# IDAES-PSE Software Tools for Optimizing Energy Systems and Market Interactions

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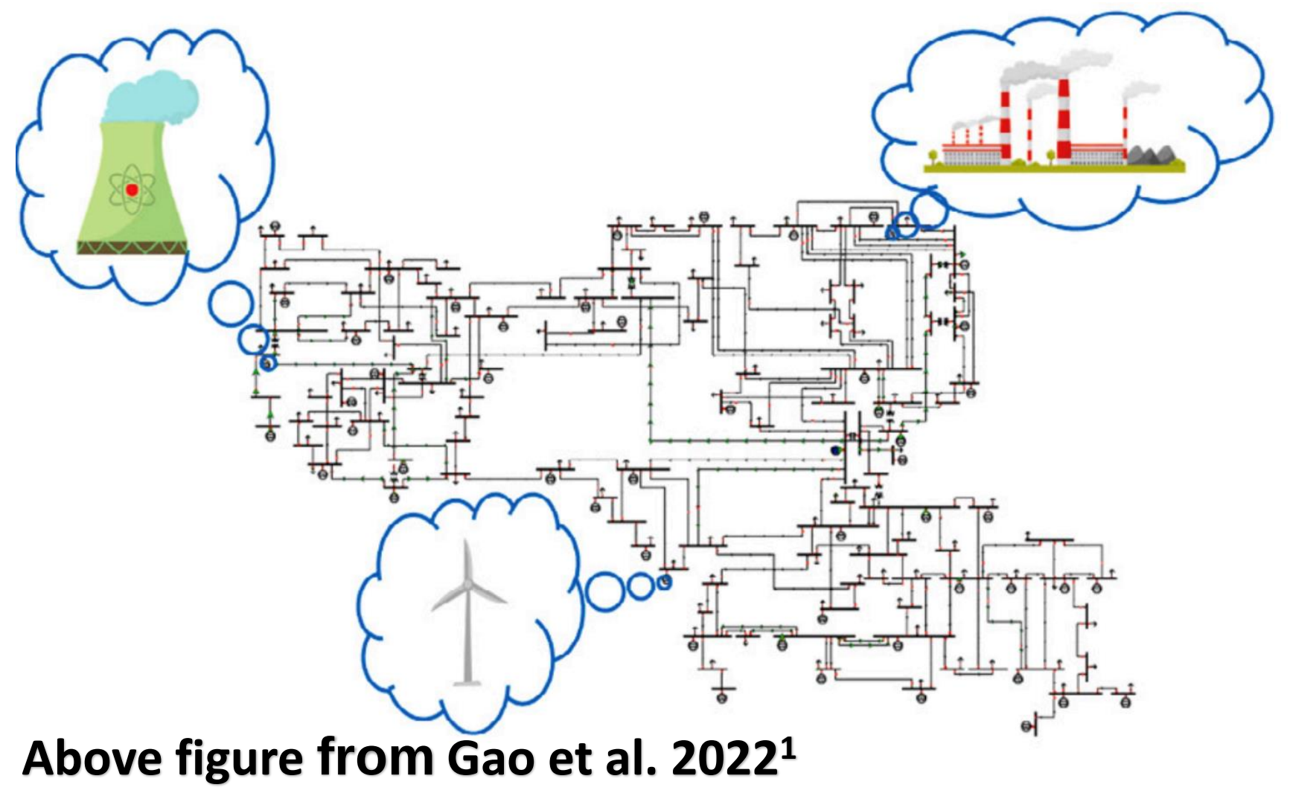
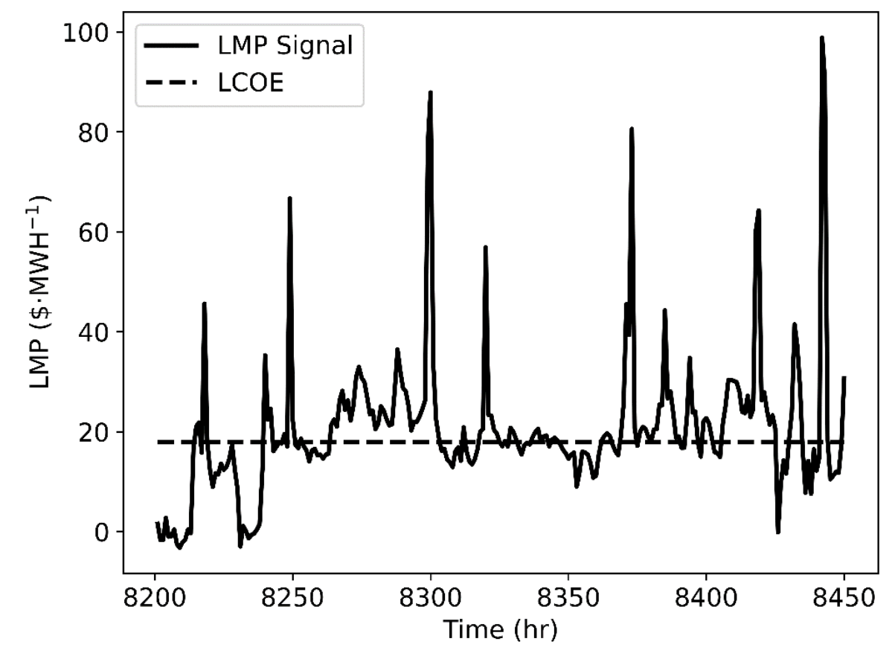
## Motivation



**Above figure from Gao et al. 2022[1]**



Installing and updating technologies within a grid need to be evaluated on:

1. Extent to which the grid is impacted by the energy system
2. Flexibility of the energy system to respond to market signals

Traditional technology evaluation uses levelized cost, ignoring grid dynamics

Price-taker considers dynamics, but ignores grid impact from participation

We developed a tool to automate price-taker optimization using IDAES for more robust technology evaluation in specific markets than LCOE

## Price-Taker Model Components

### Profit expressions at each time period

$$f_t^{\text{profit}} = \pi_t^e p_t - \frac{\pi^g}{\bar{\pi}^g} f^{\text{fuel}}(p_t) - f^{\text{var}}(p_t)$$
$$- \pi^c f^{\text{carbon}}(p_t) - f_t^{\text{fixed}}(P^{\max}) \qquad \forall t \in \mathcal{T}$$

### Capacity Constraints

$$P^{\min} y_t \le P_t \le P^{\max} y_t \qquad \forall t \in \mathcal{T}$$

### Ramping Constraints

$$\frac{(P_t - P_{t-1})}{P^{\max}} \le (r_{\text{su}} - r_{\text{op,u}}) v_t + r_{\text{op,u}} y_t \qquad \forall t \in \mathcal{T}$$
$$\frac{(P_{t-1} - P_t)}{P^{\max}} \le r_{\text{sd}} w_t + r_{\text{op,d}} y_t \qquad \forall t \in \mathcal{T}$$

### Startup and Shutdown Constraints

$$y_t \le z_{\text{build}} \qquad \forall t \in \mathcal{T}$$
$$\sum_{t-\tau^u+1}^{t} v_j = y_t \qquad \{t \mid t > \tau^u\}$$
$$\sum_{t-\tau^d+1}^{t} w_j = (1 - y_t) \qquad \{t \mid t > \tau^d\}$$
$$y_t - y_{t-1} = v_t - w_t \qquad \{t \mid t > 1\}$$

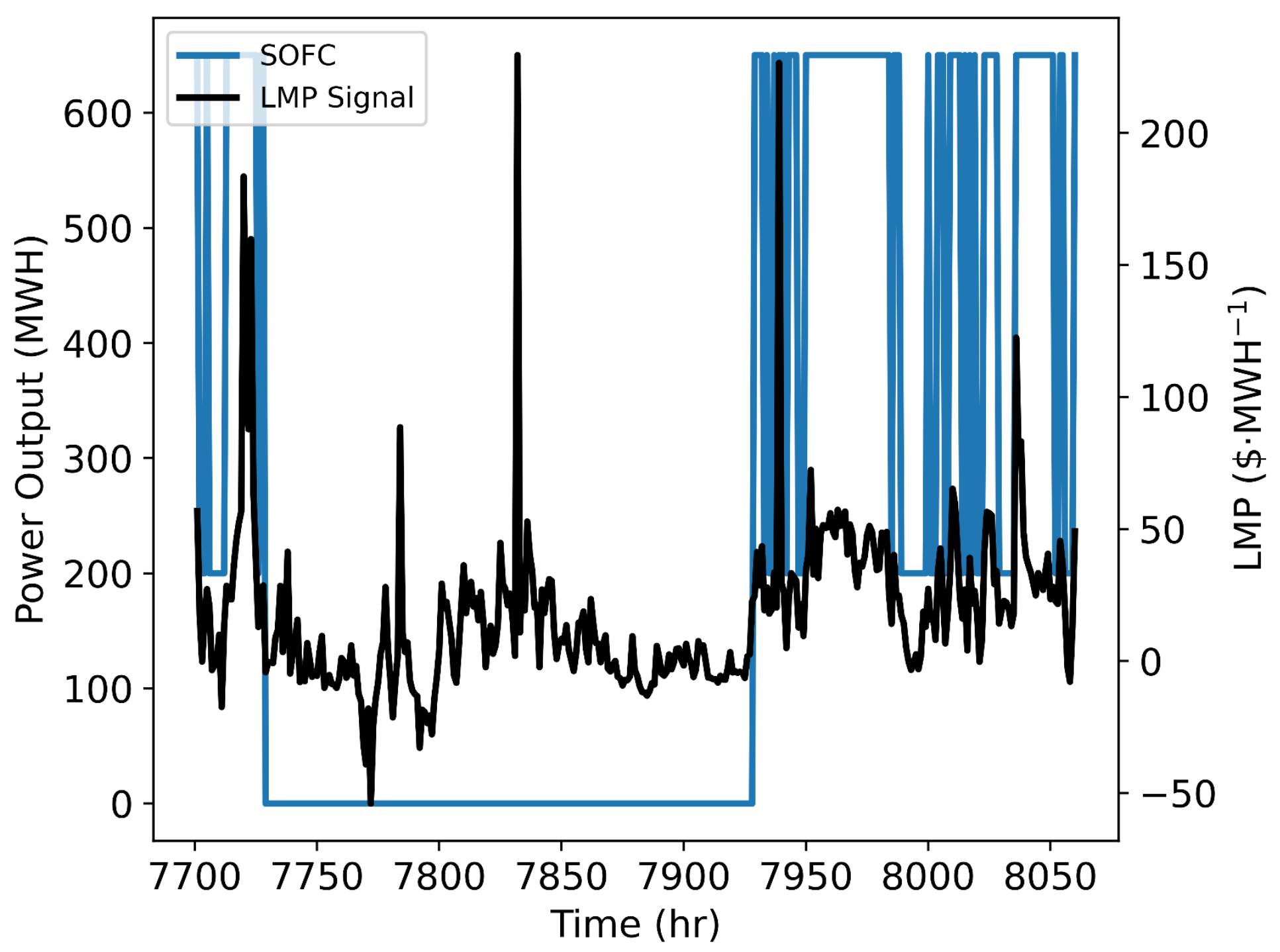
### Objective options: NPV, Annualized NPV, Net Profit

### Variable Definitions

| | | | |
|---|---|---|---|
| $P^{\max}$ : | maximum power output | $f_t^{\text{profit}}$ : | profit at time $t$ |
| $y_t$ : | operating binary variable (on $= 1$, off $= 0$) at time $t$ | $t$ : | time period |
| $r_{\text{su}}$ : | startup ramp rate | $\mathcal{T}$ : | pset of all time periods $t$ |
| $r_{\text{sd}}$ : | shutdown ramp rate | $\pi_t^e$ : | LMP price at time $t$ |
| $r_{\text{op,u}}$ : | operating ramp rate up | $P_t$ : | power output at time $t$ |
| $r_{\text{op,d}}$ : | operating ramp rate down | $\pi^g$ : | current price of natural gas |
| $v_t$ : | startup binary variable (yes $= 1$, no $= 0$) at time $t$ | $\bar{\pi}^g$ : | price of natural gas when $f^{\text{fuel}}$ was fit |
| $w_t$ : | shutdown binary variable (yes $= 1$, no $= 0$) at time $t$ | $f^{\text{fuel}}$ : | measurement response variable |
| $\tau^u$ : | startup binary variable (yes $= 1$, no $= 0$) at time $t$ | $f^{\text{fuel}}$ : | measurement response variable |
| $\tau^d$ : | shutdown binary variable (yes $= 1$, no $= 0$) at time $t$ | $\pi^c$ : | carbon tax |
| $z_{\text{build}}$ : | design binary variable (build $= 1$, not $= 0$) at time $t$ | $f^{\text{carbon}}$ : | carbon generation at time $t$ |
| | | $f_t^{\text{fixed}}$ : | fixed cost at time $t$ |

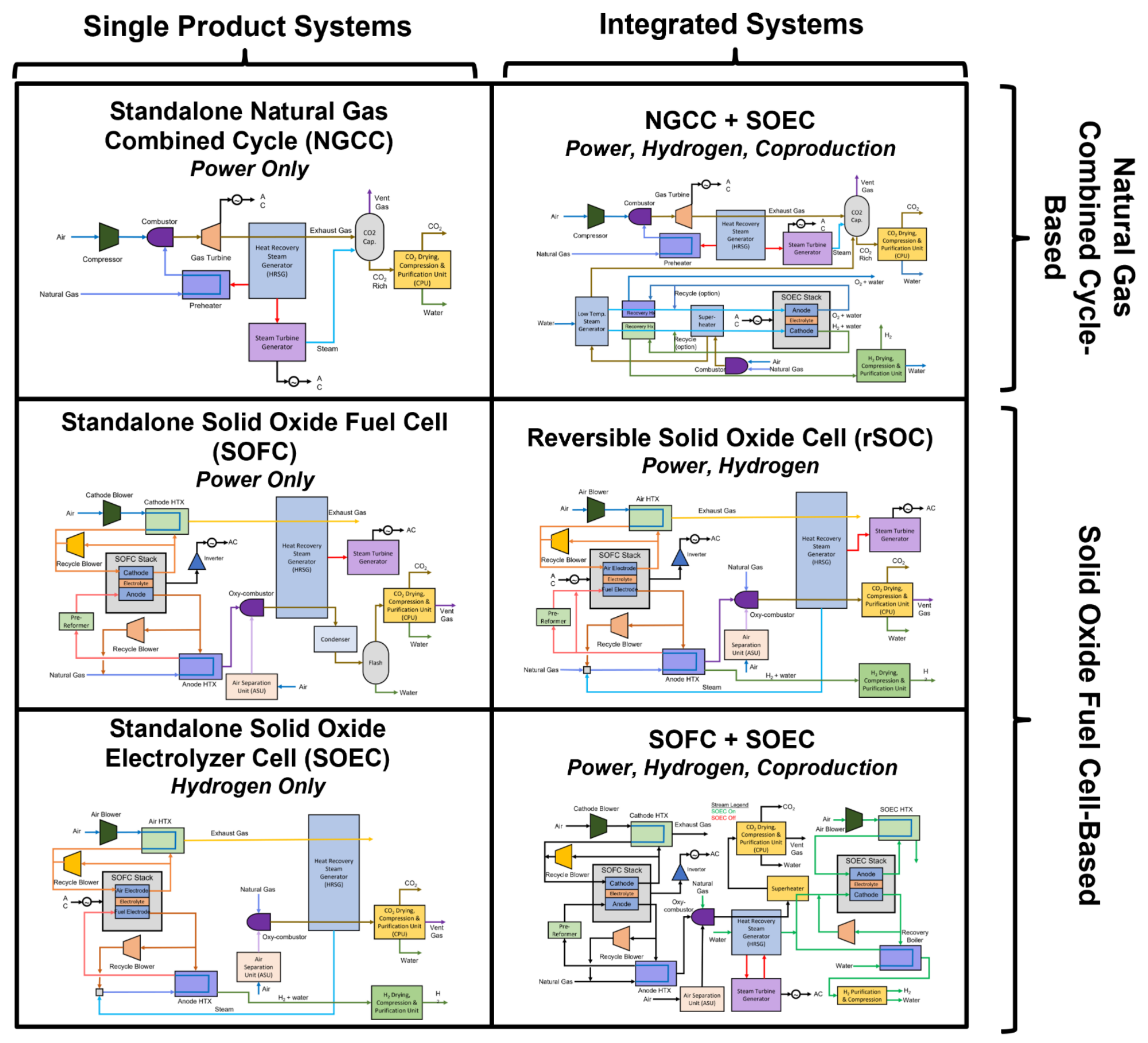
## Price-Taker Operational Output

**Goal:** Optimize the operating schedule of a candidate technology, solid oxide fuel cell (SOFC), in a potential market, NYISO 2022

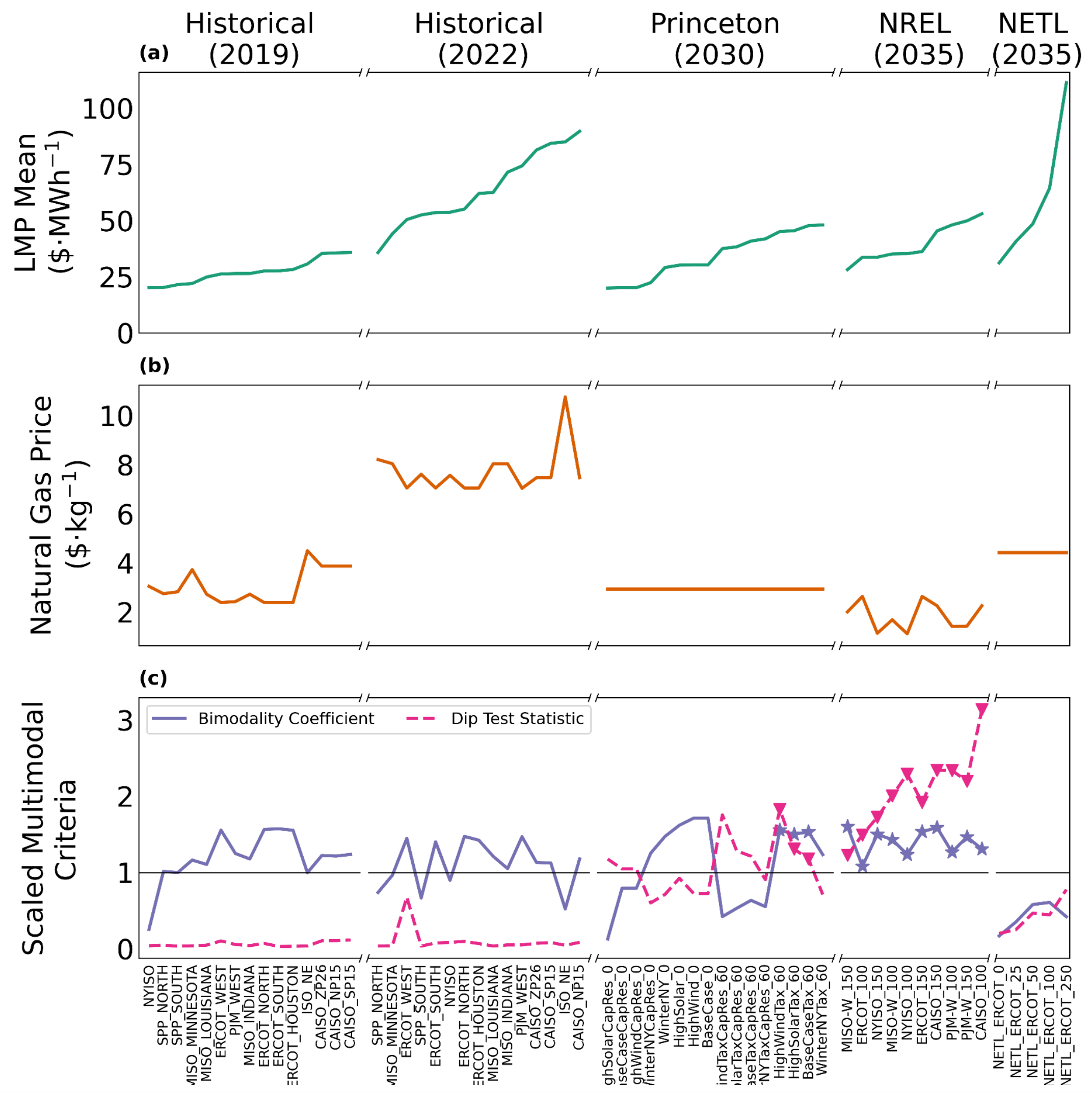


| **NYISO 2022 Conditions** | |
|---|---|
| Min uptime | 24 hours |
| Min downtime | 36 hours |
| Startup Cost | $162,015 |
| Shutdown Cost | $89,330 |
| **NYISO 2022 Results** | |
| Profit | 72.01M$ |
| Capacity Factor | 0.801 |

## Price-Taker Evaluates Coproduction Technologies



**Goal:** Evaluate solid oxide fuel cell (SOFC) and solid oxide electrolysis cell (SOEC) technologies against existing technology, natural gas combined cycle (NGCC), in many market scenarios including hydrogen coproduction.



61 markets analyzed

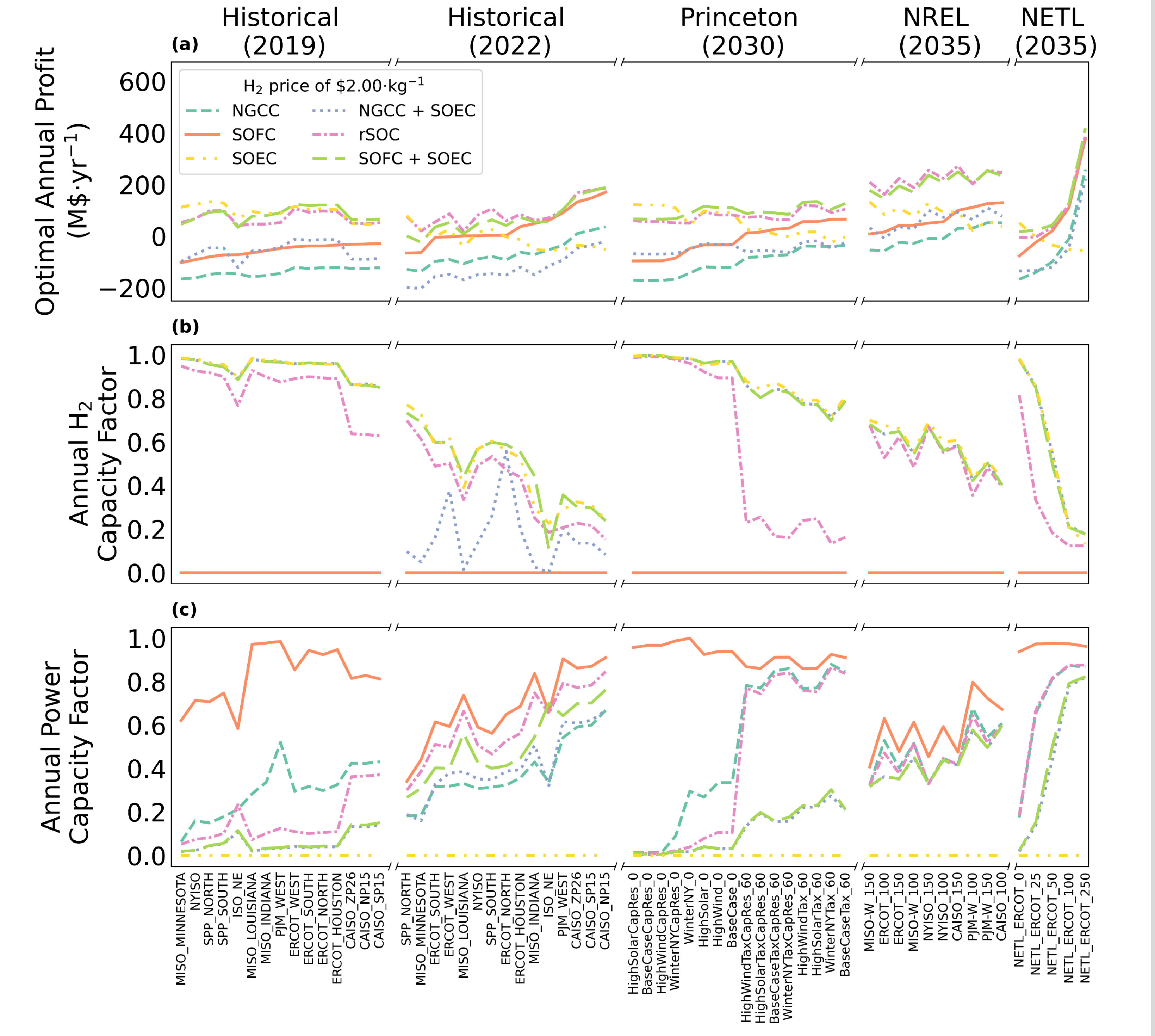
Historical[2], Current[2], and projected[3,4,5] market scenarios

Projected scenarios[3,4,5] include carbon tax and higher renewable energy penetration

Some markets exhibit multimodal price distributions

**Figure from [5]**

## Solid Oxide Based Technologies are Promising[5]



**Multimarket Analysis**

1. SOFC outperforms NGCC in every market analyzed
2. Solid oxide coproduction systems (rSOC and SOFC+SOEC) are the most profitable technology in over 75% of markets analyzed
3. Coproduction systems (rSOC, SOFC+SOEC, and NGCC+SOEC) greatly benefit from multimodal price markets
    - Cheap electricity → Produce $H_2$
    - Expensive electricity → Produce Electricity

**Figure from [5]**

## Conclusions and Future Work

1. Price taker model generalized and implemented in IDAES workflow
2. Easy to compare markets and technologies with an automated model-building tool
3. Plan to extend model components and consider modification to price-taker that will better approximate impact of selling power on market in the future

## References and Disclaimer

[1] X. Gao, B. Knueven, J.D. Siirola, D.C. Miller, and A.W. Dowling. Multiscale simulation of integrated energy system and electricity market interactions, *Applied Energy,* 316 (2022), https://doi.org/10.1016/j.apenergy.2022.119017

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[3] S. Cohen, and V. Durvasulu NREL Price Serices Developed for the ARPA-E FLECCS Program, Tech. Rep. NREL/TP-6A20-78195, National Renewable Energy Laboratory – Data (NREL-DATA), Golden, CO (United States) (December 2021)

[4] J.D. Jenkins, S. Chakrabarti, F. Cheng, N. Patankar, Summary Report of the GenX and PowerGenome runes for generating Price Series (for ARPA-E FLECCS Project), https://doi.org/10.5281/zenodo.5765798 (December 2021)

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