call, *ES&T*, 2013

Cost and carbon intensity of energy (electricity)

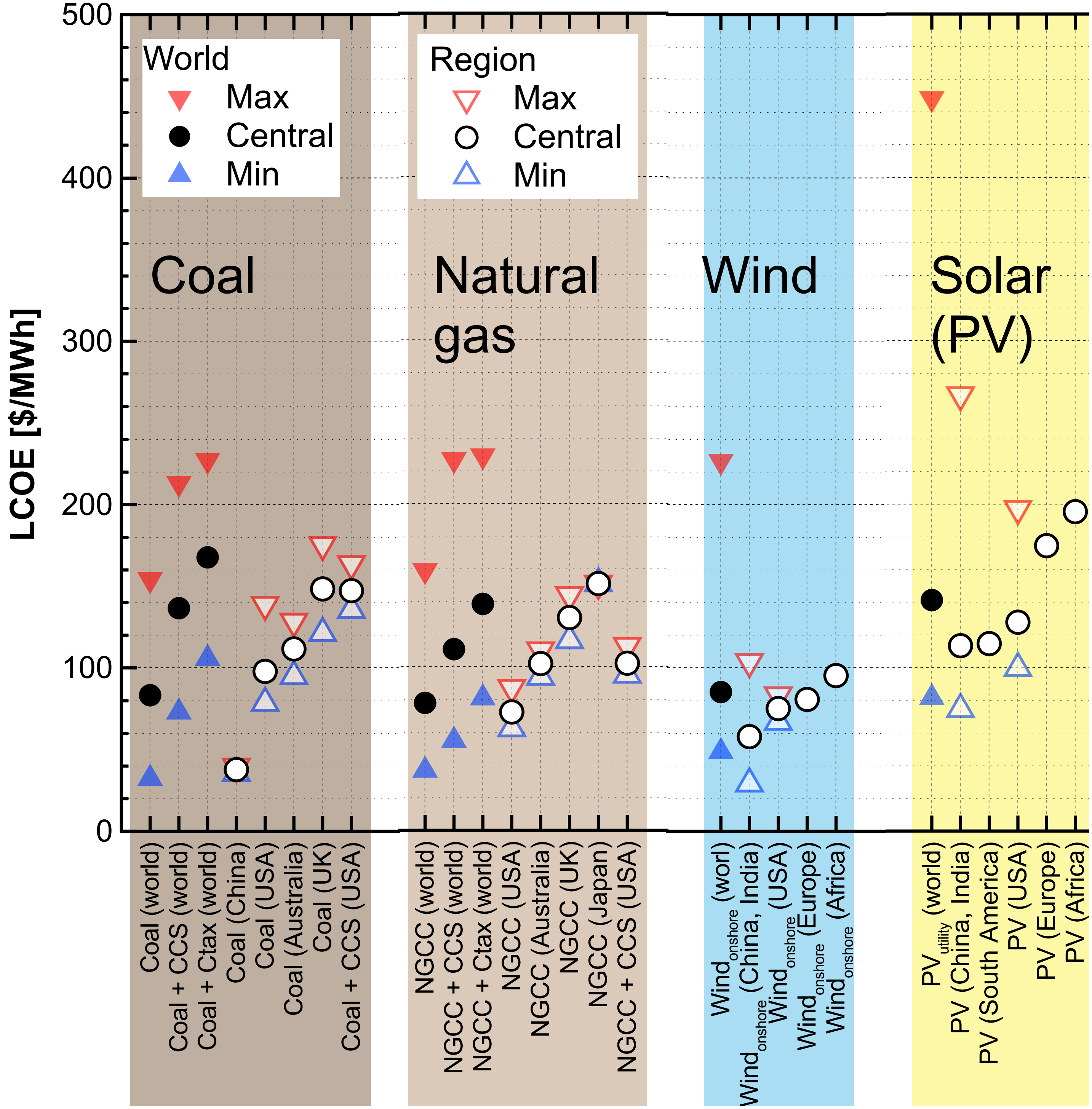


Trancik, Cross-Call, *ES&T*, 2013

Change in energy technology costs over time



Trancik, Cross-Call, Energy technologies evaluated against climate targets, *ES&T* 2013



Trancik, Brown, Jean, Kavlak, Klemun, Edwards, McNerney, Miotti, Mueller, Needell, Technical Report, 2015

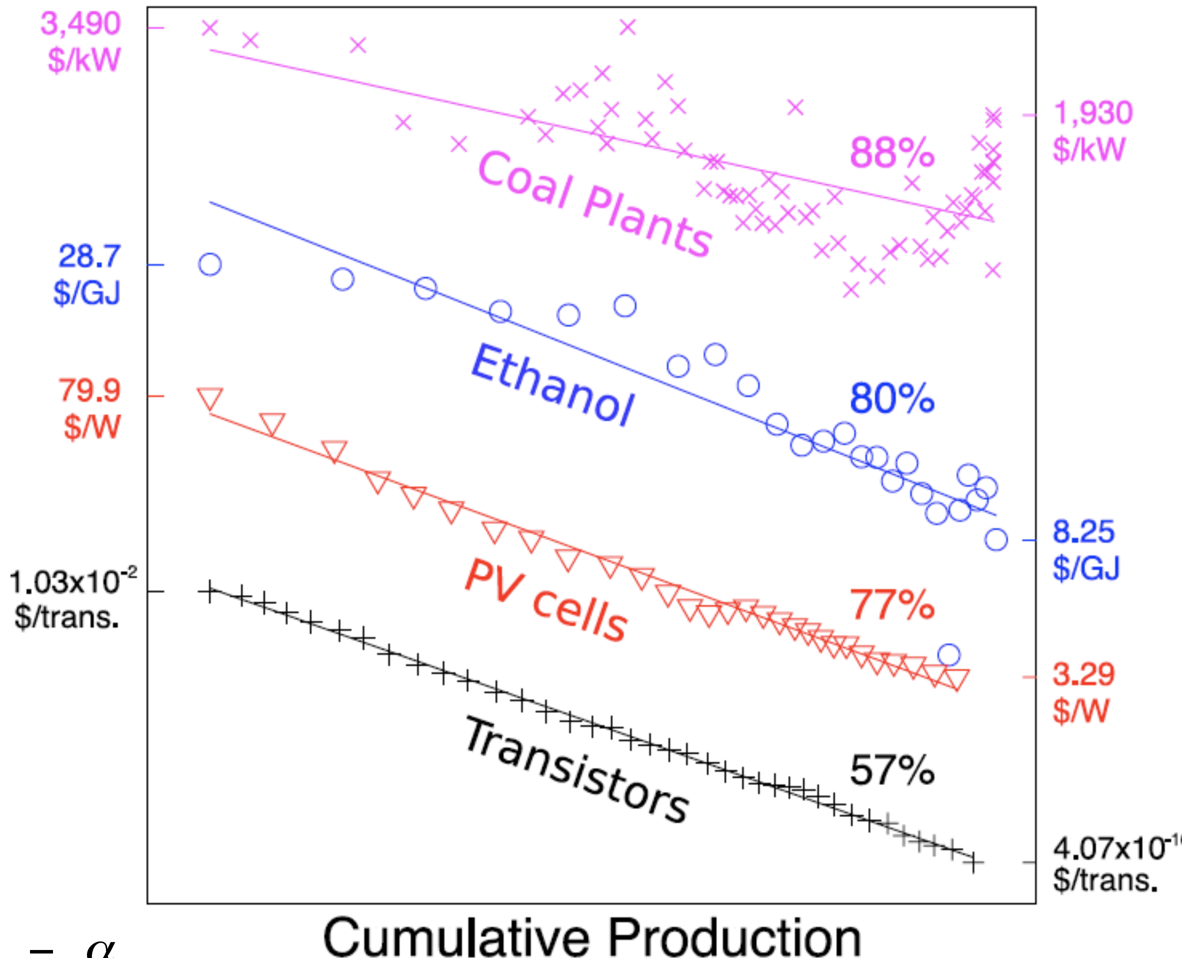
Determinants of the rate of technology innovation

Are technology costs changing in regular ways?

If so, what equations describe these changes?

How might costs change in future?

Performance curves



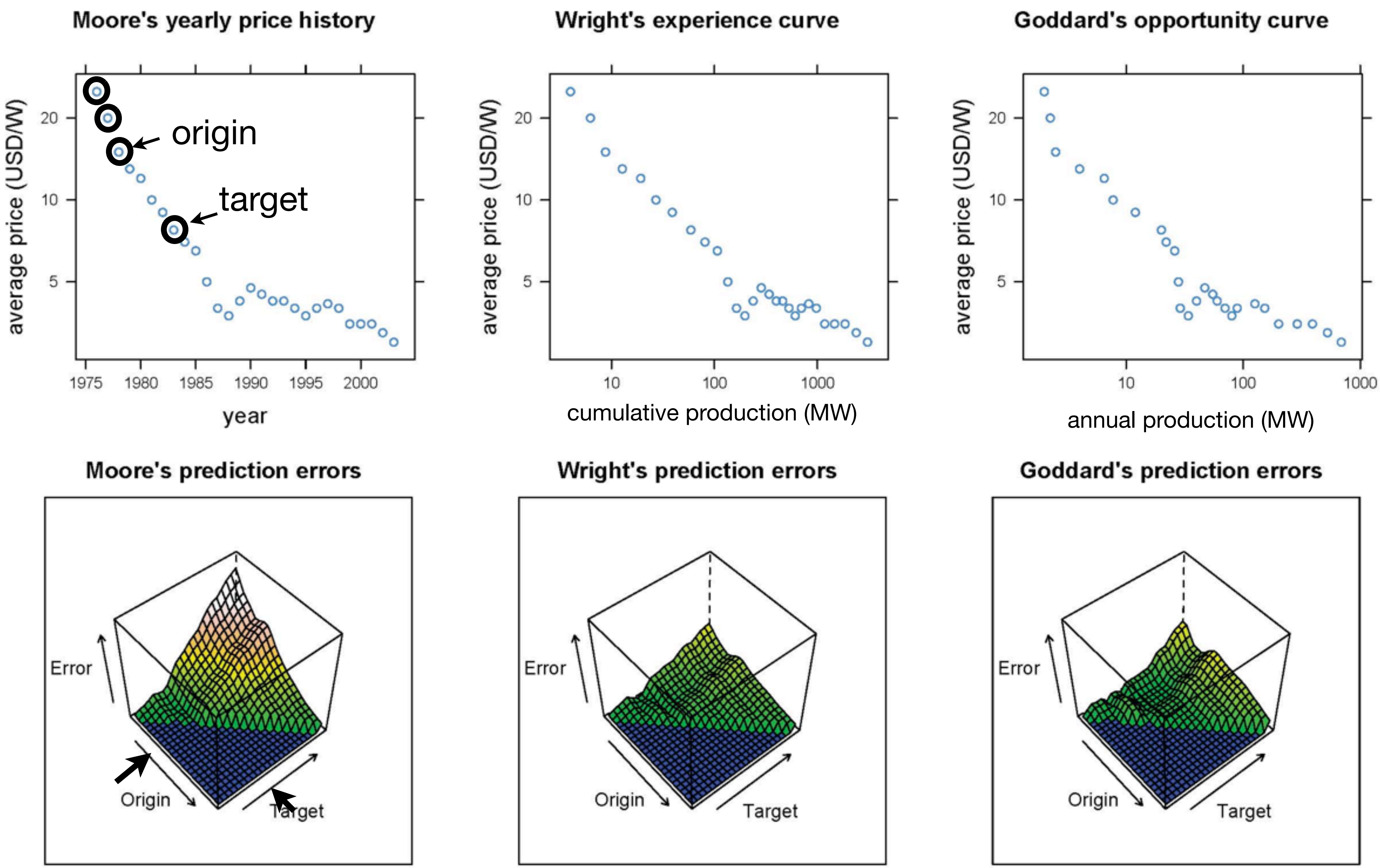
$$c(x) \sim x^{-\alpha}$$

$$PR = 2^{-\alpha}$$

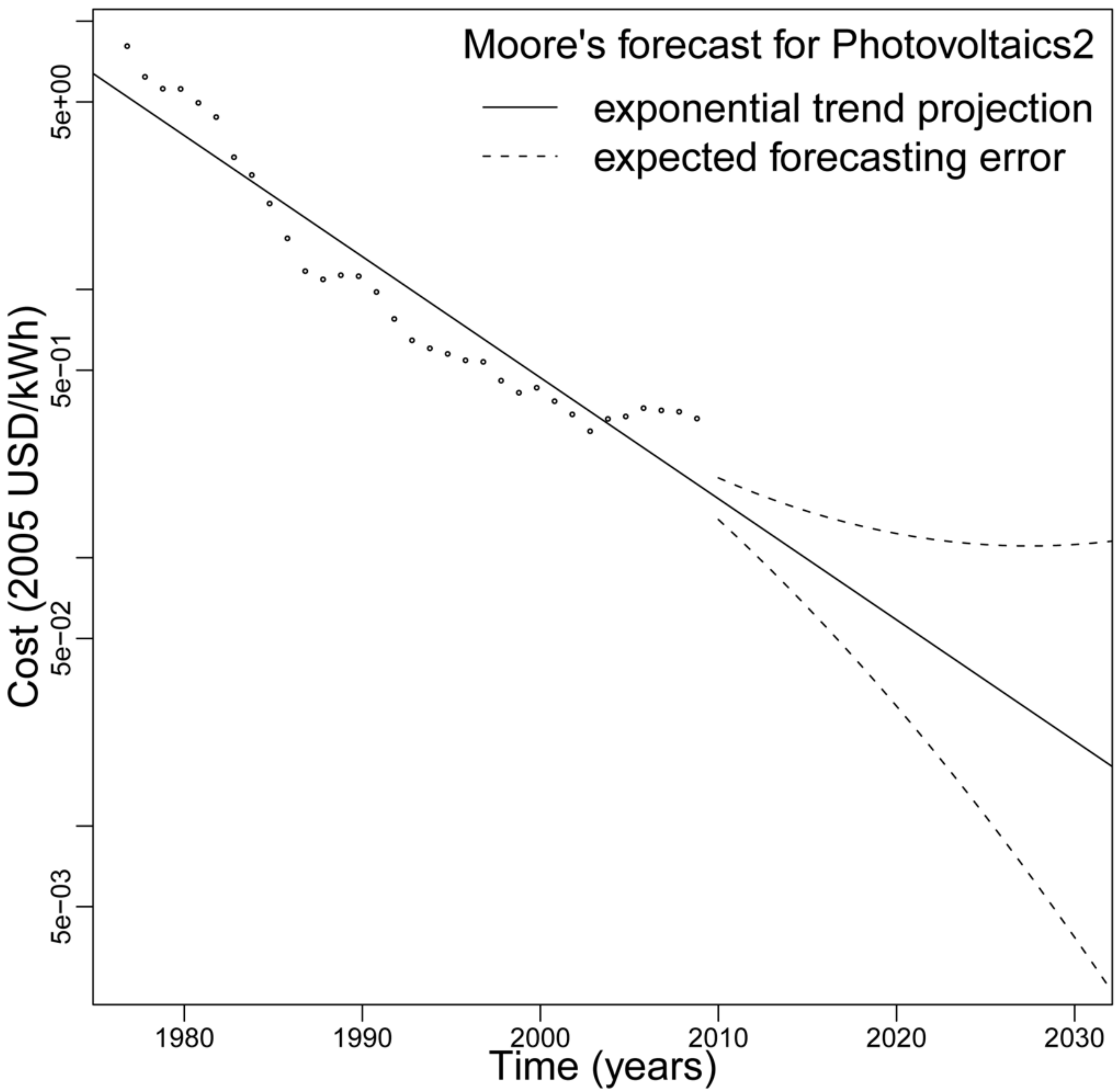
Series	Years	Range
Coal plants	1902–2006	$6.1\times10^5 - 3.1\times10^8$ kW
Ethanol	1980–2004	$3.4\times10^6 - 2.7\times10^8$ m³
PV cells	1975–2003	$5.4\times10^2 - 2.2\times10^6$ kW
Transistors	1968–2005	$2.0\times10^9 - 1.1\times10^{19}$

McNerney, Farmer, Redner, Trancik, *PNAS*, 2011

Evaluating competing models

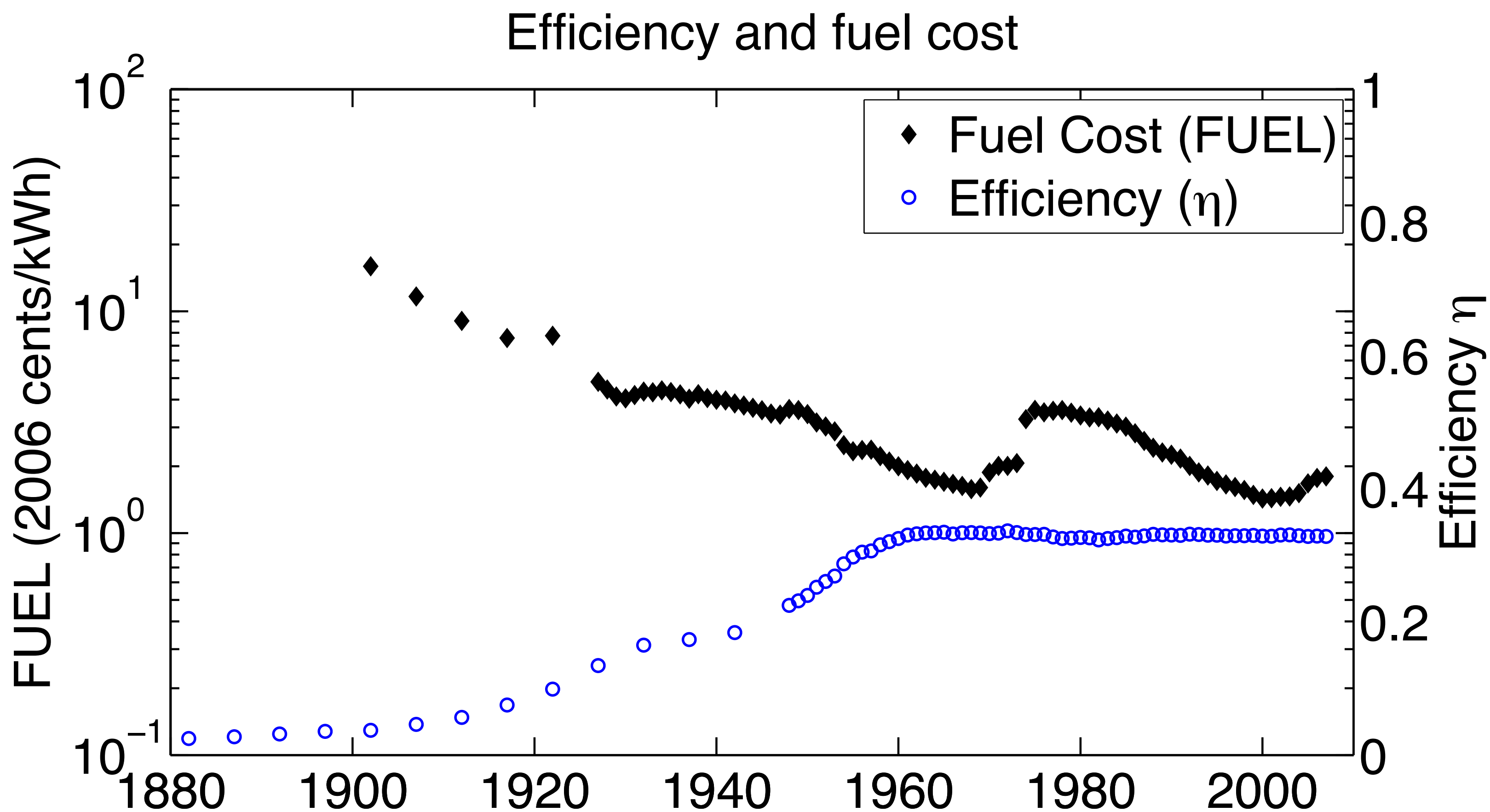


Nagy, Farmer, Bui, Trancik, *PLoS One*, 2013



Nagy, Farmer, Bui, Trancik, *PLoS One*, 2013

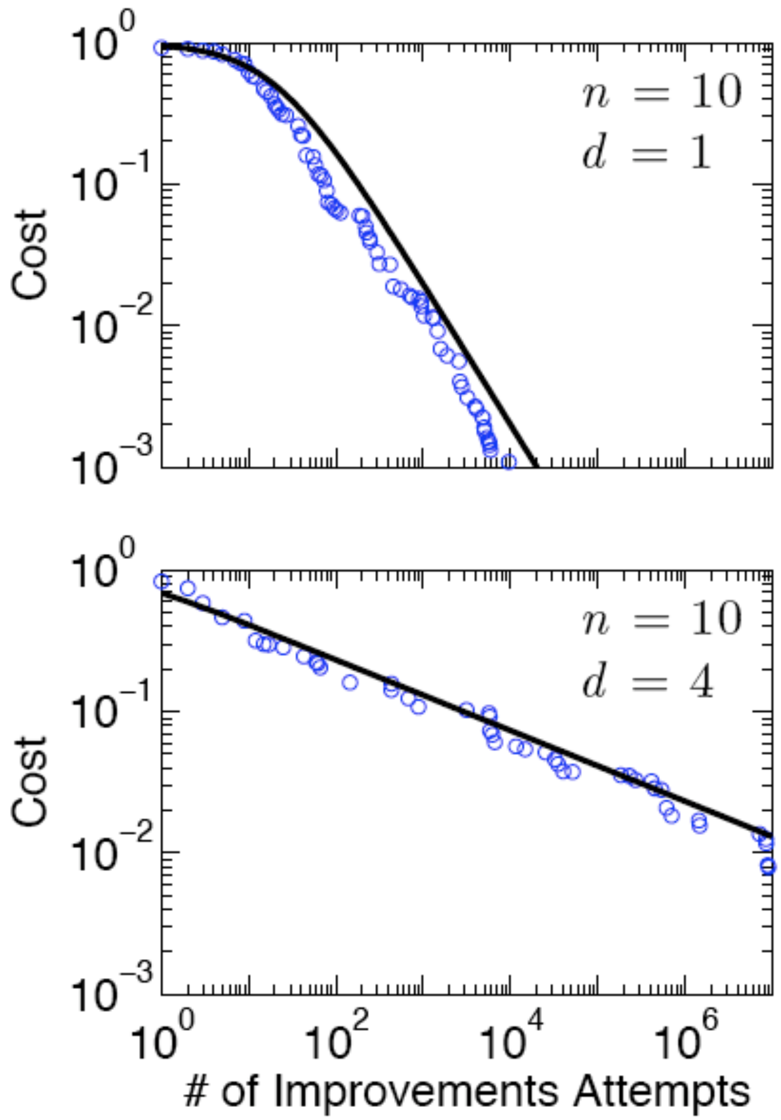
Limits to tech improvement: commodity cost floors

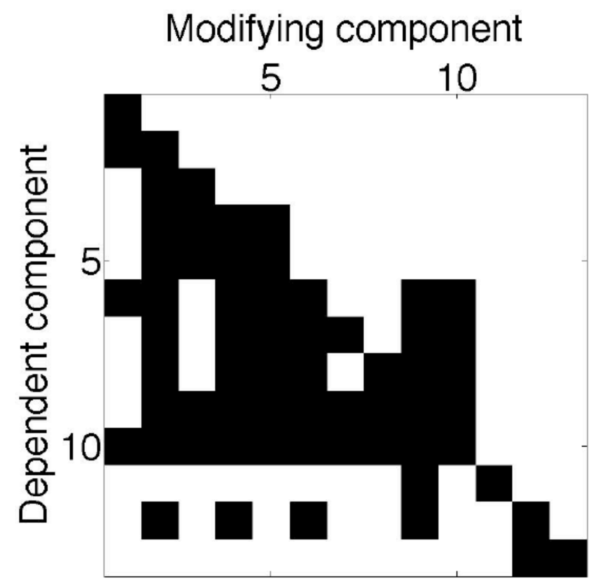


McNerney, Farmer, Trancik, Historical Costs of Coal-Fired Electricity, *Energy Policy*, 2011

Technology design and rate of improvement

Increasing complexity





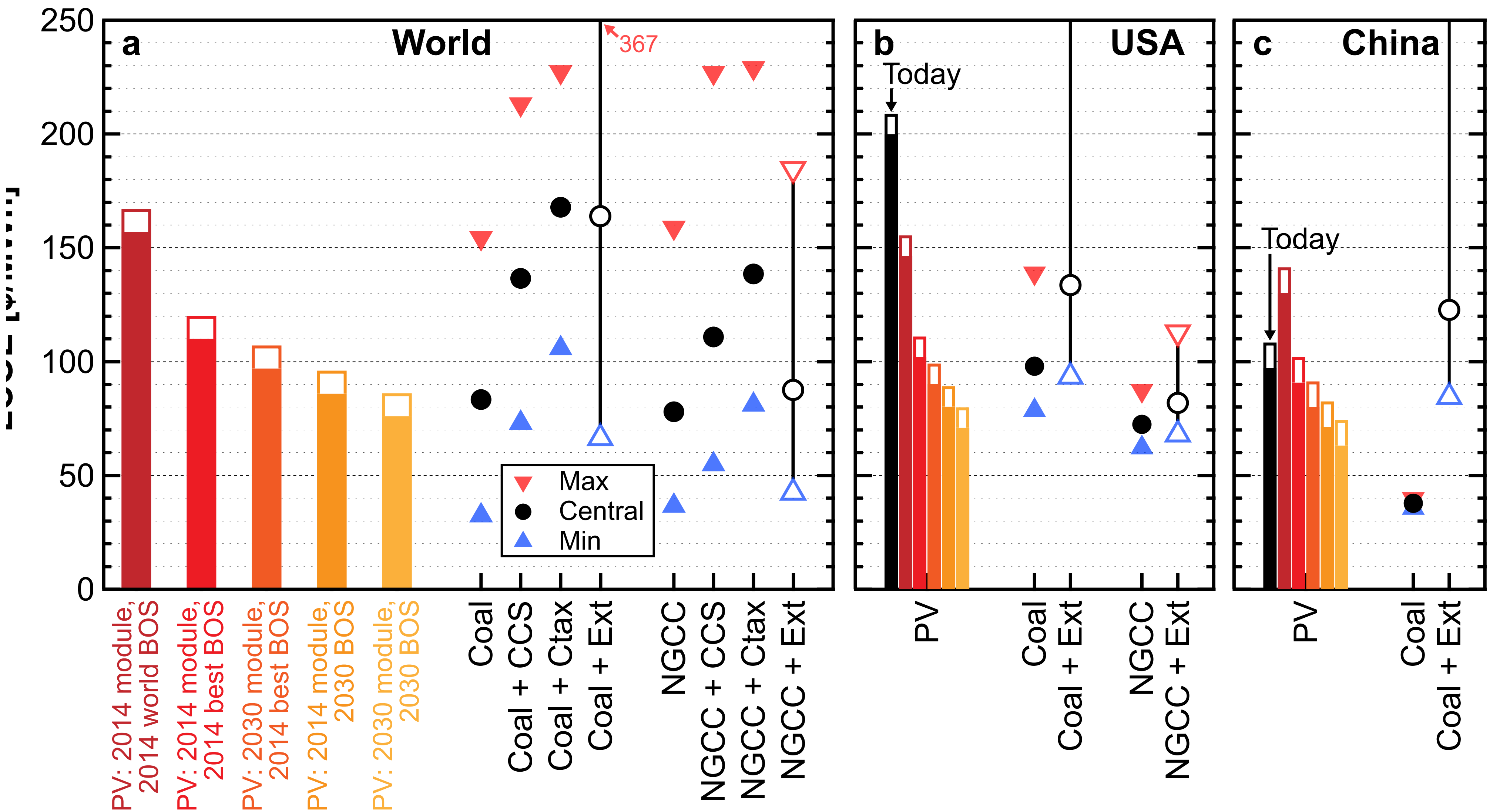
$$c(x) \sim x^{-\alpha}$$

$$\alpha \sim \frac{1}{d}$$

d=number of component dependencies; n=number of components

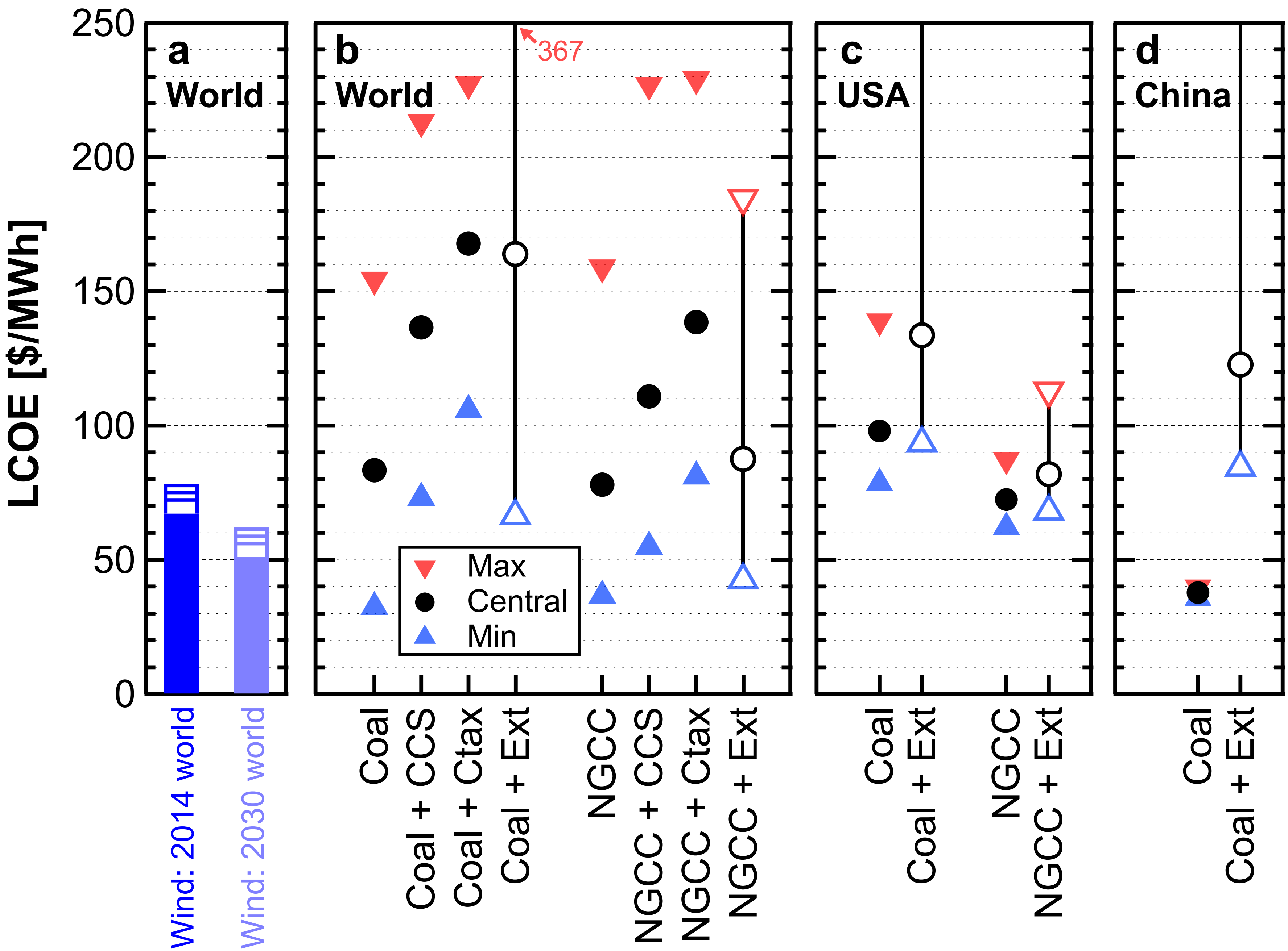
McNerney, Farmer, Redner, Trancik, *PNAS*, 2011

Forecasting cost improvement under Paris pledges



Trancik, Brown, Jean, Kavlak, Klemun, Edwards, McNerney, Miotti, Mueller, Needell, Technical Report, 2015

Forecasting cost improvement under Paris pledges

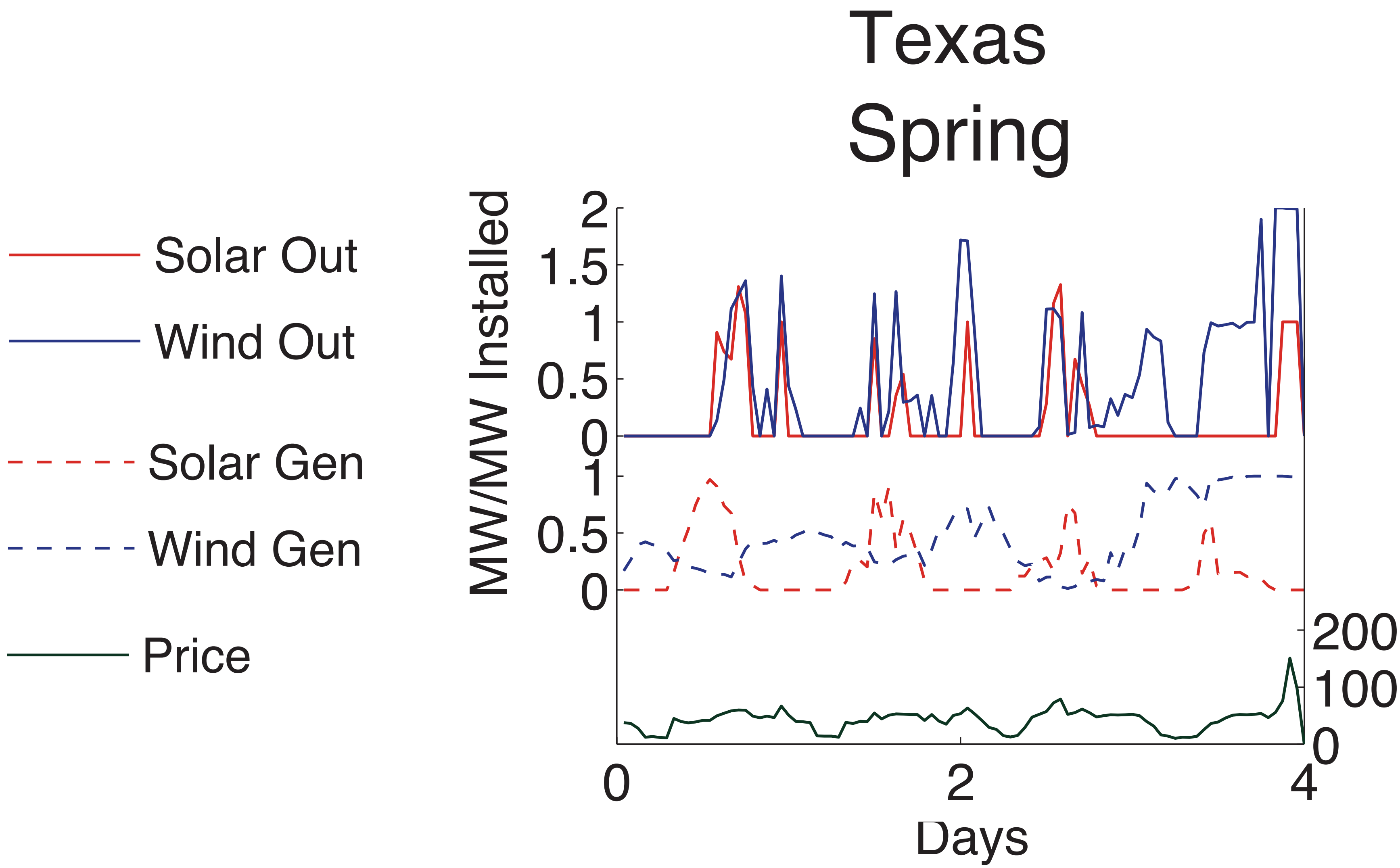


Trancik, Brown, Jean, Kavlak, Klemun, Edwards, McNerney, Miotti, Mueller, Needell, Technical Report, 2015

Evaluating technologies against demand patterns

- Stationary energy storage
- Electric vehicles

Evaluating stationary storage technologies



Braff, Mueller, Trancik, *Nature Climate Change* 2016

Balancing the cost and benefit of storage

- Value of energy storage

annual revenue

$$\chi = \frac{R_{\text{total}}}{CRF(C_{\text{gen}} + \dot{E}_{\max}(C^{\text{power}}_{\text{storage}} + hC^{\text{energy}}_{\text{storage}}))}$$

annualization factor

wind, solar cost

storage power

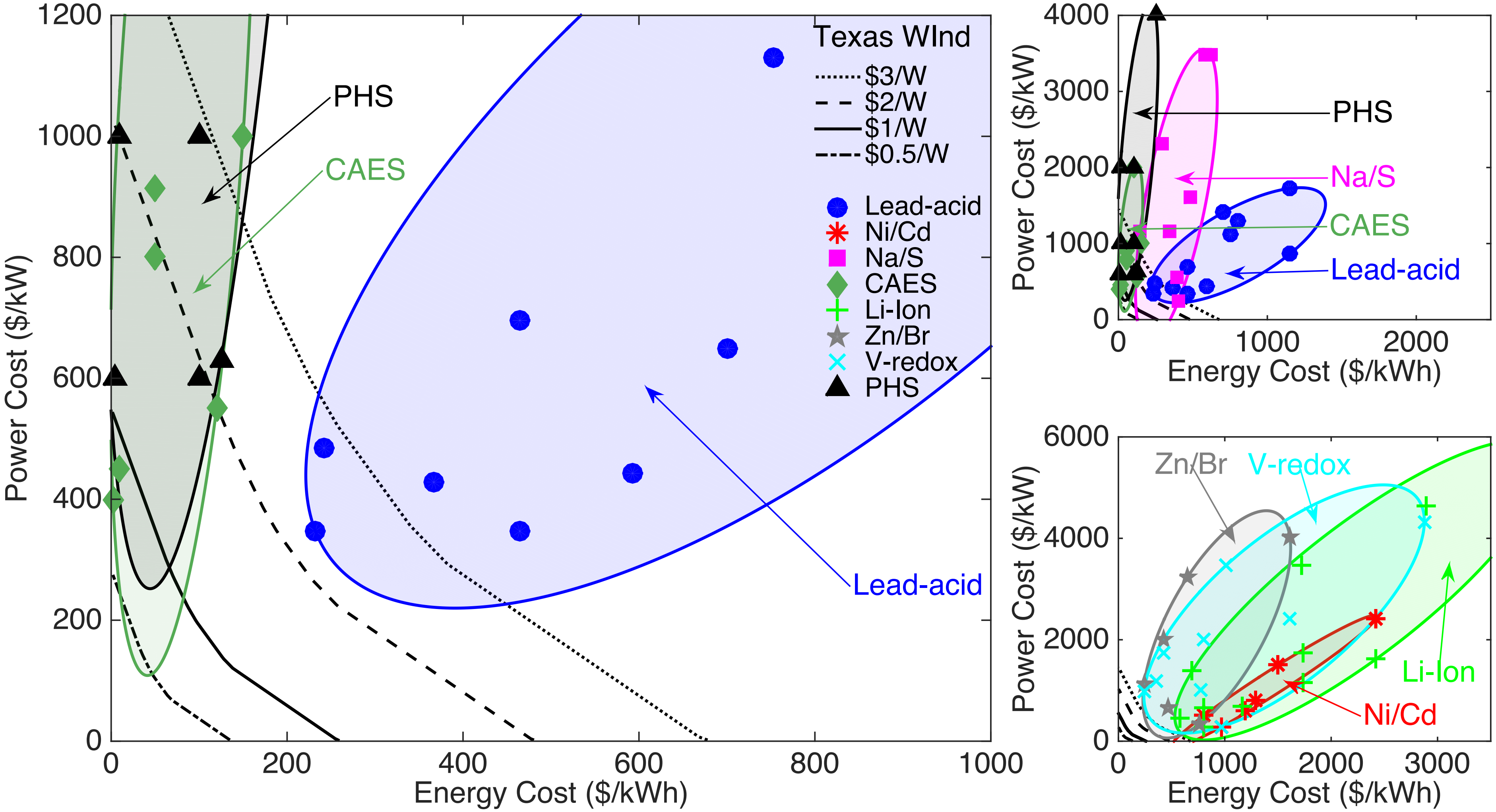
hours

storage cost

- Storage system sized to maximize chi

Braff, Mueller, Trancik, *Nature Climate Change* 2016

Evaluating stationary storage technologies



Braff, Mueller, Trancik, *Nature Climate Change* 2016

Evaluating technologies against demand patterns

- Stationary energy storage
- Electric vehicles

Today's agenda

- Role of energy systems in climate change mitigation
- Evaluating energy technologies against climate targets