Overview of Integrated Pathway Analyses to Meet the Hydrogen Energy Earthshot Goal

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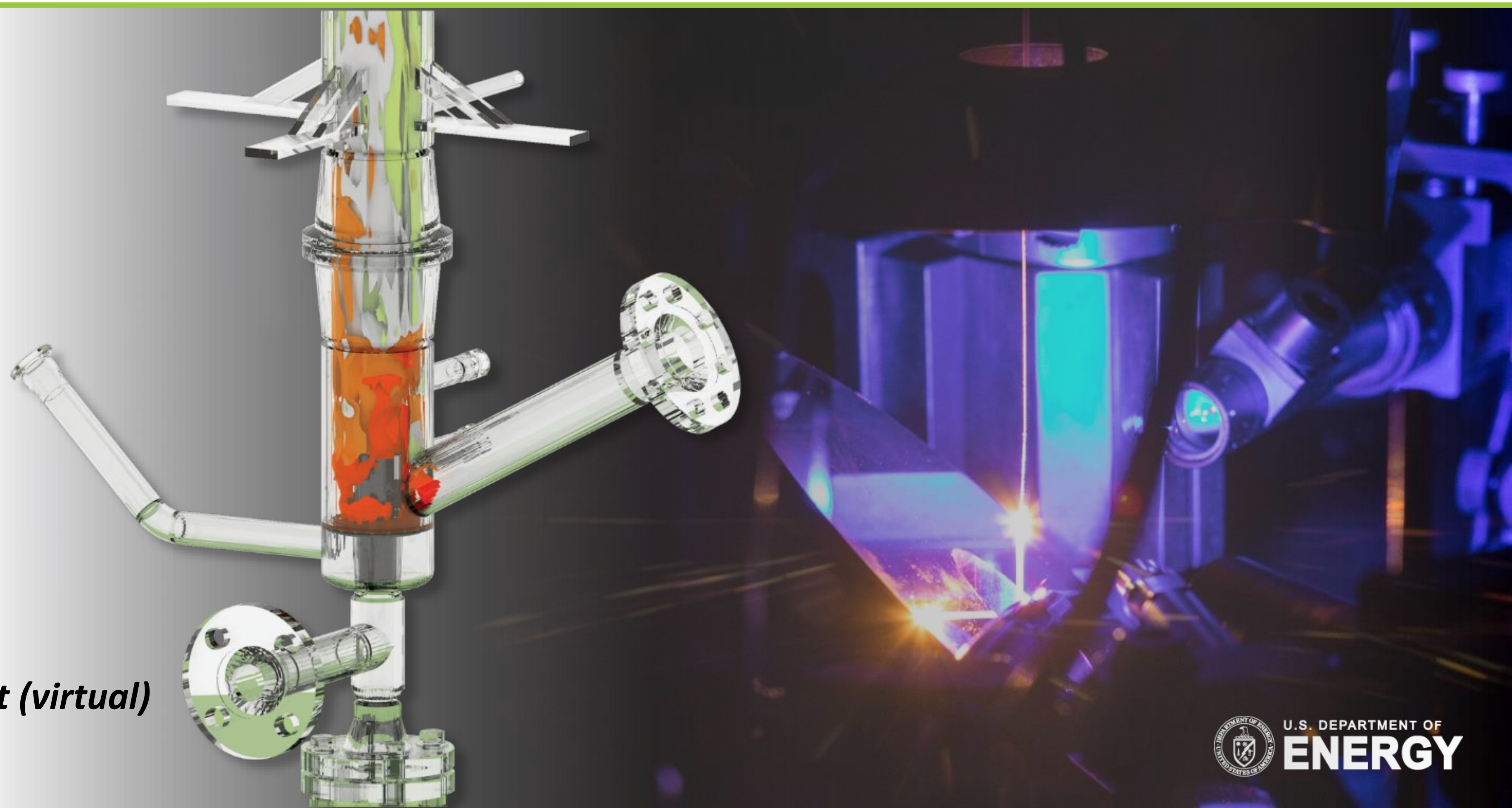
Solutions for Today | Options for Tomorrow



Eric Lewis

2021 DOE Hydrogen Shot Summit (virtual)

Aug. 31, 2021

U.S. DEPARTMENT OF ENERGY

NETL H_2 Production Systems Analyses

Current Studies

- Comparison of Commercial, State-of-the-Art, Fossil-Based Hydrogen Production Technologies
  - NETL Internal Report – Complete
  - Peer Reviewed Report Publication – In Progress
- Hydrogen Energy Earthshot Initiative Screening Analysis – In Progress

Comparison of Commercial, State-of-the-Art, Fossil-Based Hydrogen Production Technologies

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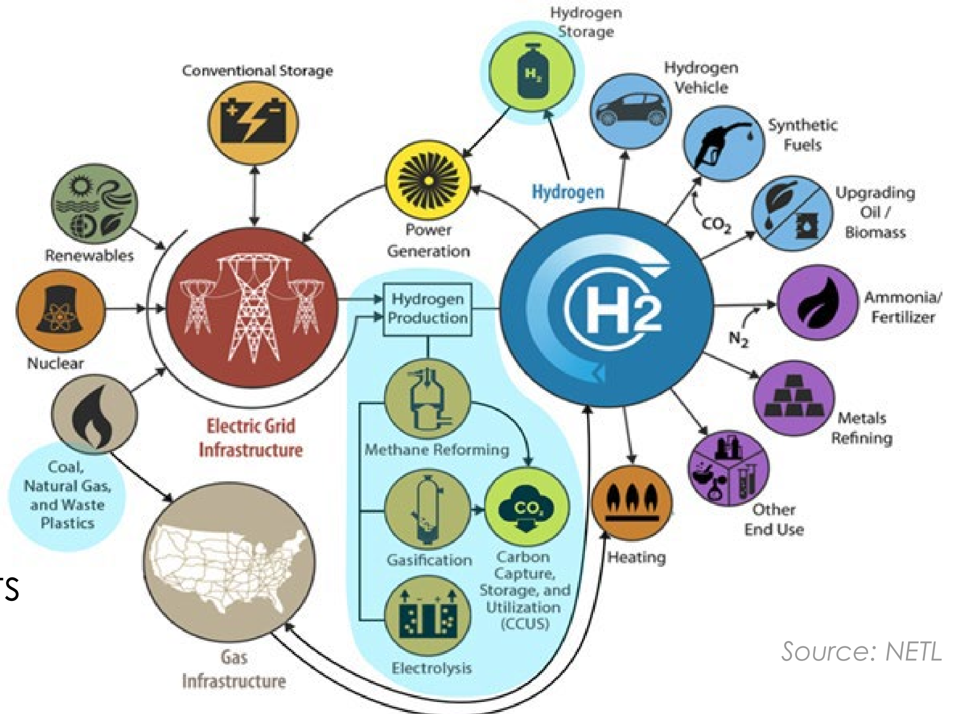
Project Summary

Objectives

- Develop a reference study of H_2 production technologies using current, commercial technologies[1] with emphasis on coal gasification, co-gasification of coal with an alternative feedstock, and NG technologies using the levelized cost of hydrogen (LCOH) (2018 $/kg) as the figure of merit
- Identify areas of R&D to further improve the performance and cost of fossil fuel-based H_2 production, including follow-on analyses

Justification

- Provide a baseline reference for DOE Office of Fossil Energy and Carbon Management (FECM) R&D program planning to reduce the LCOH and greenhouse gas (GHG) footprint of future fossil-to-H_2 plants



Source: NETL

Highlights

- Lowest LCOH of cases examined w/ carbon capture and storage (CCS) is auto-thermal reformer (ATR) – $1.58/kg H_2
- Lowest LCA GHG profile of fossil-only cases examined w/ CCS is coal gasification – 3.9 kg CO_2e/kg H_2
- Co-gasifying 43.5 wt.% biomass with coal enables net-zero GHG H_2 production
- NG supply chain and grid electricity are significant contributors to LCA GHG emissions of reforming plants w/ CCS

[1] Commercial technologies are considered process systems that do not face fundamental R&D challenges within the plant flowsheets considered and at the scales studied

Note: Project initiated September 2020

Comparison of Commercial, State-of-the-Art, Fossil-Based Hydrogen Production Technologies

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Case Matrix

<table>
<tr><th>Case</th><th>Plant Type</th><th>Feedstock(s)</th><th>Reformer Type</th><th>Gasifier Type</th><th>CO_2 Capture[A]</th><th>H_2 Purification</th><th>Hydrogen Production Capacity</th><th>Lifecycle Emissions Target (kg CO_2e/kg H_2)</th></tr>
<tr><td>1</td><td>Reforming</td><td rowspan="3">Natural Gas</td><td rowspan="2">SMR</td><td rowspan="3">-</td><td>0%</td><td rowspan="6">PSA</td><td rowspan="2">200 MMSCFD
(Single Train SMR Max)</td><td rowspan="5">N/A</td></tr>
<tr><td>2</td><td>Reforming</td><td>96.2%</td></tr>
<tr><td>3</td><td>Reforming</td><td>ATR</td><td>94.5%</td><td>274 MMSCFD
(Match H_2 output of Cases 4 and 5)</td></tr>
<tr><td>4</td><td>Gasification</td><td rowspan="2">Coal (Illinois No. 6)</td><td rowspan="3">-</td><td rowspan="3">Shell</td><td>0%</td><td rowspan="2">274 MMSCFD
(BBR Rev. 4 Case B1B
Shell Gasifier Capacity)</td></tr>
<tr><td>5</td><td>Gasification</td><td>92.5%</td></tr>
<tr><td>6</td><td>Gasification</td><td>Illinois No. 6/Torrefied Woody Biomass</td><td>92.6%</td><td>55 MMSCFD
(1,400 tpd gasifier feedstock)[B]</td><td>0</td></tr>
</table>

[A] CO_2 capture targets the maximum amount of feedstock carbon captured from the syngas (ATR and gasification cases) and syngas + furnace flue gas steam methane reformer (SMR) case

[B] The smaller-scale co-gasification case reflects the feedstock capacity of the Buggenum IGCC facility

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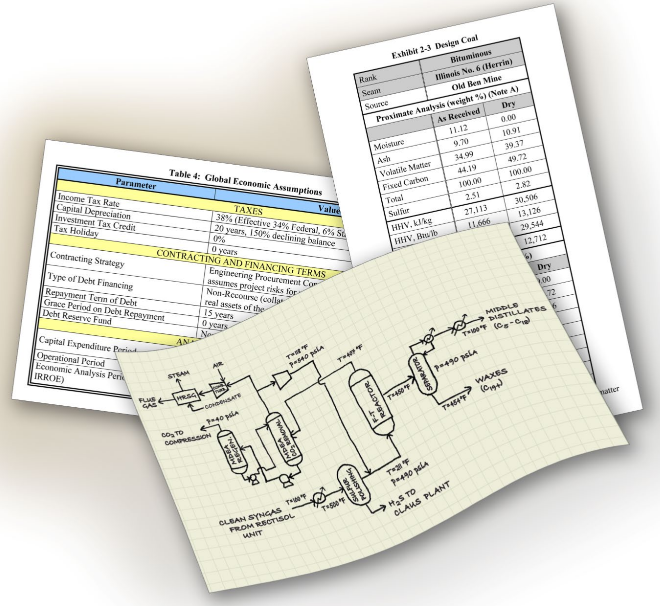
General Evaluation Basis

- **Performance and economic modeling conforms to the 2019 revision of NETL's QGESS reports:**
  - CO_2 Transport and Storage
  - CO_2 Purity
  - Cost Estimation Methodology
  - Capital Cost Scaling Methodology
  - Energy Balance
  - Feedstock Specifications
  - Fuel Prices
  - Process Modeling Design Parameters
  - Techno-Economic Analysis
- **Transparent, consistent, highly-detailed analysis methodology**

Quality Guidelines for Energy System Studies (QGESS)



Comparison of Commercial, State-of-the-Art, Fossil-Based Hydrogen Production Technologies

Feedstock/Byproduct Pricing

- **Site-delivered feedstock prices (2018$)**
  - Natural Gas, levelized
    - $4.42/MMBtu (HHV basis)
  - Coal (Illinois No. 6), levelized
    - $2.23/MMBtu (HHV basis)
  - Woody Biomass (torrefied, non-pelletized), levelized
    - $5.43/MMBtu (HHV basis)
  - Grid Electricity (Imports and Sales)
    - $71.7/MWh – 2019 MISO average industrial consumer price
    - Only coal + biomass gasification sells electricity, <1 MWh/day
- **No revenue from the sale of export steam**

Comparison of Commercial, State-of-the-Art, Fossil-Based Hydrogen Production Technologies

H_2 Product Purity

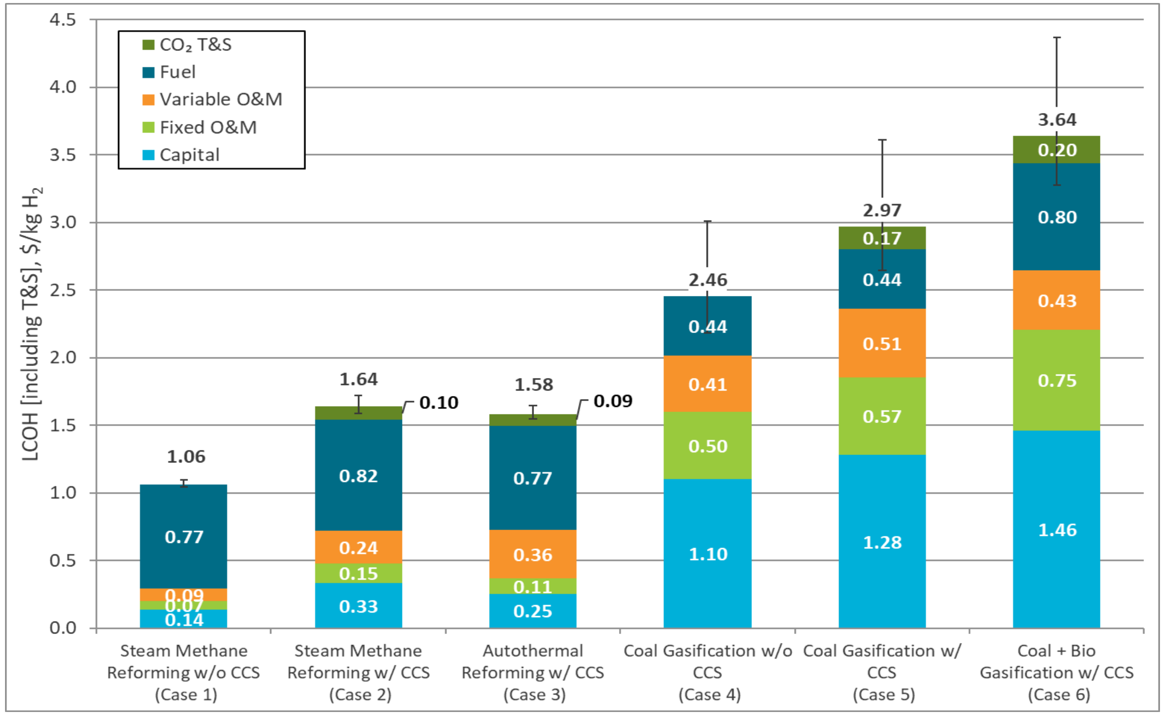
Characteristics	Concentration
Hydrogen Purity (vol%)	99.90
Max. CO_2 (ppm)	A
Max. CO (ppm)	A
Max. H_2S (ppb)	10
Max. H_2O (ppm)	A
Max. O_2 (ppm)	A

[A]The maximum total concentration of all oxygen containing species is 10ppm

- **The hydrogen product meets the purity specification shown, which results in a product suitable for several potential applications**
- **Contaminant levels are for ammonia-grade H_2 to avoid catalyst poisoning**
- **Additionally, the specification results in a product exceeding specifications for the following ISO 14687:2019 gaseous H_2 grades:**
  - Grade A – combustion applications
    - Internal combustion engines, residential/commercial heating appliances
  - Grade B – industrial power and heat applications
    - Excluding PEM fuel cells
- **H_2 product is compressed to 925 psig for pipeline injection**

Comparison of Commercial, State-of-the-Art, Fossil-Based Hydrogen Production Technologies

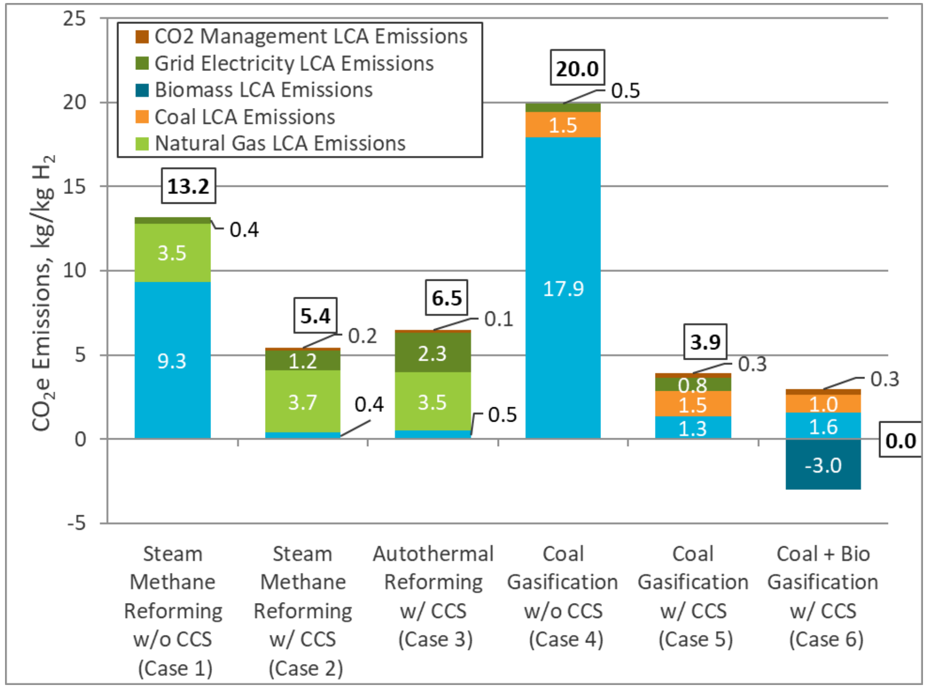
Results (Pending Peer Review)



- Lowest reforming cases – SMR w/o CCS ($1.06/kg H_2)
- Highest reforming case – SMR w/ CCS ($1.64/kg H_2)
- Lowest gasification case – coal w/o CCS ($2.46/kg H_2)
- Highest gasification case – "net-zero" coal/biomass ($3.64/kg H_2)

Global Warming Impact Factors (100-yr, with climate feedback)

- U.S. Electricity, 2016 National Average Profile[1]: 590 kg CO_2e/MWh
- Production and Delivery, Cradle-to-city gate[2]: 0.99 kg CO_2e/kg NG
- Bituminous, Transport Distance (MRO Average)[3]: 0.19 kg CO_2e/kg of coal
- Torrefied, non-pelletized SRWC[4] : -0.72 kg CO_2e/kg AR biomass
- CO_2 Management, saline aquifer[5]: 0.02 kg CO_2e/kg CO_2 sequestered



$1 Announcement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Department of Energy

Secretary Granholm Launches Hydrogen Energy Earthshot to Accelerate Breakthroughs Toward a Net-Zero Economy

JUNE 7, 2021

Home » Secretary Granholm Launches Hydrogen Energy Earthshot to Accelerate Breakthroughs Toward a Net-Zero Economy

First Energy Earthshot Aims to Slash the Cost of Clean Hydrogen by 80% to $1 per Kilogram in One Decade

WASHINGTON, D.C. — Secretary of Energy Jennifer M. Granholm today launched the U.S. Department of Energy's (DOE) Energy Earthshots Initiative, to accelerate breakthroughs of more abundant, affordable, and reliable clean energy solutions within the decade. The first Energy Earthshot—Hydrogen Shot—seeks to reduce the cost of clean hydrogen by 80% to $1 per kilogram in one decade. Achieving these targets will help America tackle the climate crisis, and more quickly reach

https://www.energy.gov/articles/secretary-granholm-launches-hydrogen-energy-earthshot-accelerate-breakthroughs-toward-net

Key Details:

- $1/kg H_2
- One decade (i.e., 2030)
- "1, 1, 1"

https://www.energy.gov/eere/fuelcells/hydrogen-shot

Project Goals and Benefits

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Identify potential pathway scenarios to meet the Hydrogen Energy Earthshot 2030 production cost and (informal) emissions intensity goals via screening analyses

- Opportunities for holistic reductions in production cost and life cycle emissions will be critically reviewed
- Both natural gas and waste coal primary feedstocks will be evaluated
- Advancements to contemporary commercial technologies (e.g., SMR, ATR, gasification), advanced technologies (e.g., chemical looping, pyrolysis, etc.), unit siting choices, the application of biofuels, and finance assumptions at a minimum will be considered
- VRE-based H_2 production pathways will be examined for comparison purposes

Provide an informed framework for FECM H_2 R&D

- Screening-level analyses intended to be performed quickly
- Pathway scenarios to guide program R&D
- Facilitate office and programmatic communications with stakeholders

Project Approach

Five (5) Tasks:

Task 1: Establish baseline

- Ongoing H_2 baseline work and other contemporary estimates available
- Summarize key process information (including LCA data)

Task 2: Literature review/information gathering on advanced H_2 production

- Consider both current commercial and advanced (future) H_2-production technologies
- Summarize detailed descriptions, flow diagrams, performance/cost data, strengths/weaknesses, etc.

	Process	Markets	LCA	Sub-Surface
Task 1	‡		•	
Task 2	‡		•	
Task 3	•	‡	•	•
Task 4	‡	•	•	•
Task 5	‡	•	•	•

‡ = Lead; • = Support

Task 3: Additional options for improvements (cost and emissions)

- Plant Siting, Process Intensification, Financing and Byproduct Sales, Biofuels, CO_2 Transport and Storage costs

Task 4: Exploratory analyses to identify candidate pathways

- From Tasks 2 and 3, identify/propose pathways, summarize design basis and assumptions, **estimate** H_2 production costs and emission intensities
- Down-select 4-6 scenarios for detailed analyses

Task 5: Final analyses, presentation, and whitepaper

- Refine analyses on 4-6 down-selected scenarios
- Conduct sensitivity analyses

Project Timeline:

- September 2021 – January 2022

Acknowledgements

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Disclaimer

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