THE OXFORD INSTITUTE FOR ENERGY STUDIES

جامعة الملك عبدالله للعلوم والتقنية
King Abdullah University of Science and Technology

Opportunity and Cost of Green Hydrogen in Kuwait:
A Preliminary Assessment

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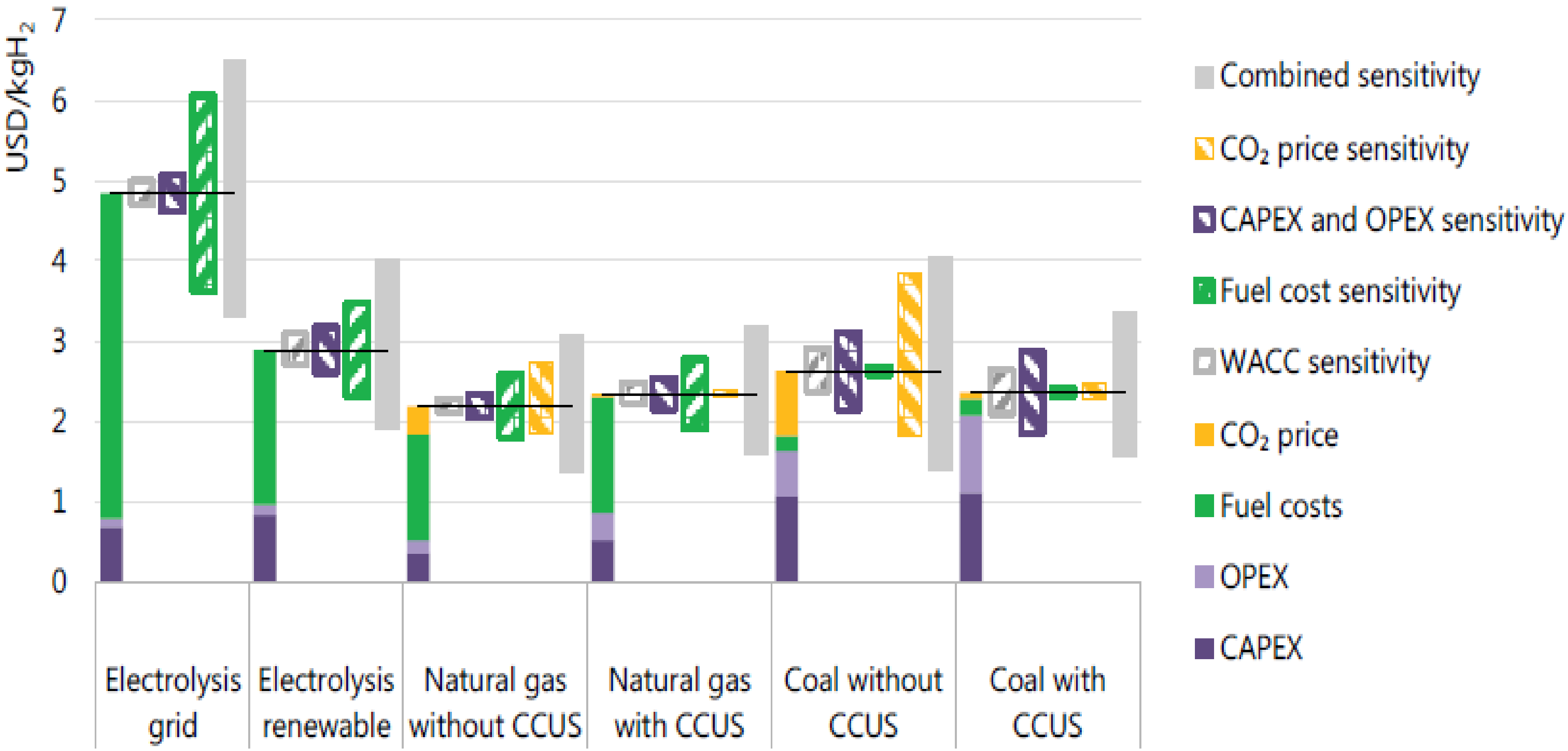
Outline

1. **Introduction, technology options, and pricing**
2. Green hydrogen production in Kuwait: Scenarios and assumptions
3. Preliminary assessments
4. Policy implications and future research

Rationale and Objective of Study

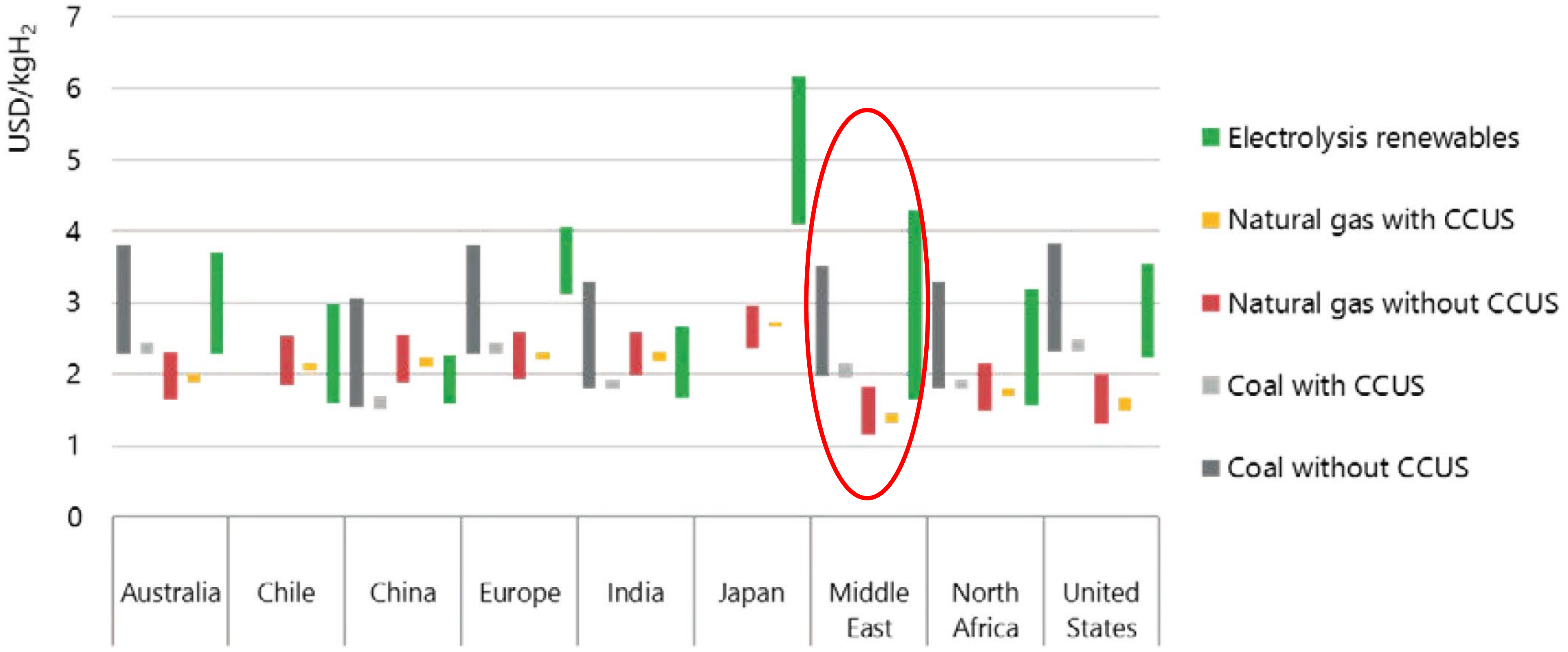
- Economic assessment is an integral part of a national hydrogen strategy
- Out of 4 GCC states vying for hydrogen exports, Kuwait is yet to announce undertaking hydrogen projects
- Producing blue hydrogen for exports is the natural starting point for an oil exporter, yet we focus on green technology
  - Kuwait is a net gas importer, unlikely to use natural gas and CCUS
- In this talk, we present:
  - Overview of current and future green hydrogen technology and projected costs
  - First known estimate of green hydrogen production costs in Kuwait (Gulf)
  - A combined insights into technology and economic assessments
  - Insights from results on Kuwait's hydrogen options given available resources, global markets and profitability
  - Implications for hydrogen policy and future direction.

Introduction: Hydrogen Production Costs by Technology



Source: IEA (2019).

Hydrogen Production Costs by Region



Source: IEA (2019).

Green Electricity Storage and Integration

- Green power contributes a substantial fraction of the cost of H2 production;
- Kuwait has one of the best solar resource in the world with 5.2 kWh/m^2/day with maximum annual sun hours of ~9.2 hours daily[1];
- Shagaya region has very good wind resource with ~5 m/s wind speed and average capacity factor of 45%[2];
- Energy storage and hybridization will be needed to:
  - Keep green electricity cost down
  - Guarantee reasonable capacity factors for the electrolyzers
  - Ensure longevity of some electrolyzers
- Cost of hydrogen production does not include compression and storage.

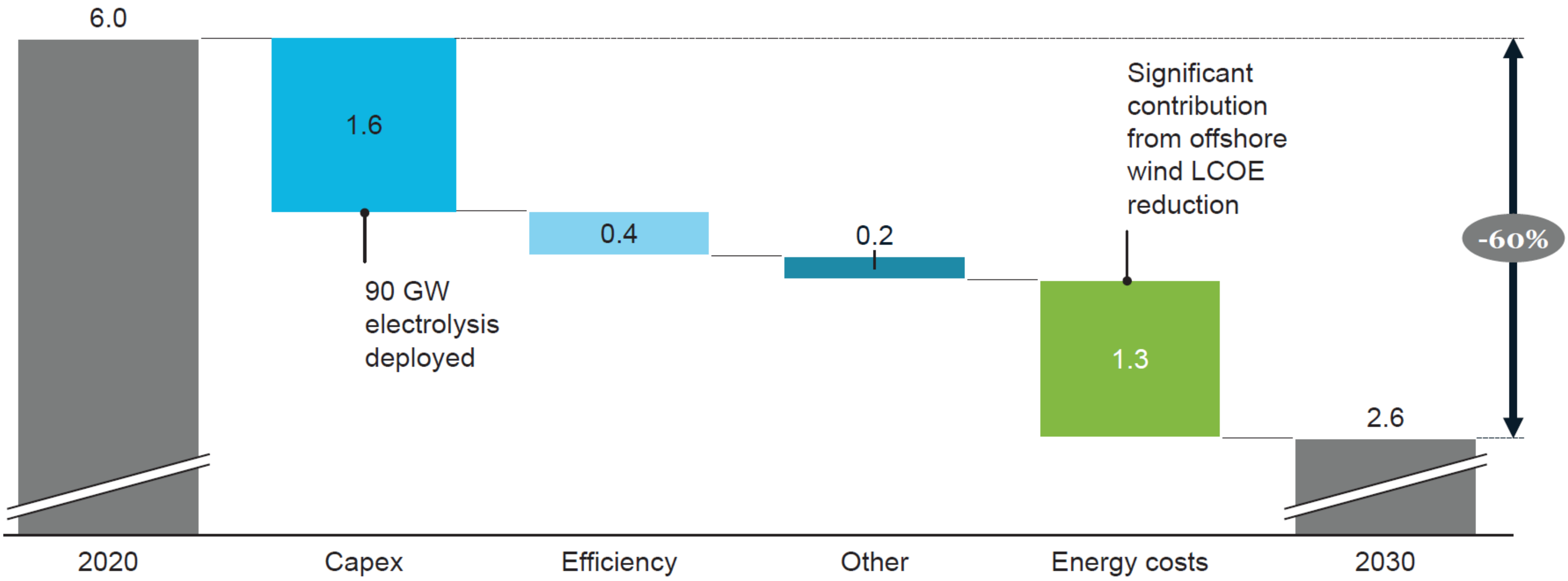
1. Majid Al-Rasheed et al., KISR, EuroSun 2014 Aix-les-Bains (France), 16 – 19 September 2014
2. Climatology of wind variability for the Shagaya region in Kuwait, Renewable and Sustainable Energy Reviews, Volume 133, November 2020, 110089

Key Performance Indicators for electrolyzers

	2020				2050			
	Alkaline	PEM	AEM	SOEC	Alkaline	PEM	AEM	SOEC
Cell pressure [bar]	<30	<70	<35	<10	>70	>70	>70	<20
System electric use [kWh/KgH_2]	50-78	50-83	57-69	45-55	<45	<45	<45	<40
Lifetime [1000s Hrs]	60	50-80	>5	<20	100	100-120	100	80
Capital costs (stack only ~1MW) [USD/kW_{el}]	270	400	-	>2000	<100	<100	<100	<200
Capital cost range (system >10MW) [USD/kW_{el}]	500-1000	700-1400	-	-	<200	<200	<200	<300

PEM= Polymer Electrolyte Membrane, AEM – Anion Exchange Membrane, SOEC = Solid Oxides Electrolyzers. *Source*: IRENA (2020).

Cost Drivers – Where Reduction will Come from?



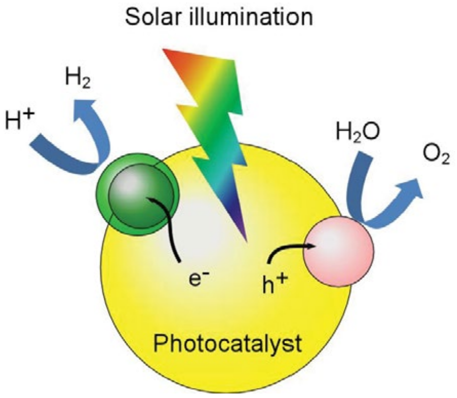
Assume 4,000 Nm3/h (~20 MW) PEM electrolyzers connected to offshore wind, excludes compression and storage. Location Germany.

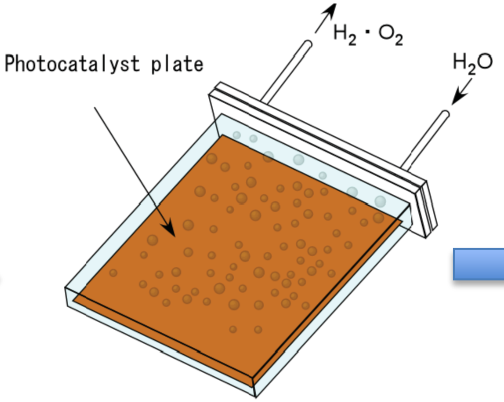
Source: H21; McKinsey; Expert interview

Promising Future Production Technologies

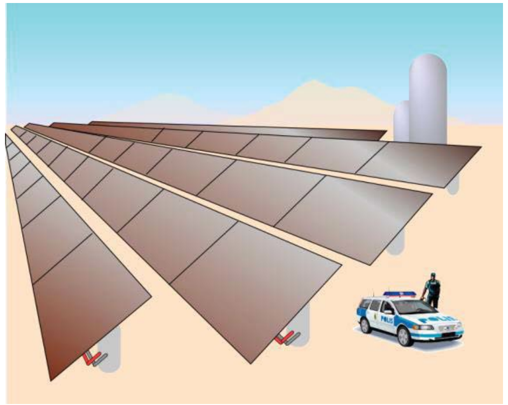
Example 1: Photo-Catalysis for Hydrogen production (TRL 5)

- New promising approach that utilizes the UV part of the spectrum
- Aiming for 3-5% solar to hydrogen ratio (STH)
- With solar concentration it is likely to reach 15-17% and compete with PV and electrolyzers.





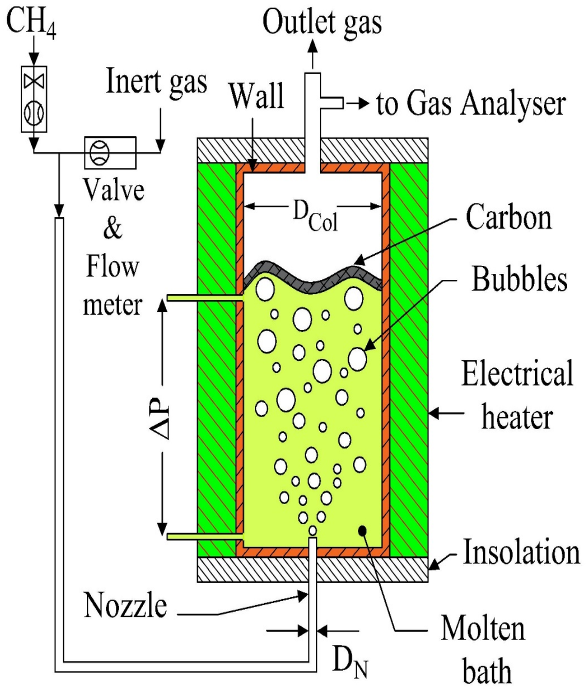
30 × 30 cm Photocatalysis module



Promising Future Production Technologies

Example 2: Thermo-Catalysis of Hydrocarbon Fuels using Molten Metals (TRL3)

- Process produces H2 and solid carbon from crude oil
- Concept proven in laboratory for methane conversion
- H2 cost depends on fuel cost, (>2.2 Euros from CH4)
- Opportunities to add steam and maximize hydrogen yield
- The solid carbon has value that may exceed that of hydrogen.



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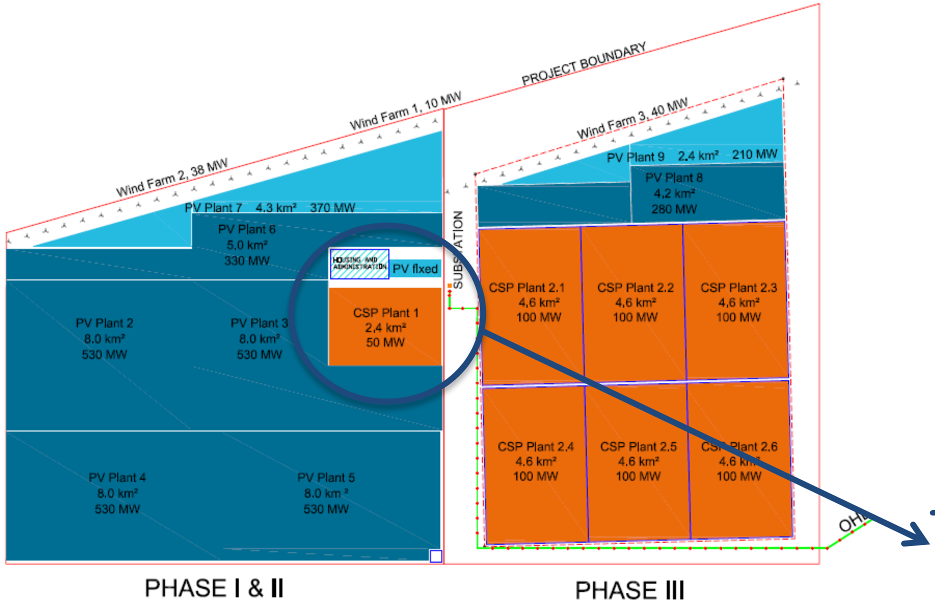
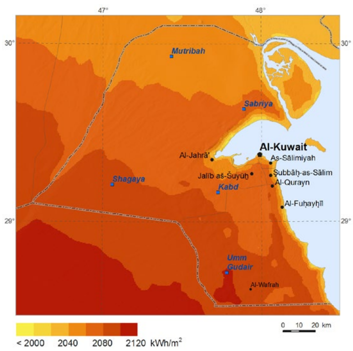
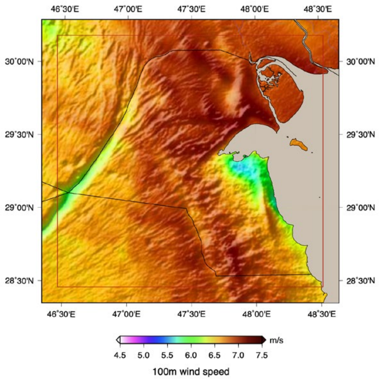
Green Power from Shagaya Renewable Energy Park







Solar and wind resource forecasting system. *Source:* KISR, RE&EE.


Wind 10 MW


PV 10 MW


CSP 50 MW + 10 hr Thr storage

Model Summary

- Model analyzes the technical and economic aspects of hydrogen-production technologies
- Estimates the levelized hydrogen cost (or hydrogen selling price)
- Uses a standard discounted-cash-flow methodology that calculates levelized hydrogen cost that yields a specified after-tax internal rate of return from the production technology

- To ensure equitable comparison, methodology and assumptions use standardized approach and set of assumptions for estimating the lifecycle costs of hydrogen production and delivery technologies, based on public literature info (e.g., used by US Department of Energy (DOE))
- Assumptions can be amended as required.

- Assumes:
  - Firm supply (constant green electricity supply)
  - 50% equity financing
- Excludes:
  - Only hydrogen gas is modelled
  - No by-products
  - Compression and storage costs

Selective Model Data and Assumptions

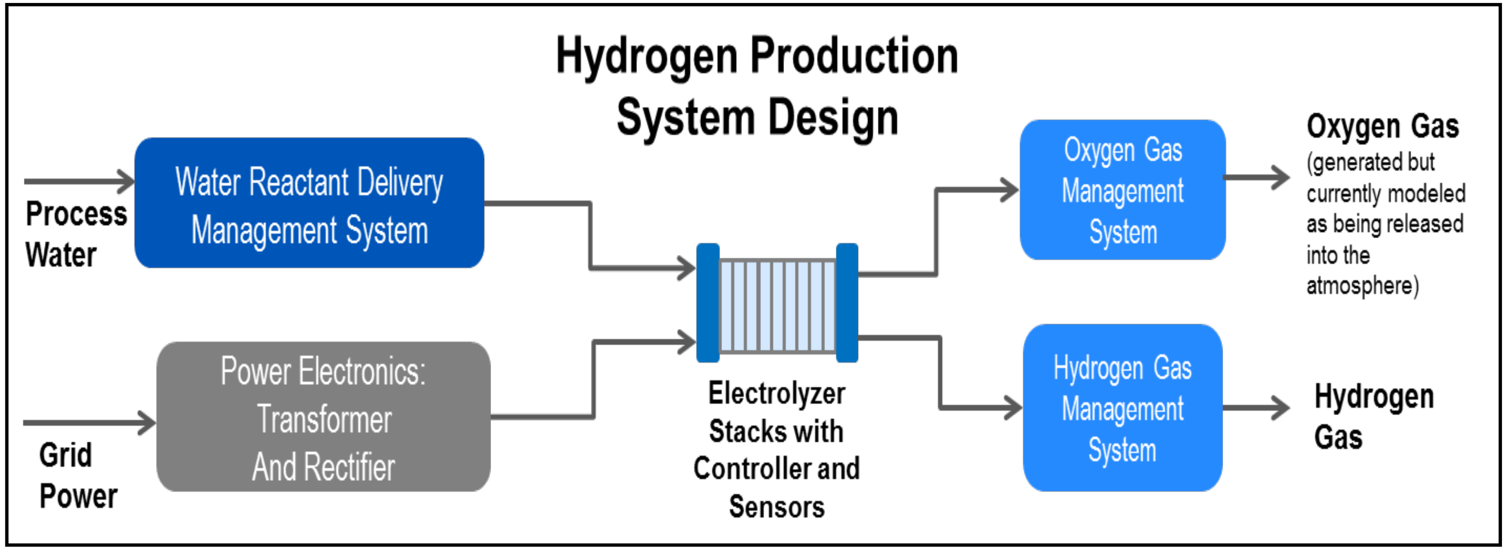
	PEM/SOEC	Data and assumptions source
Plant start year	2032	Shagaya project 2030 + construction
Construction time	2	Industry information
Plant life	40	Industry standard
Equity finance	50%	Reasonable estimate
Depreciation type and year	MACRS; 40 years	Industry standard
IRR	10%	Reasonable value conservative, but high enough to attract investors
Feedstock costs: Renewable electricity prices	$0.04785/KWh	IRENA estimates; Aghahosseini et al (2020), lower end for Gulf and assumption of long-term contract with MEW
Feedstock costs: Natural gas	Variable per year	KPC, Average estimates for MENA, estimates for future demand

Selective Model Data and Assumptions

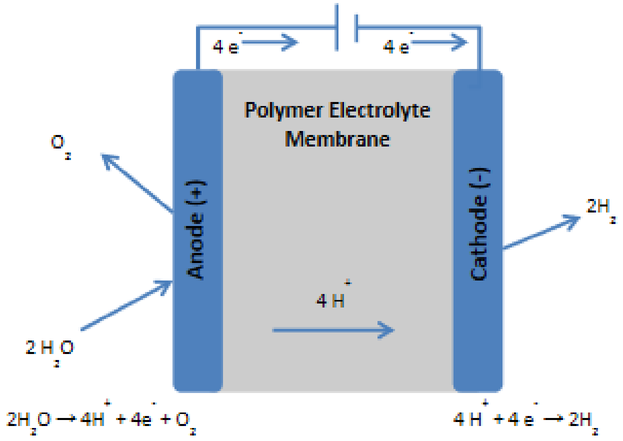
	PEM	SOEC	Assumption source
Average Production Rate (kg H2/day)	150,000	150,000	Conservative value to achieve scale and commensurate with 300-450MWe of expected available electricity capacity; closer to firm supply; relative regional scale
Plant production capacity (kg H2./day)	177,450	153,000	Calculated based on recommended degradation rate per technology
Operating capacity factor	97%	87.5%	Recommended technology standard
Electrolyzer BOP system life (years)	20	20	Recommended technology standard
Stack replacement interval (years)	10	3	Recommended technology standard
Capital investment: Baseline installed costs ($)	338,788,230	445,500,000	Average IRENA data; scaled to production capacity
System electric use [kWh/KgH_2]	61 (2020) 45 (2050)	50 (2020) 40 (2021)	Average IRENA data; linear interpolation

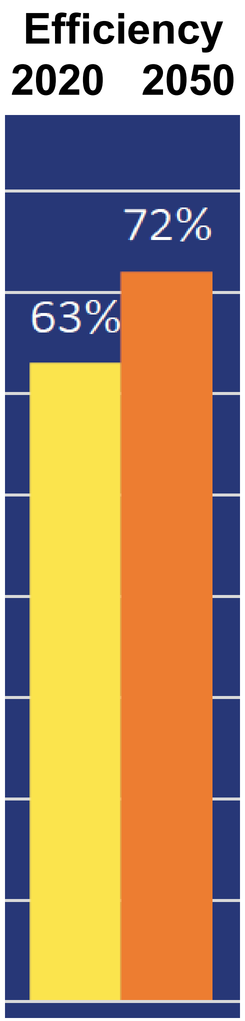
Considered Technologies and Process Flows: PEM

Projected Polymer Electrolyte Membrane process and PEM water splitting process



Source: DOE (2018).



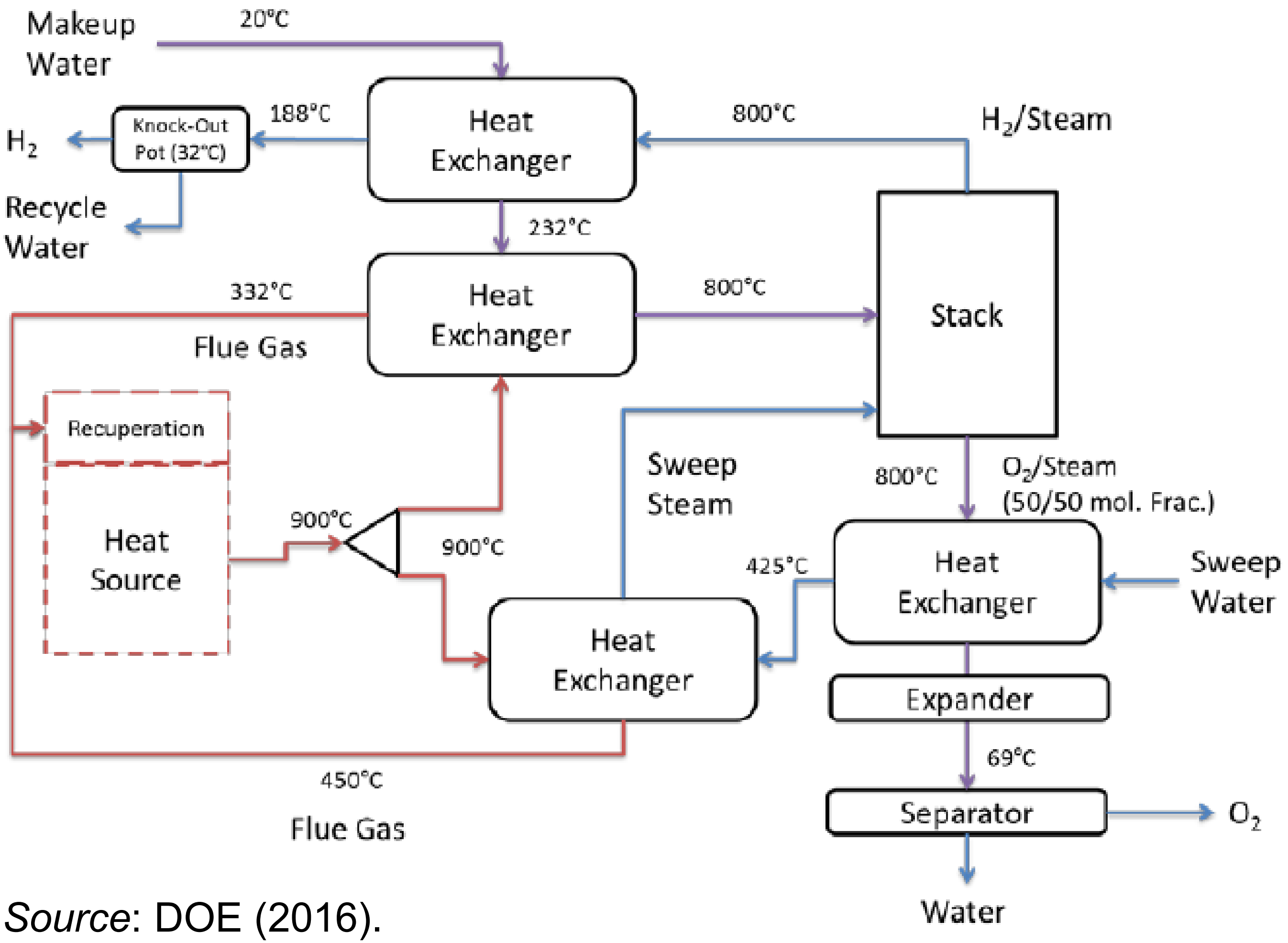


Source: EY (2020).

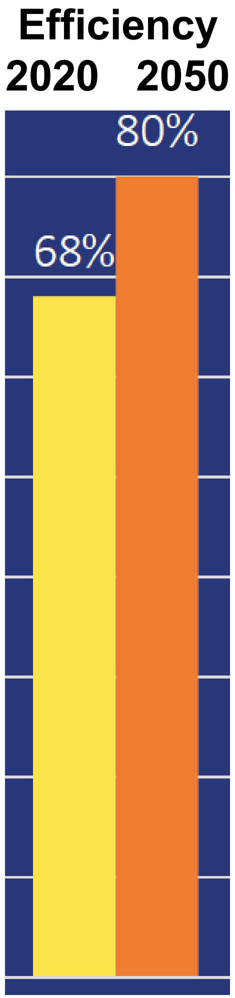
* Only hydrogen gas is modeled in our work

Considered Technologies and Process Flows: SOEC

Projected solid oxide electrolysis cells process



Source: DOE (2016).



Source: EY (2020).

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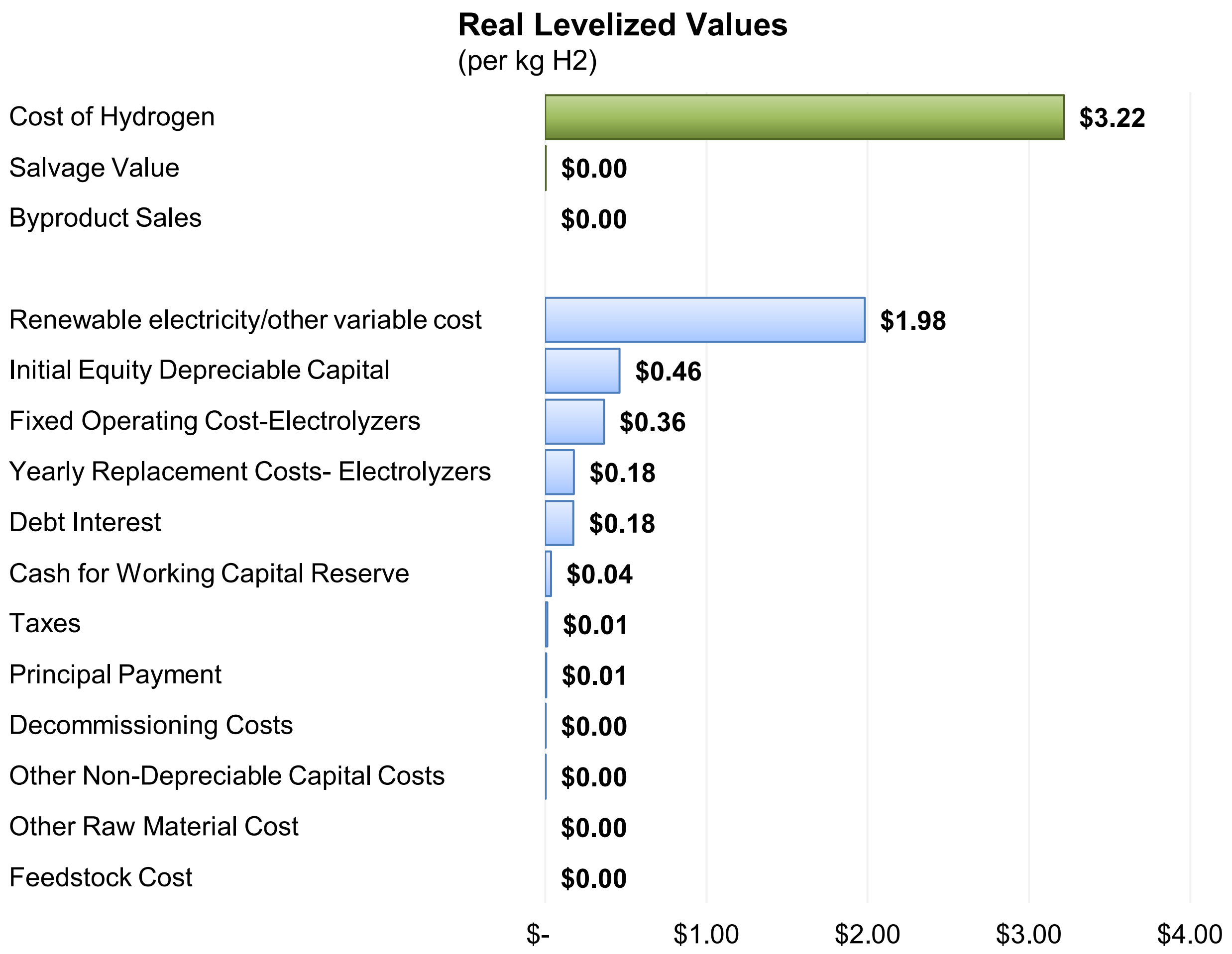
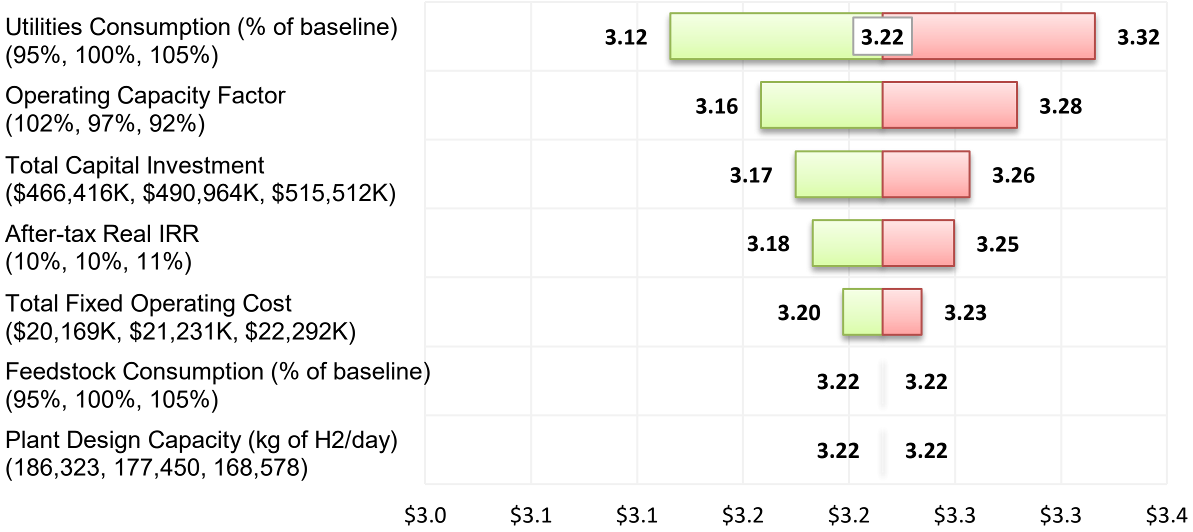
Preliminary costs of producing green hydrogen – PEM



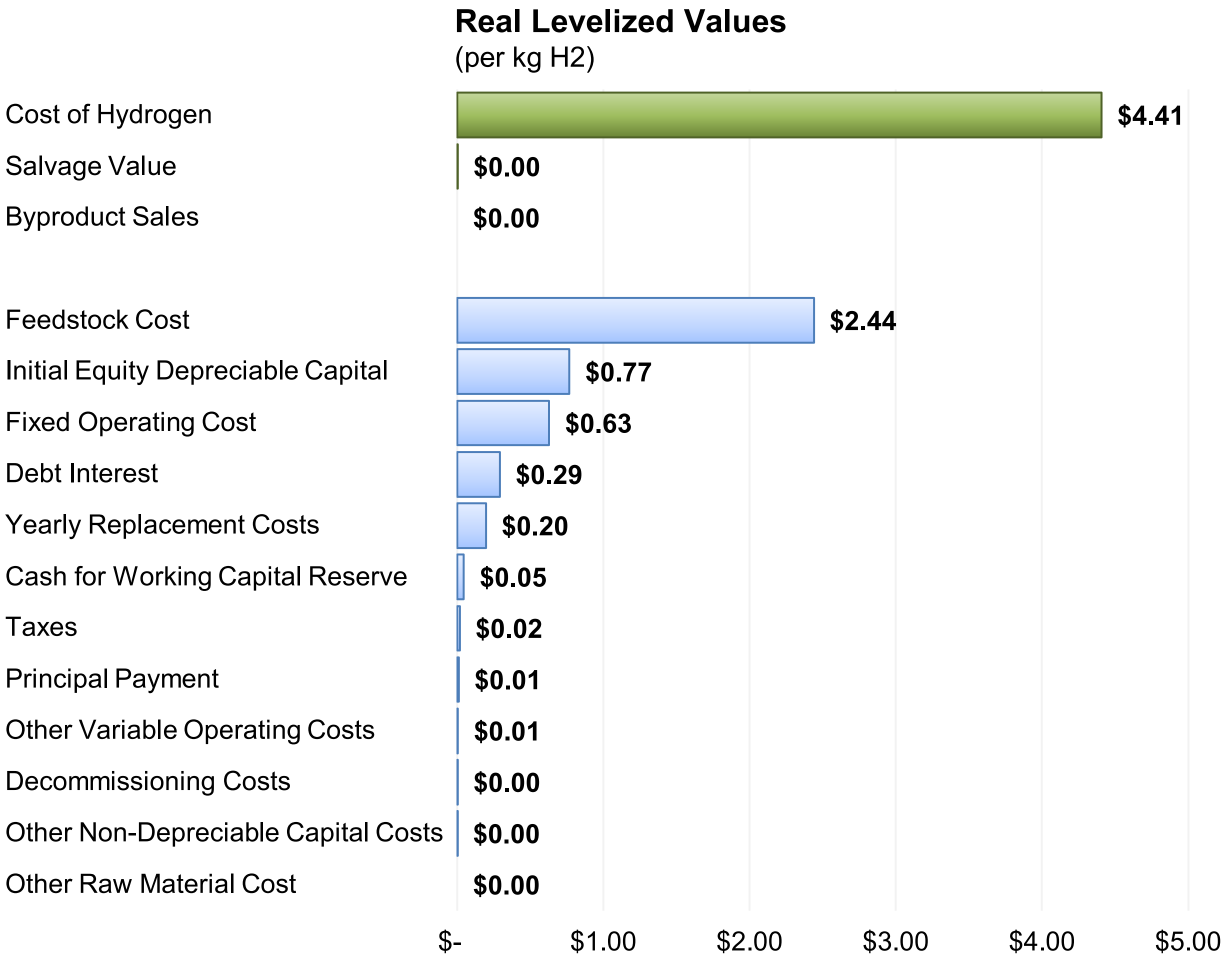
Source: Model results.



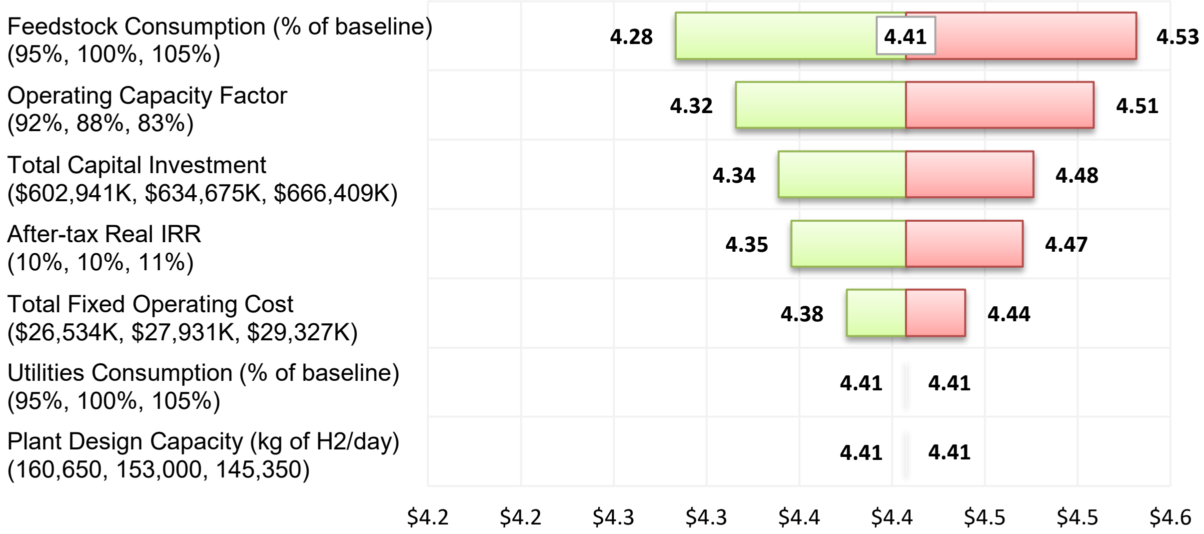
Source: Model results.

Electrical power: 450 MWe

Preliminary costs of producing green hydrogen – SOEC



Source: Model results.



Source: Model results.

Electrical power: 315 MWe

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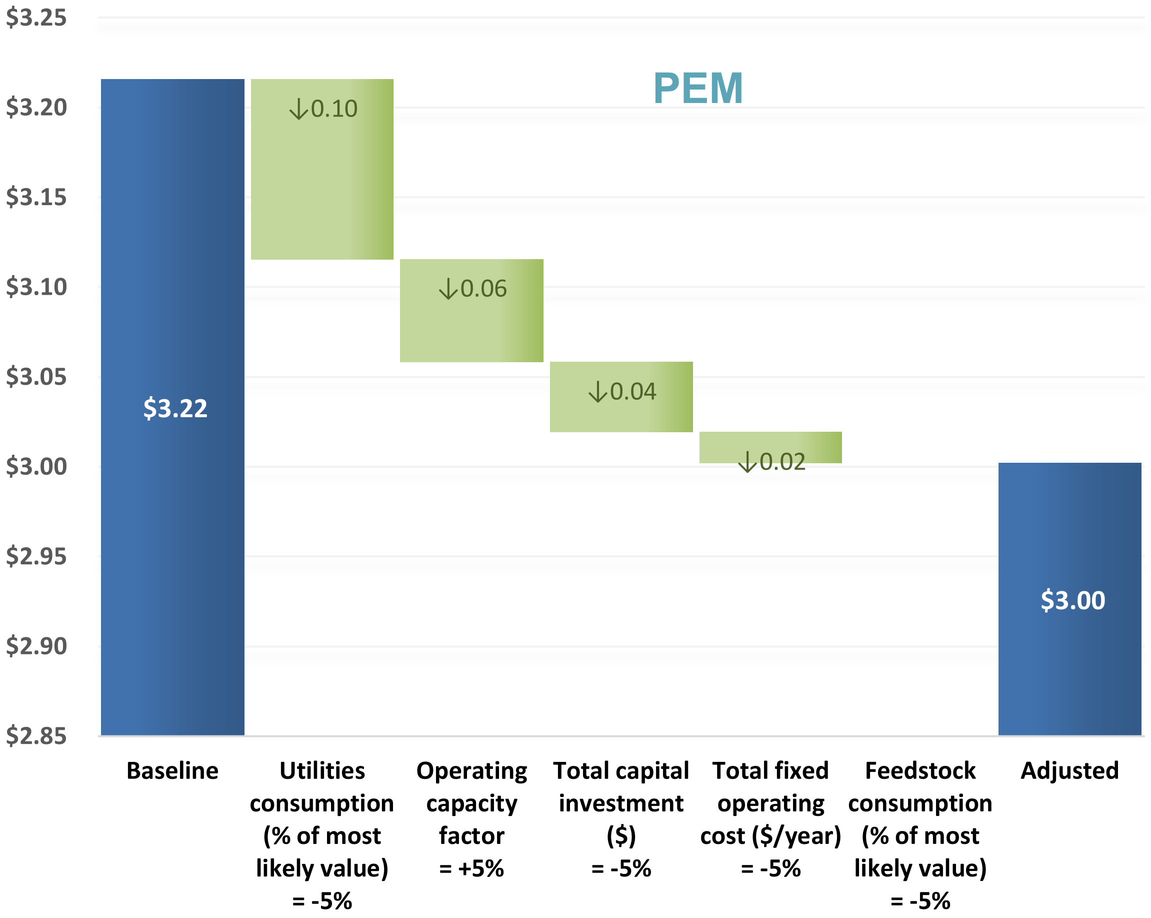
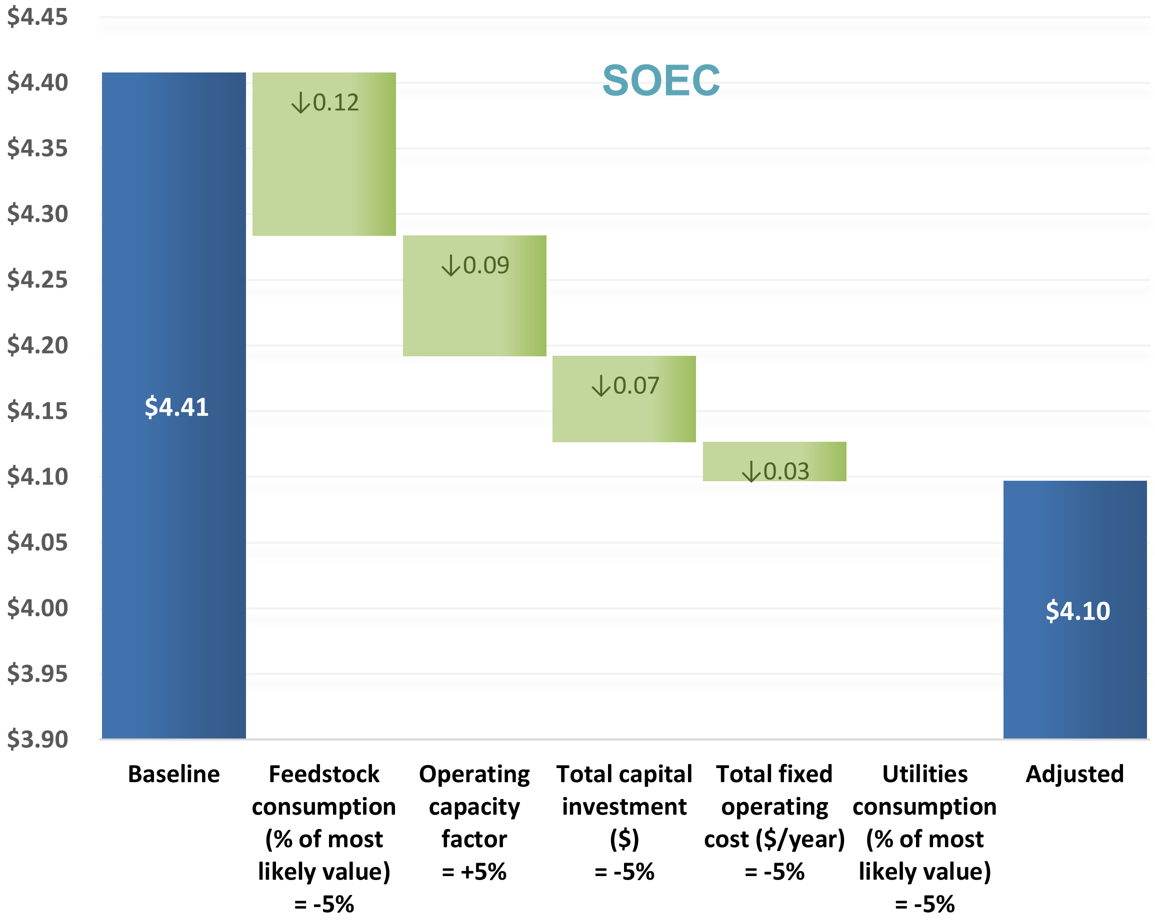
Insights from the Hydrogen Production Costs





Reducing PEM electrolyzers costs by 34% between 2020 and 2032 results in a reduction of H2 real levelized values by 15%, from $3.22/Kkg to $3.8/kg, with maximum capacity.

Source: Model results.

Reducing Solid Oxides electrolyzers costs by 37% between 2020 and 2032 results in a reduction of H2 real levelized values by 20%, from $4.41/Kkg to $5.50/kg.

Source: Model results.

Policy Implications and Future Research

- **Competitiveness: Costs to infer strategy and markets**

  In markets driven by some decarbonization and cost, not green technology not yet competitive

  - $1.5/kg hydrogen to compete coal, oil and gas without a carbon price
  - Requires renewable cost drop by approximately 50% and electrolyser costs decline by 75%

  In markets driven by some decarbonization and emissions, possibly competitive
  - Competitive production costs: At current electrolyzers costs, our assessment H2 by PEM \$3.8-\$4.1 < \$5-6/Kg (DOE).

  - BUT higher shipping costs for export markets (no pipelines)

- **Policy:**
  - More competitive pricing with technology improvement and cost reductions of electrolyzers. Larger renewable energy scale. Ways to reduce shipping costs (e.g., ammonia shipment).
  - economic and reliable infrastructure for transmission and storage of hydrogen
  - Implications on fiscal costs.

- **Part of ongoing research**

Discussion