

# Measuring technological progress toward a clean energy transition

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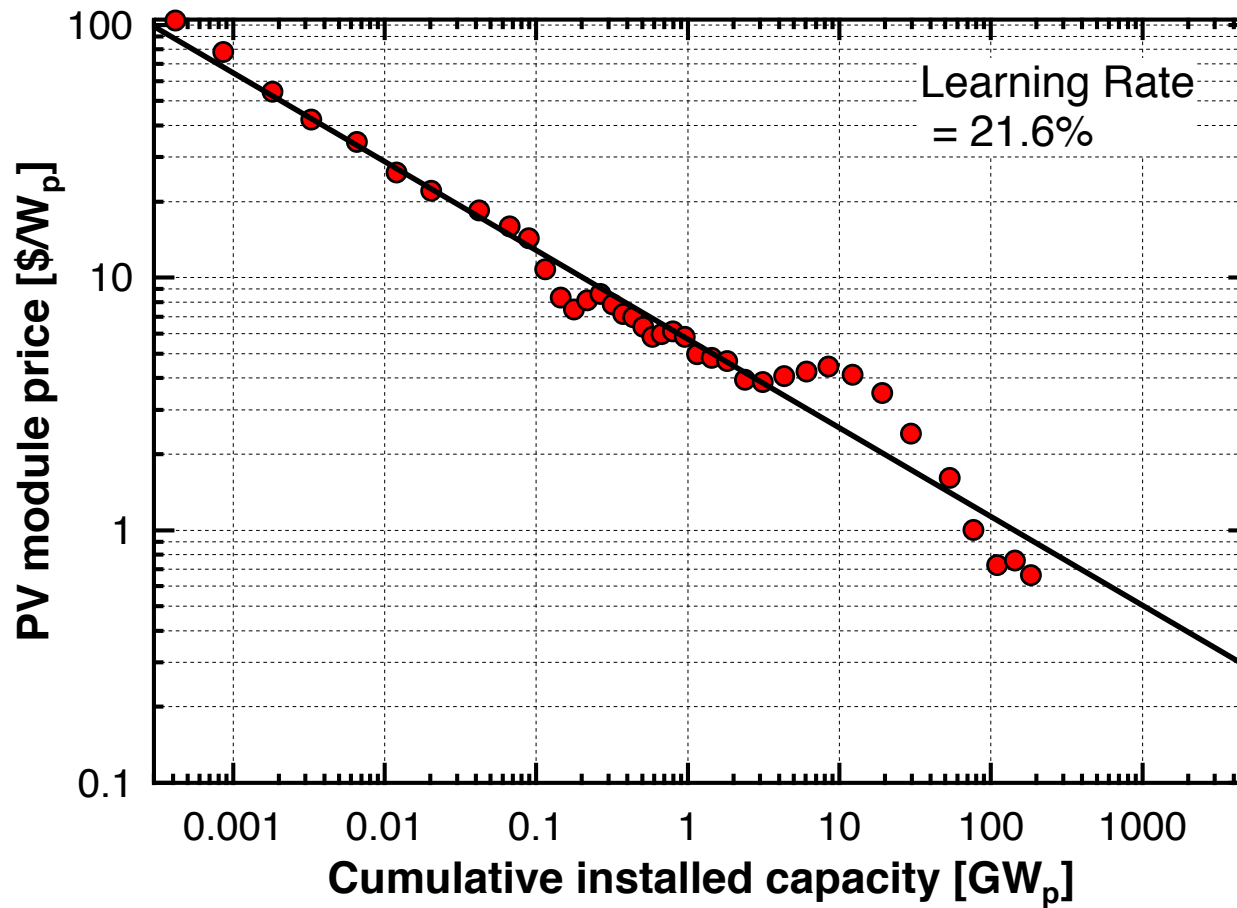
International climate agreement reached in 2015

# Measuring progress toward decarbonization

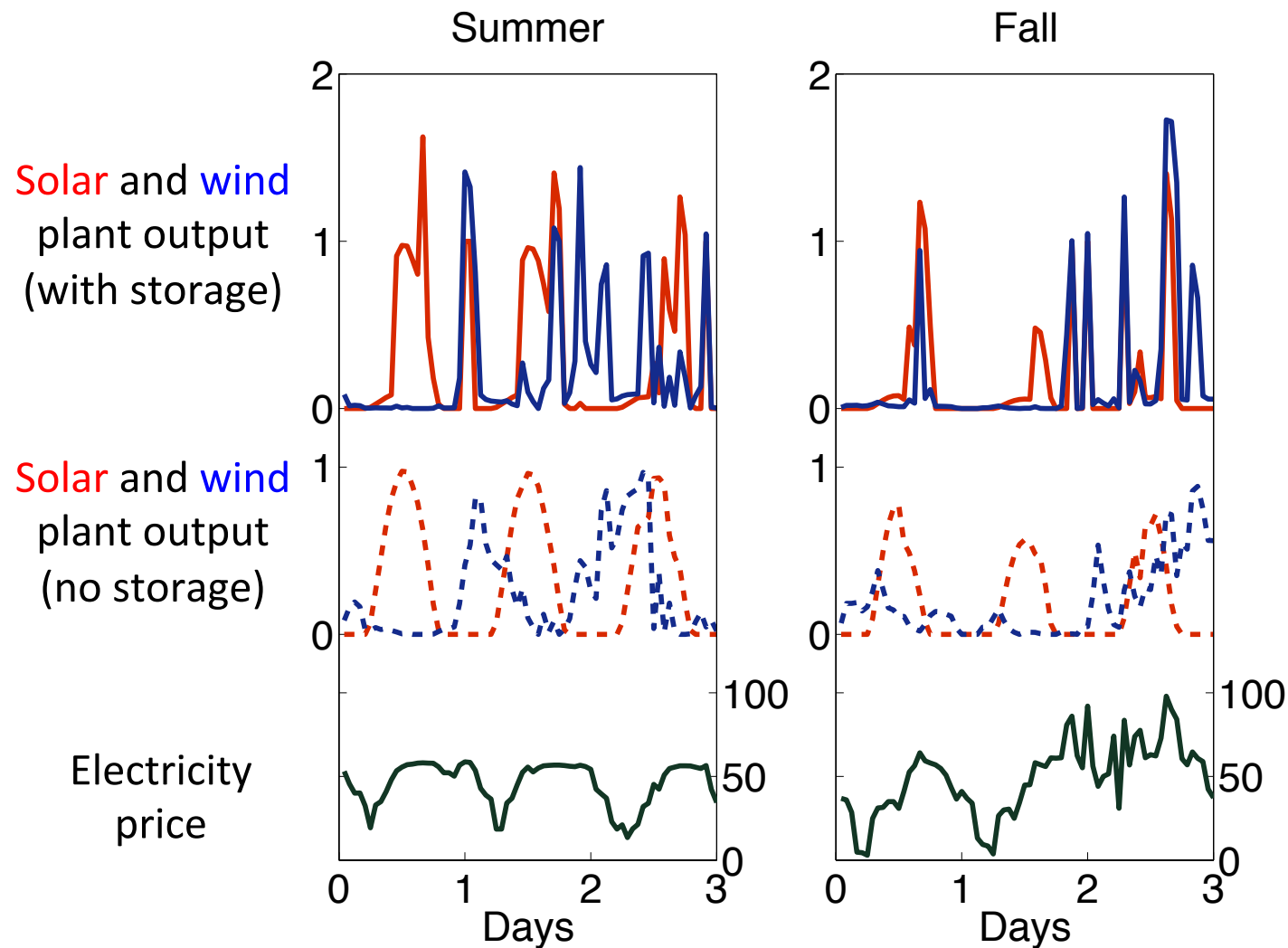
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- *Example 1:* Photovoltaics' cost decline prospects for the future
- *Example 2:* Profitability thresholds for stationary storage
- *Example 3:* Batteries evaluated against driving behavior

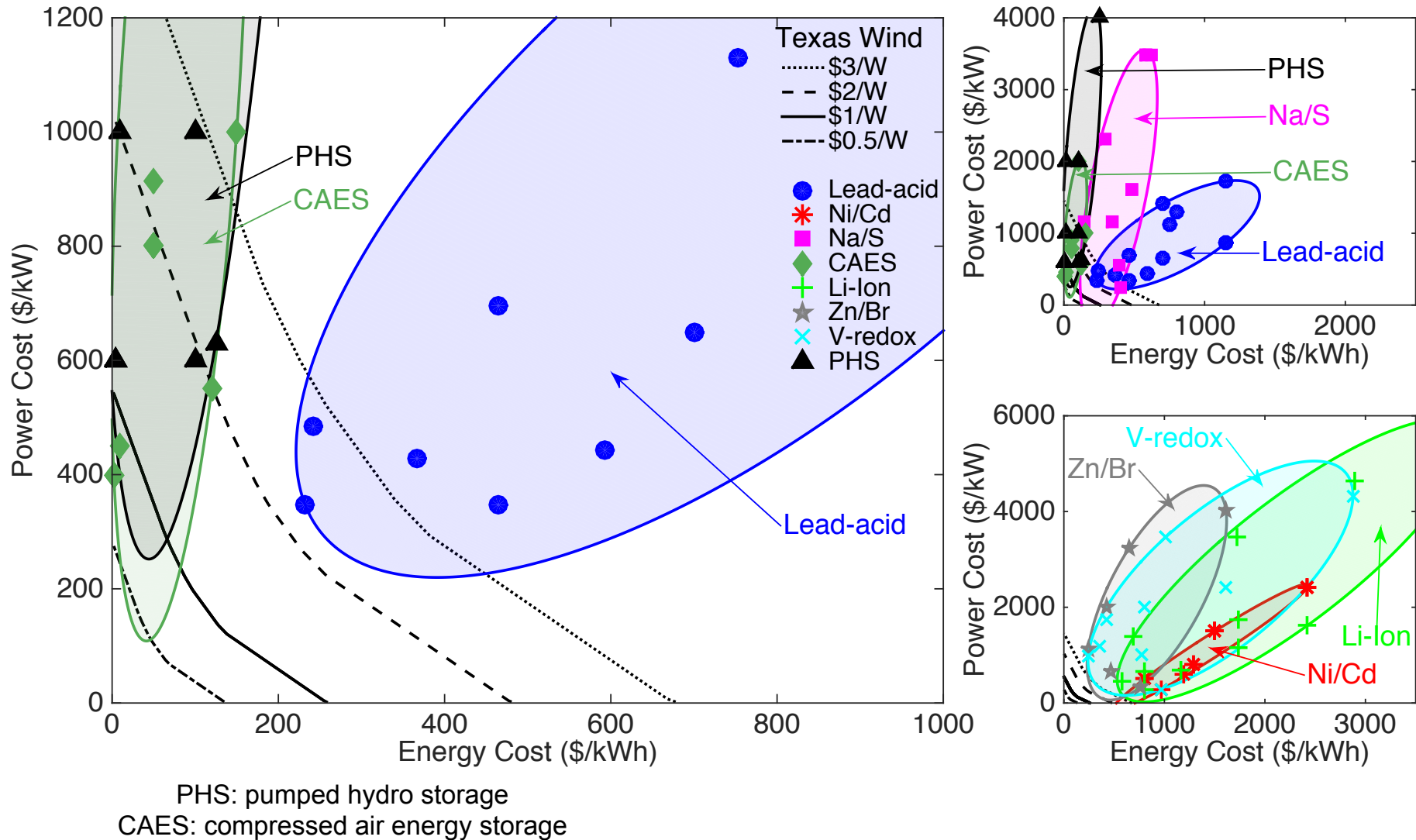
# Price decline in photovoltaics modules



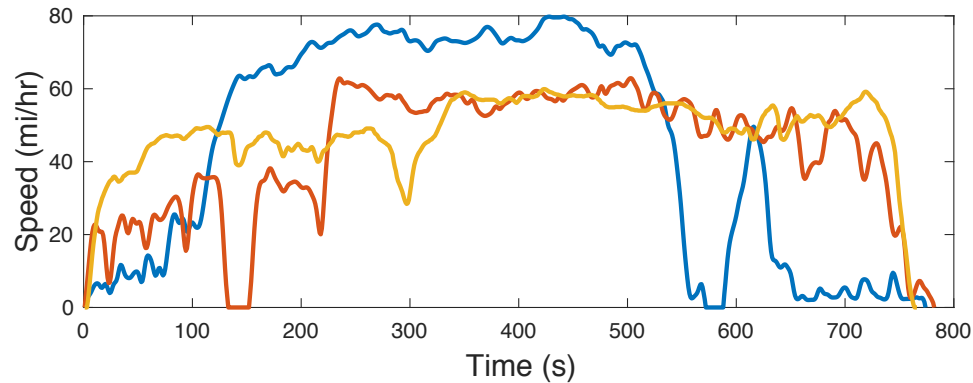
# Profitability of storage technologies for solar and wind energy



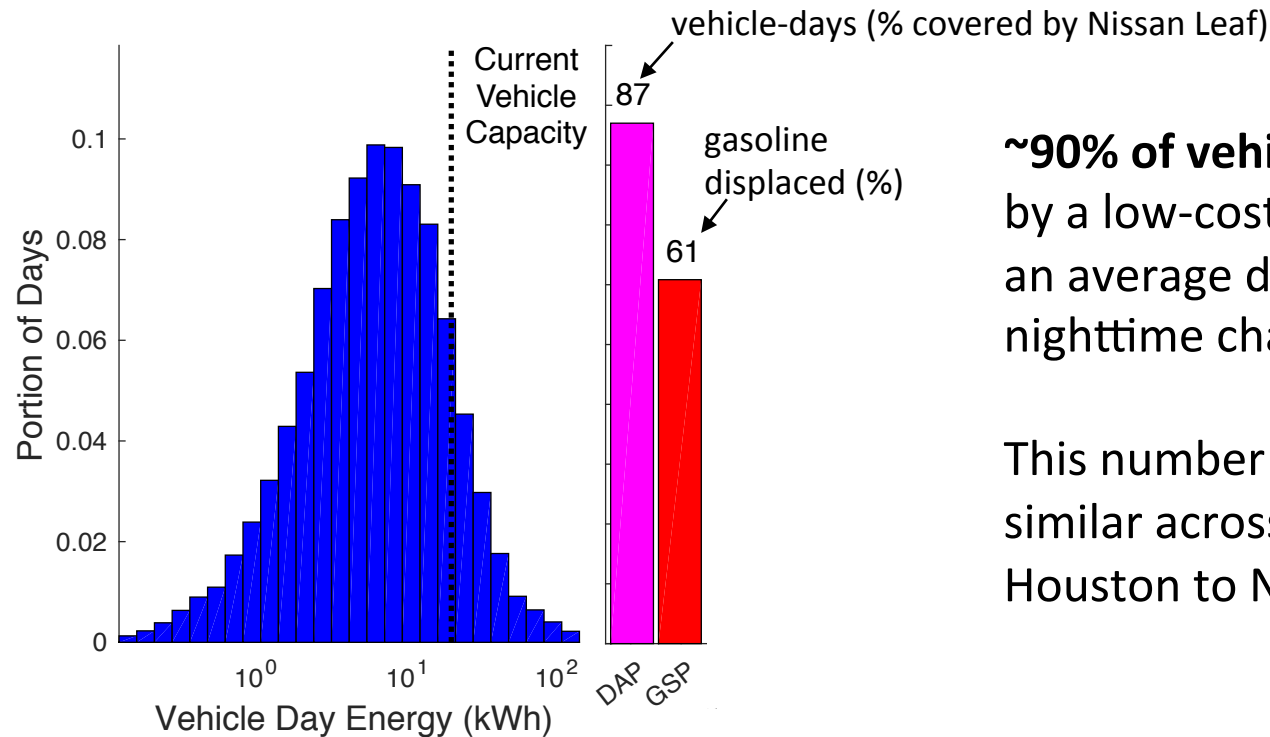
# Profitability of storage technologies for solar and wind energy



# Batteries evaluated against U.S. driving patterns



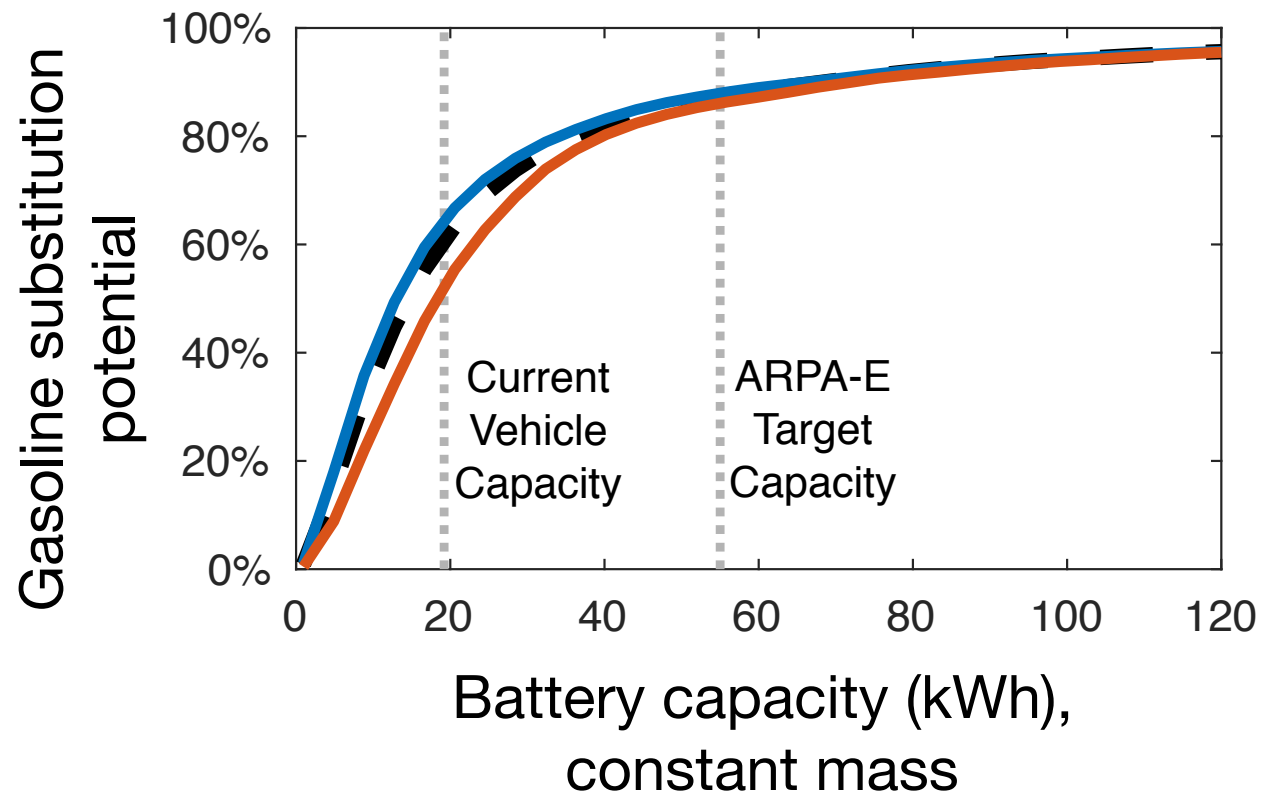
Based on driving patterns across all U.S. cities and millions of drivers....



**~90% of vehicles** can be replaced by a low-cost electric vehicle on an average day, even if only nighttime charging is available.

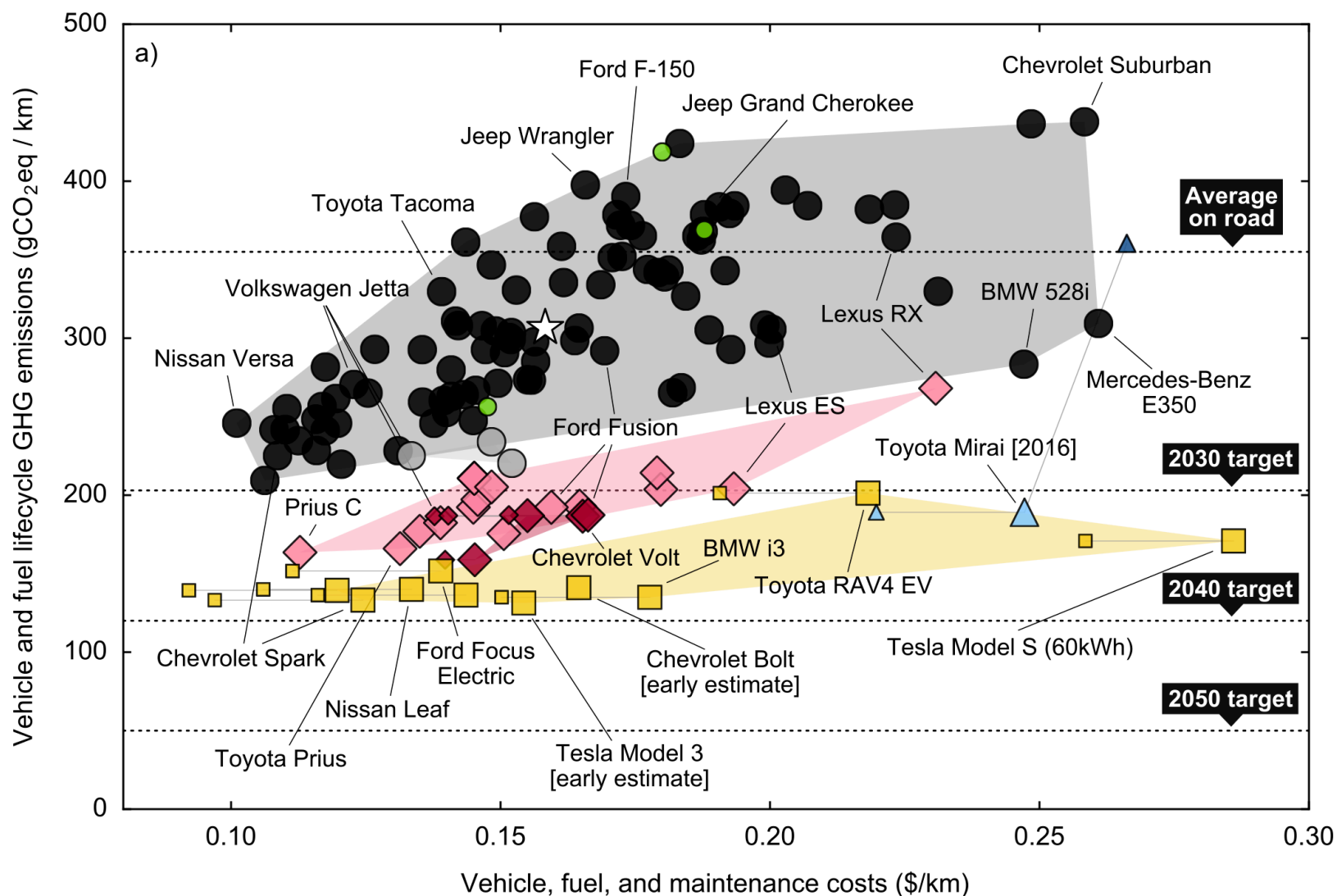
This number is remarkably similar across diverse cities, from Houston to New York.

# Diminishing returns to battery improvement





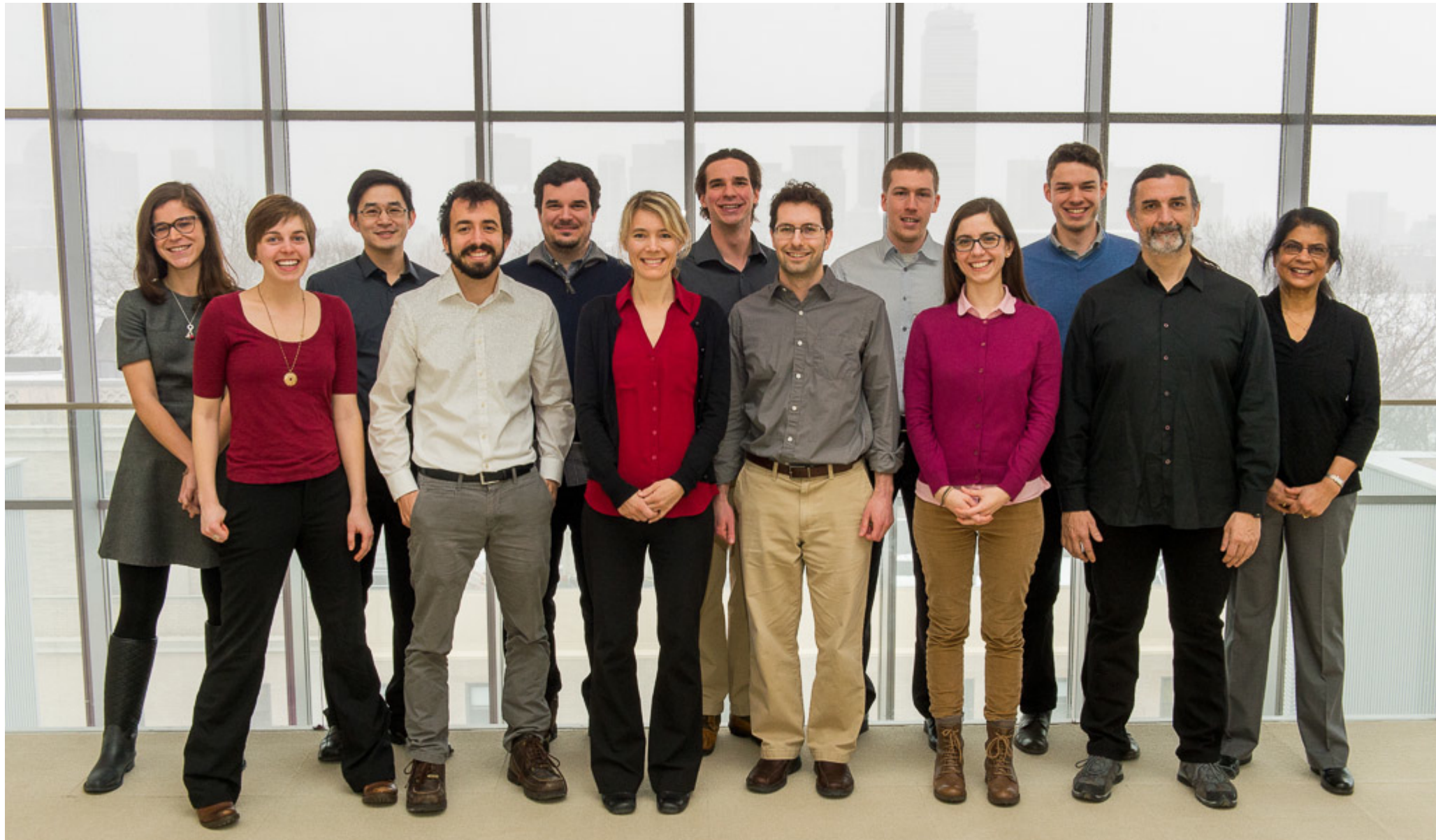
# Cost and emissions of vehicle powertrains (see carboncounter.com)



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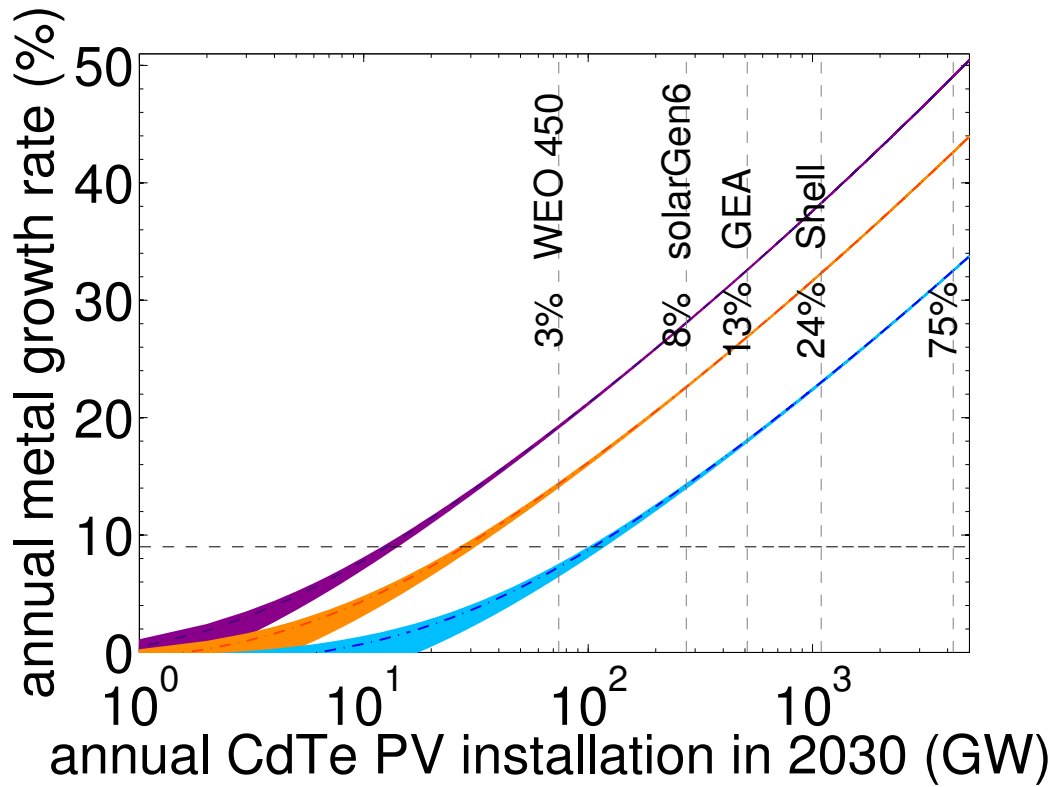
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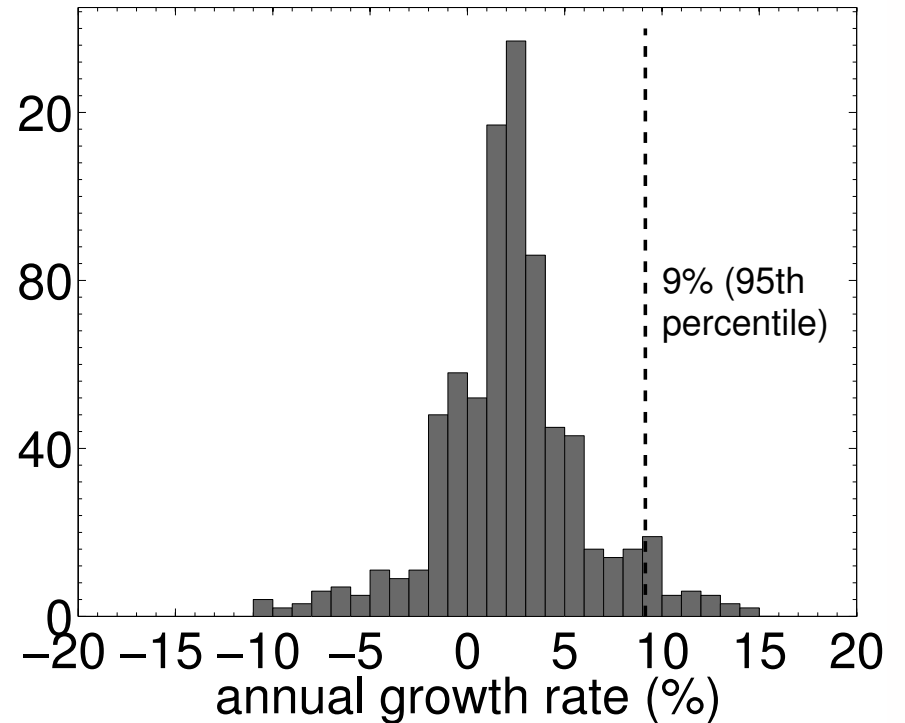
**Magdalena Klemun, Michael Chang, Gonçalo Pereira, Joshua Mueller, Fabian Riether, Marco Miotti, Mandira Roy  
Morgan Edwards, Zach Needell, Jessika Trancik, James McNerney, Göksin Kavlak, Victor Ocana**



# Limits to technology improvement



(d) Tellurium,  $n_{Te} = 1.4\%$



(a) Histogram of historical growth rates