NREL
NATIONAL RENEWABLE ENERGY LABORATORY

40
1977 - 2017





Cost-Competitive Electrolysis-Based Hydrogen Under Current U.S. Electric Utility Rates

Omar J. Guerra

Josh Eichman, Bri-Mathias Hodge, and Jennifer Kurtz

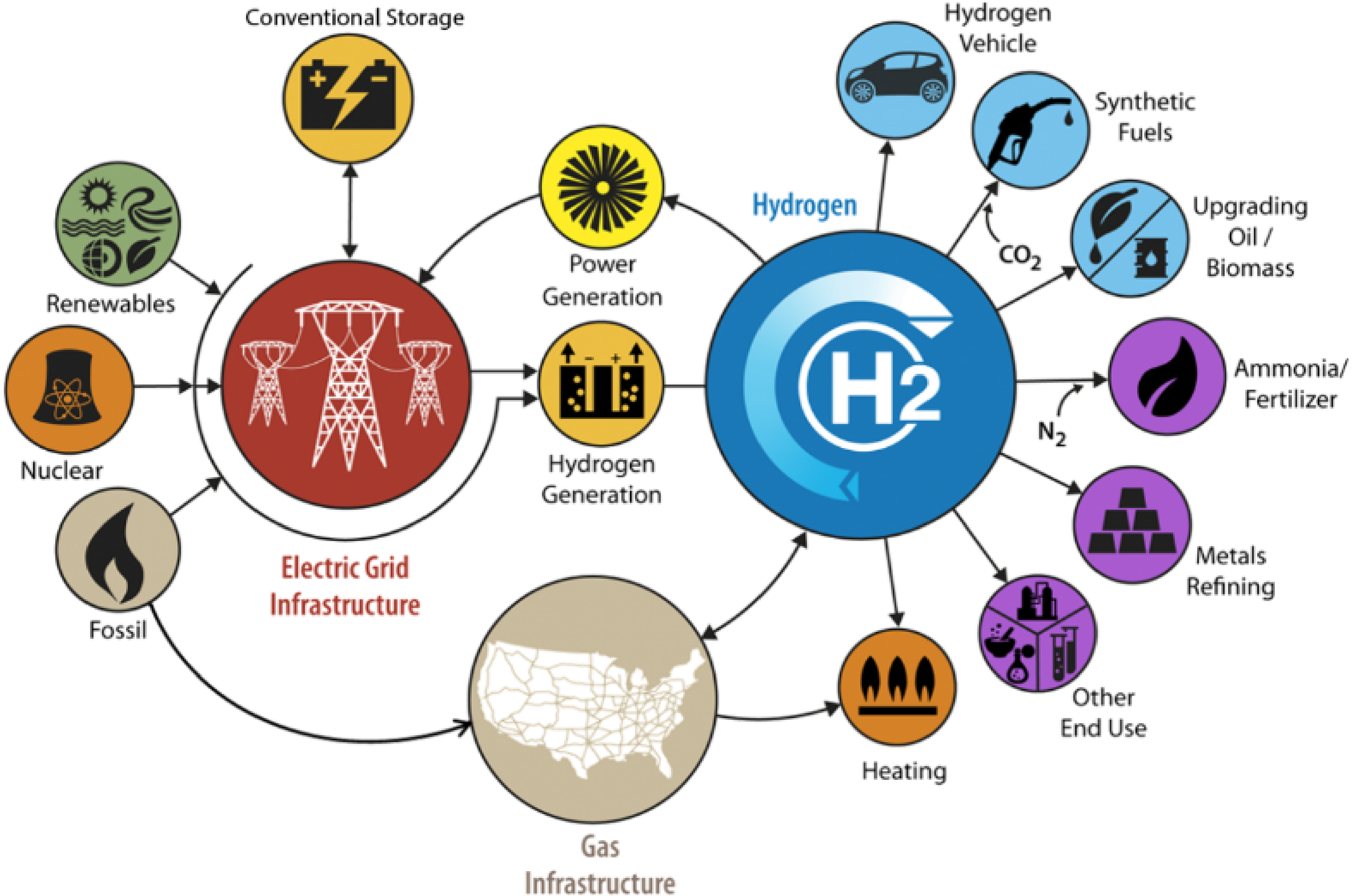
October 30, 2018
2018 AIChE Annual Meeting
Pittsburgh, Pennsylvania

NREL/PR-5D00-72710

Outline

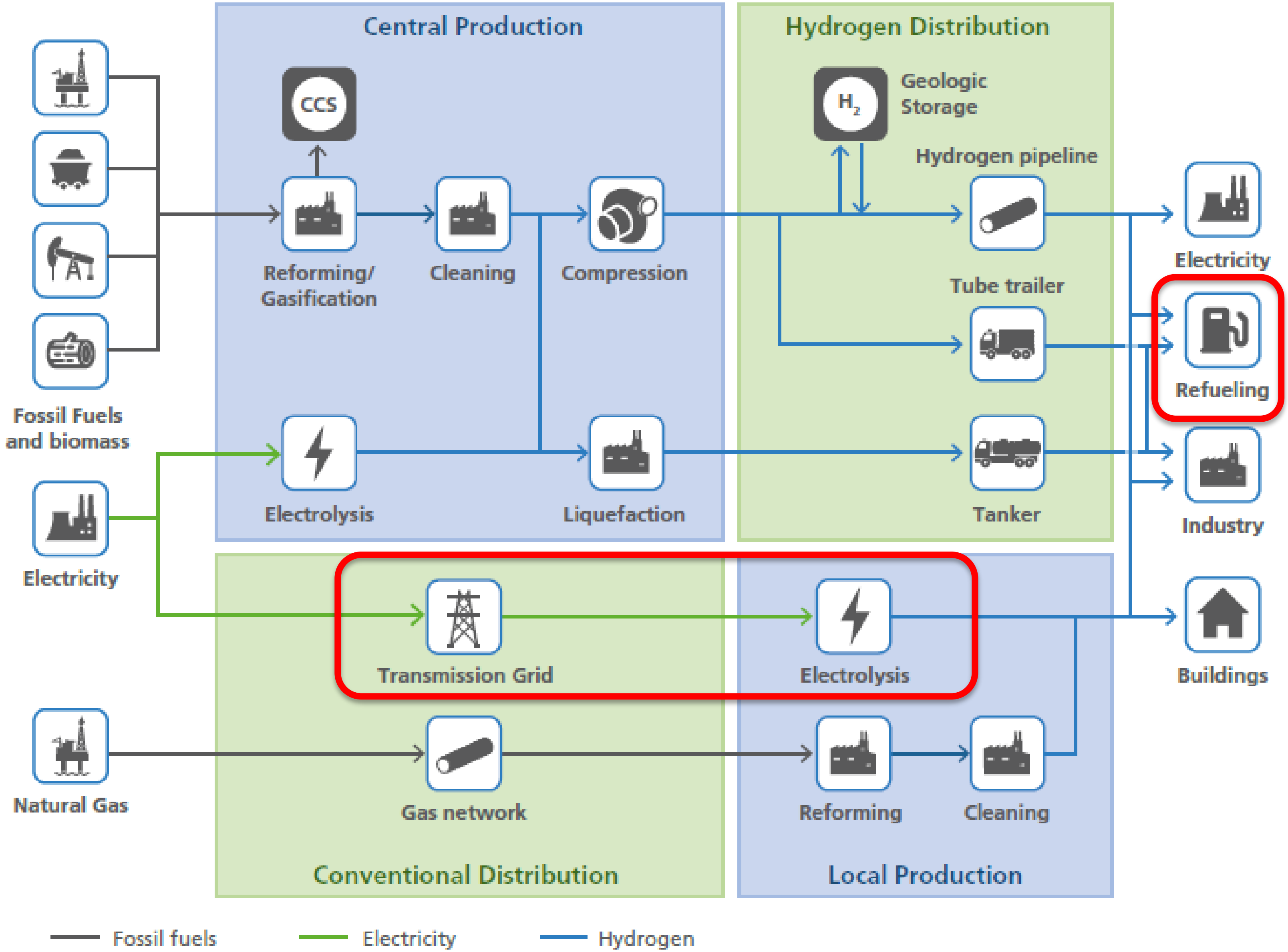
- Motivation
- Methods
- Electric utility rates
- H2 production cost & Fuel cost for transportation
- Conclusions & future work

Motivation: H2@SCALE concept



Electrolysis-based hydrogen production and storage could improve the operation of the electric grid while integrating a variety of disparate systems including transportation, agricultural, industrial, and residential sectors.

Motivation: H2 production pathways (Staffell et al. 2017)



Motivation: Challenges for H2 and fuel cell technologies

- Reduce capital costs and increase the efficiency of electrolyzers and fuel cells.
- Development of new materials with improved stability and activity for electrolyzers, storage devices, and fuel cells.
- Assessing the increased operational flexibility of electrolyzers.
- Obtaining increased data on hydrogen production costs at national and regional scales.

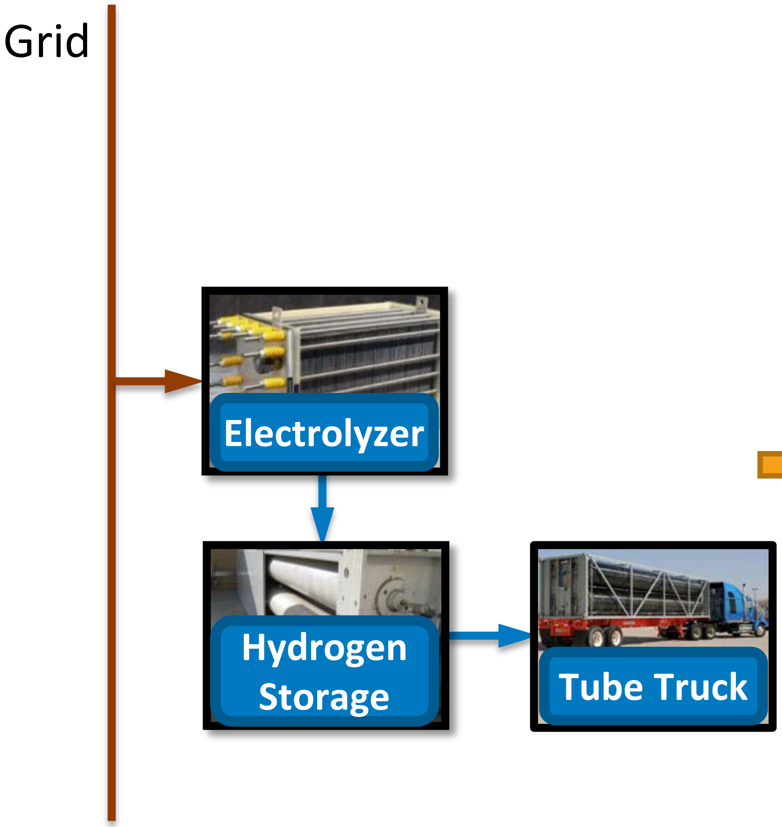
Research questions

Q1: Which are the locations (regions, cities, etc.) with potential market for hydrogen and what is the hydrogen production cost for these locations?

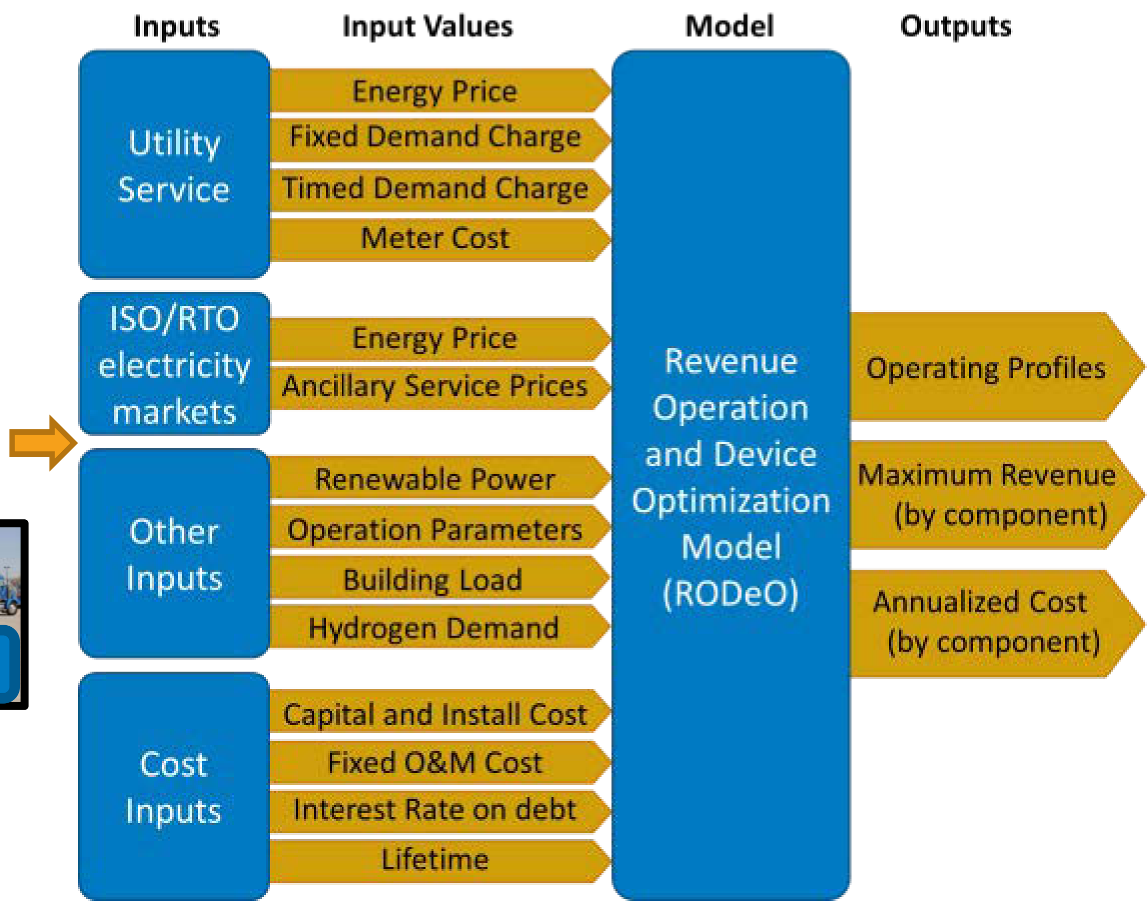
Q2: What is the optimal operational strategy for electrolysis-based hydrogen production?

Methods: RODeO-Revenue Operation and Device Optimization Model

System to be modeled



Optimization framework



Research aims:

- Explore electrolysis-based hydrogen production cost, optimizing retail rates
- Improve competitiveness of hydrogen technologies

Electric utility rates: Retail tariff structure (Faruqui et al. 2010)

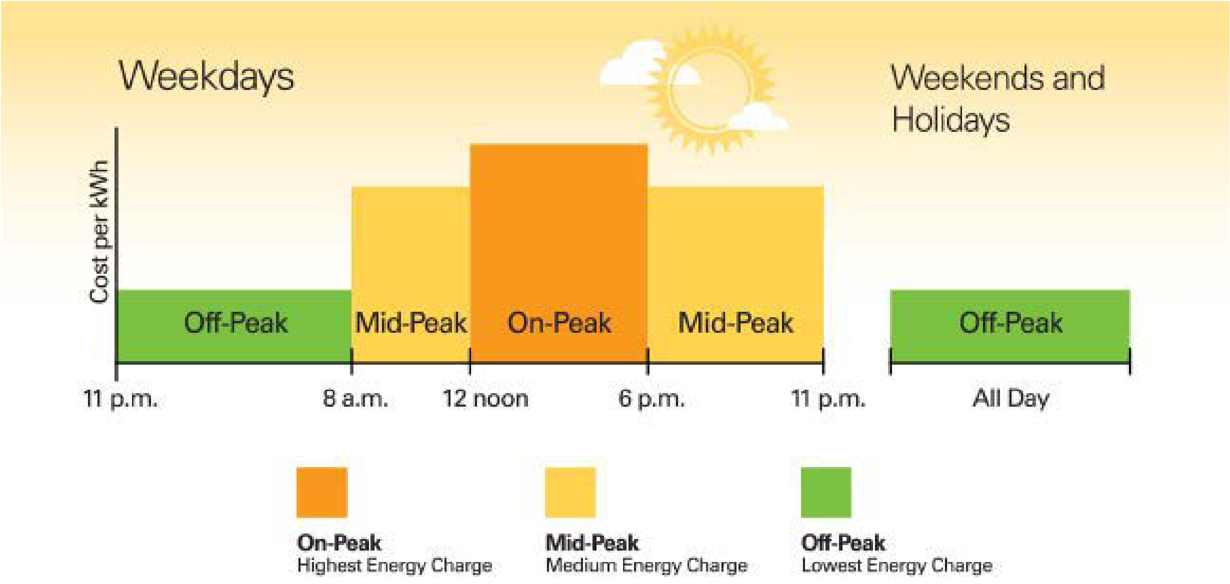
Energy and demand charges:

Energy charges are associated with the quantity of energy consumed during a single interval, i.e., kWh, while demand charges refer to the maximum demand that occurs during a billing period, i.e., kW.

No charge (NO): There is no charge for either energy or demand.

Flat rate (Flat): A single constant charge is used for electricity during each billing period.

Time of use rate (TOU): Time-varying rates, including time-of-use (TOU), critical peak pricing (CPP), and real-time pricing (RTP).



https://www.sce.com/wps/wcm/connect/sce_content_en/content/business/rates/time+of+use/time+of+use+faqs

Electric utility rates: Data set of retail tariffs

Data set: 7,182 commercial and industrial utility rates (retail prices) from the utility rate database (URDB)--> https://openei.org/wiki/Gateway:Utilities

Tariff structure: EnergyCharge_DemandCharge

	Tariff structure (retail tariff)	Energy charge (US cents/kWh)	Demand charge (US$/kW)
78.8%	Flat_NO (2670)	2.8-18.3	0
	Flat_Flat (2500)	0.045-15.9	0.01-21.7
	Flat_TOU (489)	1.1-11.7	0.4-19.5
21.2%	TOU_NO (723)	5.2-15.5	0
	TOU_Flat (224)	1.6-15.7	0.5-23.4
	TOU_TOU (576)	1.0-13.1	0.3-20.1

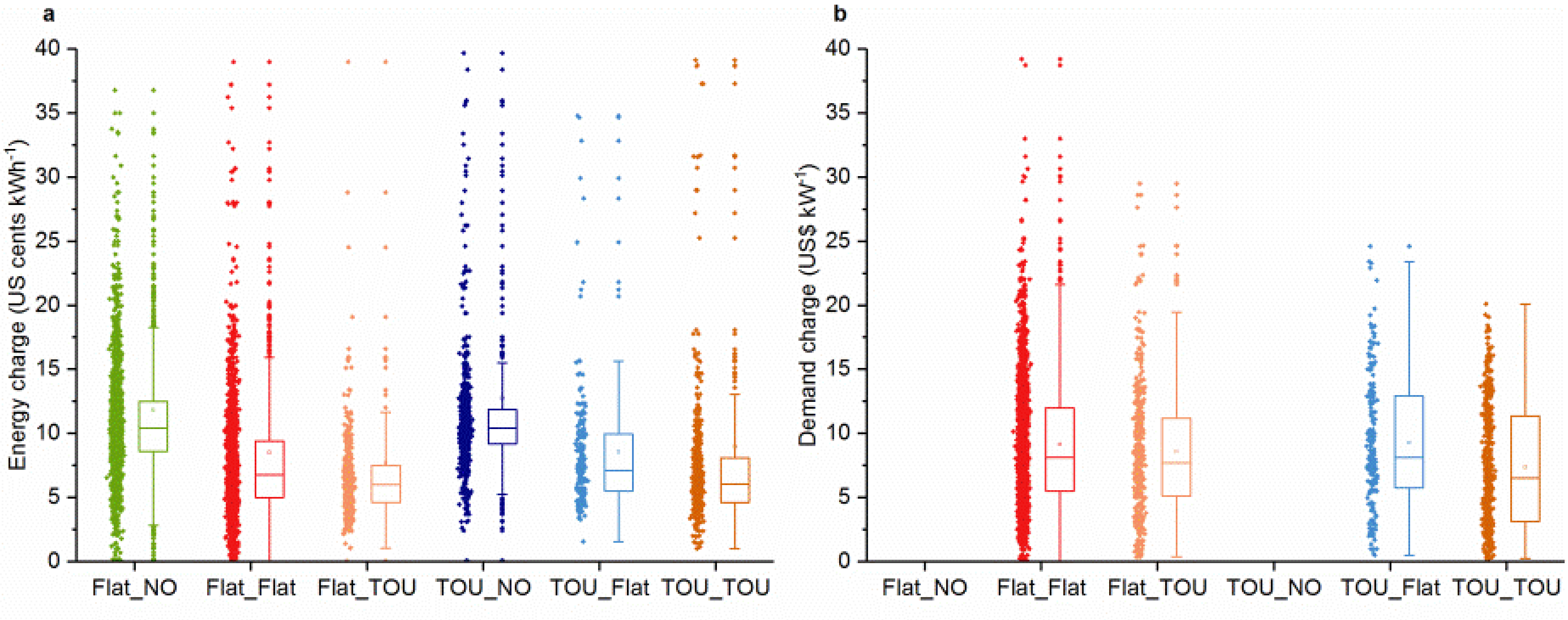
47.2%

37.9%

14.8%

Outliers: Based on interquartile range (IQR), which is defined as the difference between 75th (Q3) and 25th (Q1) percentiles, i.e. IQR= Q3-Q1. The potential outliers were identified as any value that lies outside the lower and upper whiskers, which were defined as Q1-1.5*IQR and Q3+1.5*IQR, respectively.

Electric utility rates: Energy (Fig. a) & demand charges (Fig. b)

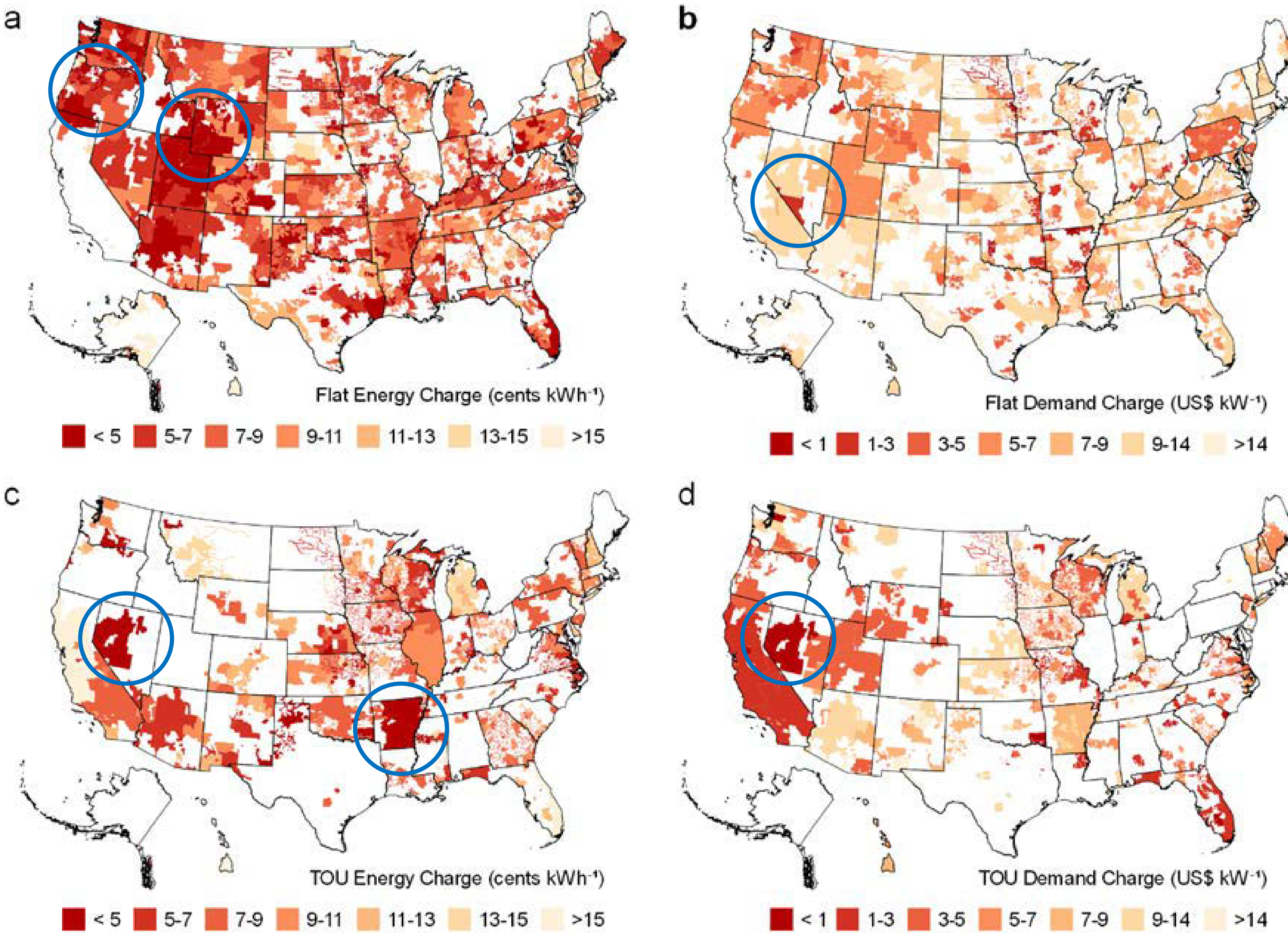


Tariff structure: EnergyCharge_DemandCharge. NO = no charge, Flat = flat charge, TOU = time of use charge

- Energy charges are higher for utility rates that have no charge for demand: Flat_NO →~US¢11.8/kWh, Flat_Flat →~US¢8.5/kWh, and Flat_TOU →~US¢7.7/kWh. TOU_NO →~US¢12.7/kWh, TOU_Flat→~US¢8.6/kWh, and TOU_TOU →~US¢9.0/kWh.

- Flat demand charges are higher than average TOU charges: Flat_Flat→US$9.1/kW, and Flat_TOU→ ~US$8.6/kW. TOU_Flat→ US$9.3/kW, and TOU_TOU→ US$7.4/kW.

Electric utility rates: Geographic distribution of tariffs

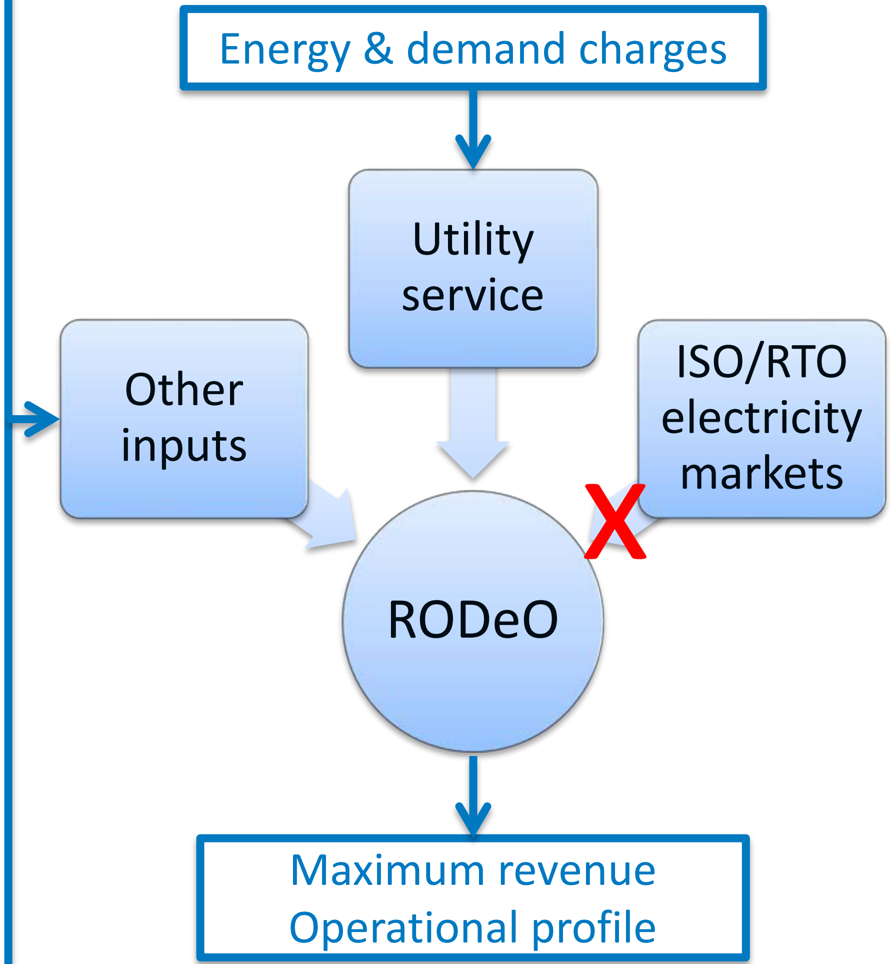


H2 production cost: Modeling framework & assumptions

System configurations and technology assumptions (1 MW electrolyzer)

- Capital cost: $1,691/kW
- Replacement cost: $18.64/kW-year
- H2 storage capital cost: $1000 /kg
- Fixed O&M cost: $75.2/kW-year
- Lifetime: 20 years
- Interest rate: 7%
- Efficiency: 54.3kWh/kg
- Minimum part load: 10%
- Operation modes: Base load and Flexible
- Capacity factor (CF): 40%, 60%, 80%, 90%, and 95%
- Storage duration: 8 h
- Time horizon: 1 year (8,760 time periods)

Ref: Eichman J. et al. National Renewable Energy Laboratory (NREL), Golden, CO, 2016.



RODeO: Revenue Operation and Device Optimization price taker model. It is formulated as a mixed-integer linear programming (MILP) model in GAMS.

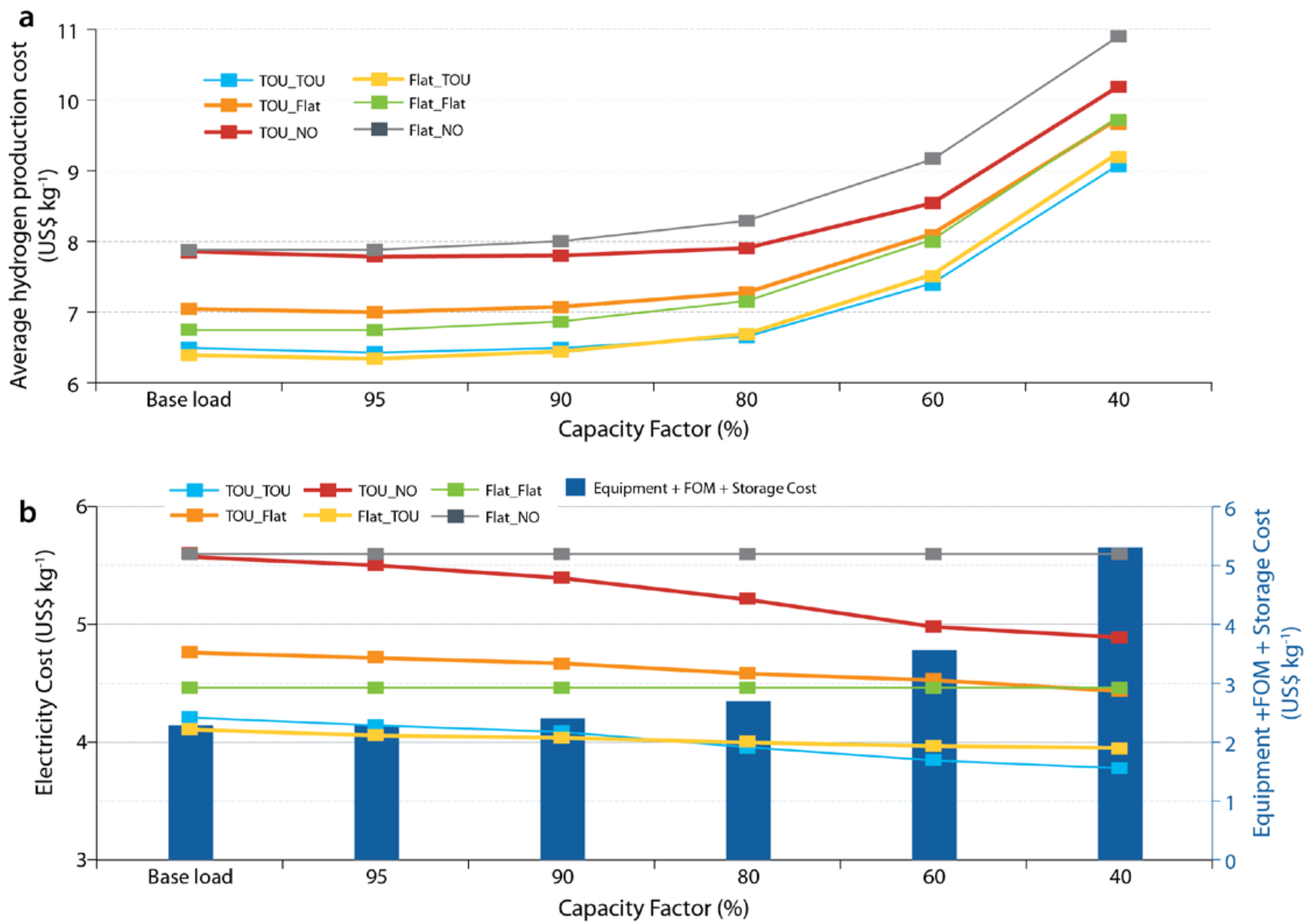
H2 production cost: Effect of tariff structure

- Base load and flexible electrolyzer operation modes were evaluated using RODeO.
- Hydrogen demand was constant for each CF.
- The objective function reduces to the minimization of the total annual system cost.

Tariff structure (retail tariff)	Base load (US$/kg)	Average reduction in electricity cost for flexible mode @CF=90% (%)
Flat_NO (2670)	3.9-12.3	0
Flat_Flat (2500)	2.6-11.4	0
Flat_TOU (489)	3.4-9.7	~0
TOU_NO (723)	4.7-11.2	2.8 (max 14.4%)
TOU_Flat (224)	4.5-11.4	1.8 (max 7.0%)
TOU_TOU (576)	3.3-10.5	3.2 (max 13.7%)

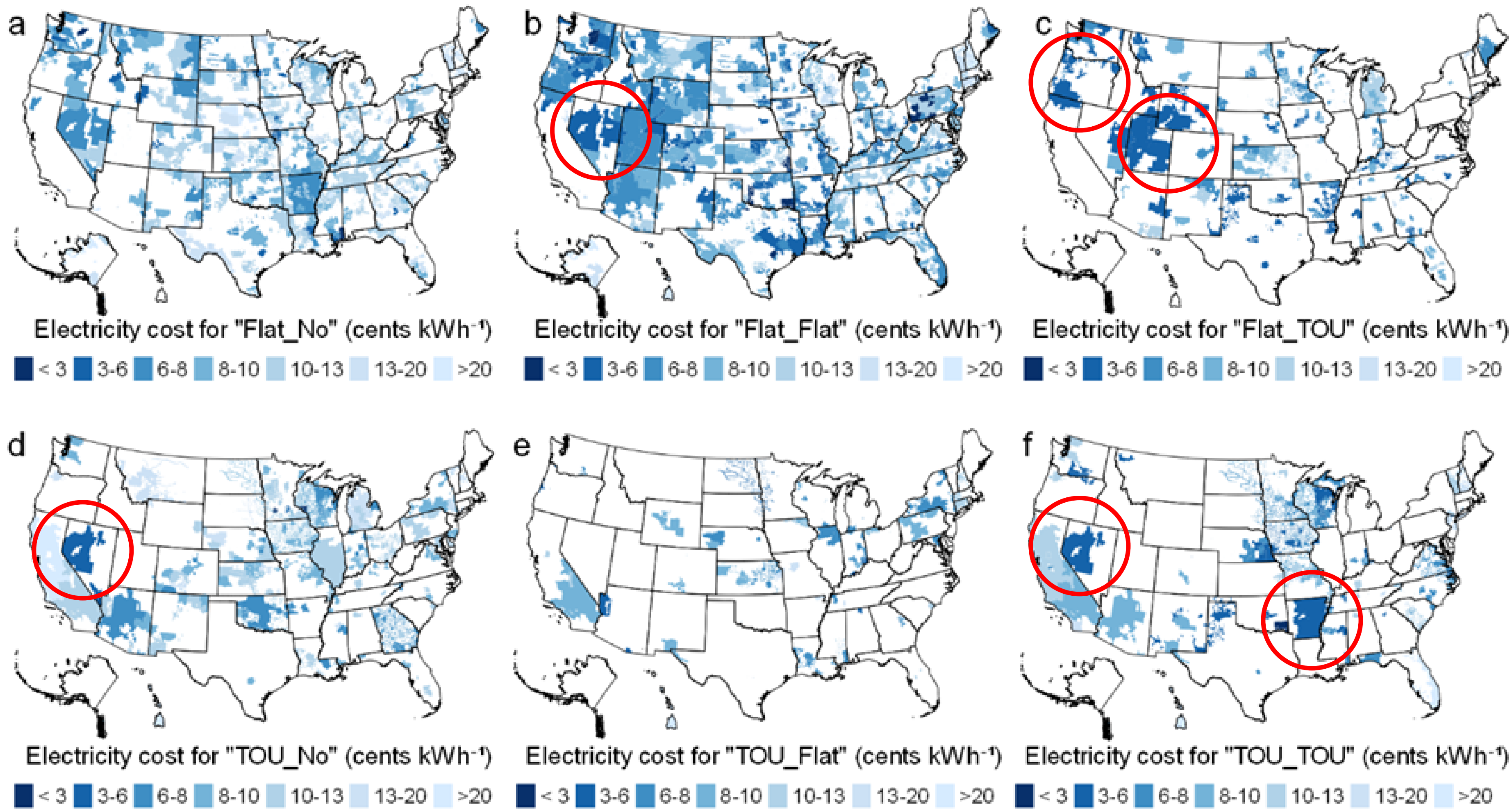
- U.S. Department of Energy (DOE) technical targets: @2011→U.S. $4.2 kg^{-1}, @2015→U.S. $ 3.9 kg^{-1}, and @2020→U.S. $2.3 kg^{-1}
- Hydrogen production cost < U.S. $4 kg^{-1} for 81 commercial & industrial utility rates
- Hydrogen production costs are cheaper for tariffs that include demand charges.

H2 production cost: Effects of capacity factor



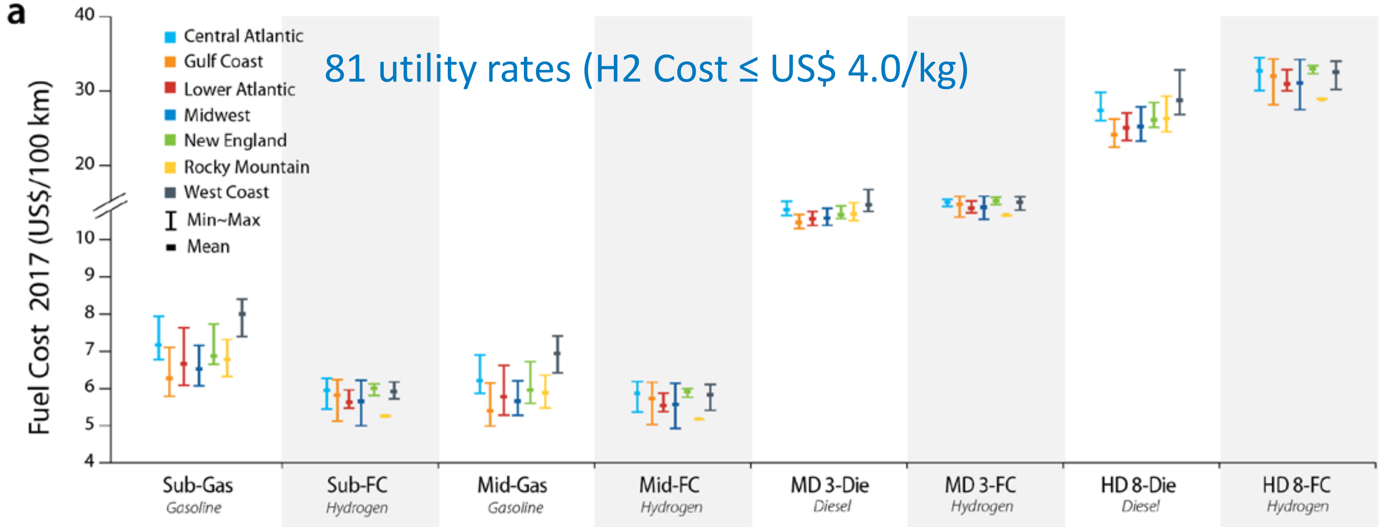
For tariffs with dynamic pricing for energy and/or demand, there is a trade-off between electricity cost and equipment, FOM, and storage costs.

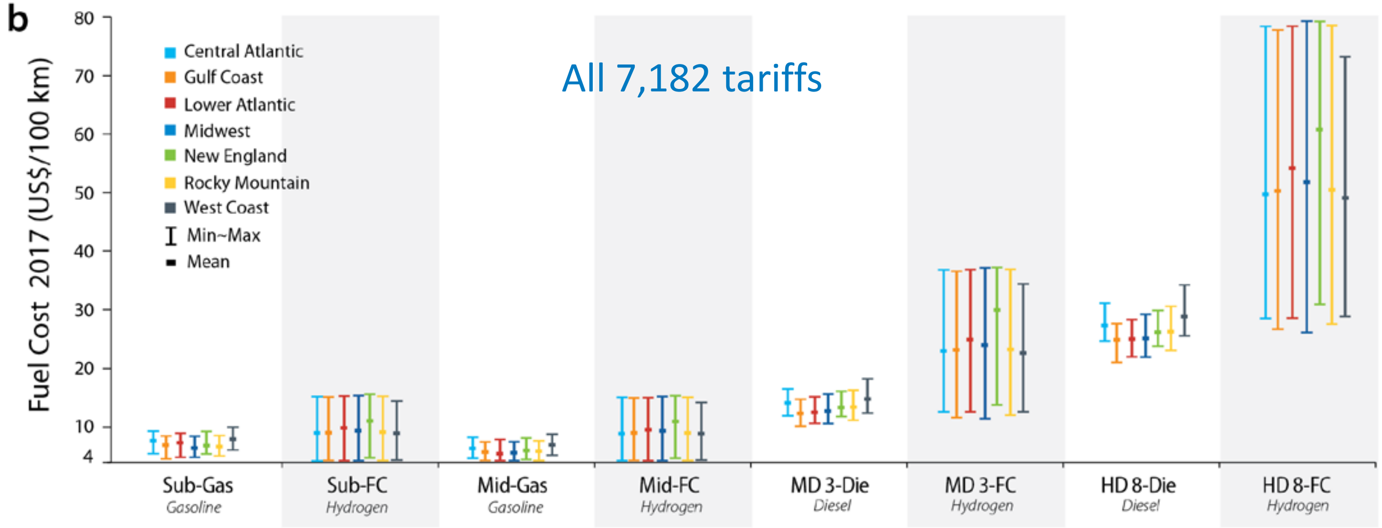
H2 production cost: Geographic distribution of electricity cost



- Hydrogen electricity costs vary depending on the structure of the tariffs.
- Hydrogen electricity costs are lower for tariffs that have demand charge.

Fuel cost for transportation: Gasoline and Diesel versus H2





- Fuel cost gasoline cars: US$5.0-8.6 per 100 km. H2 cost fuel cell cars: US$4.9-6.3 per 100 km.
- Hydrogen cost is more competitive for medium duty than for heavy duty vehicles.

Conclusions & future work

Conclusions

- There are 81 utility rates for which hydrogen costs are below US$4/kg.
- Electrolysis-based hydrogen is cost-competitive with gasoline and medium duty diesel vehicles in several locations in the United States.
- Optimal equipment sizing is a balance between the equipment costs and how dynamic are the rates (extends beyond electrolysis).

Future work

- Analysis of projected hydrogen demand and future wind and solar power curtailment across the U.S.
- Hydrogen-based long-term energy storage for power systems with high penetrations of variable renewables.

Thank you!

www.nrel.gov

NATIONAL RENEWABLE ENERGY LABORATORY