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THE RESEARCH LANDSCAPE FOR GREEN ENERGY

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BETWEEN PROBLEMS AND PROGRESS ARE CONNECTIONS THAT MATTER

Expert Panelists & Moderator

Leilani Lotti Diaz  
Information Scientist, CAS

Yiying Wu  
Leet Professor, The Ohio State University

Dharik Mallapragada  
Research Scientist, MIT Energy Initiative

Gilles Georges  
Chief Scientific Officer, CAS
Green energy technologies
Why we need them and renewable energy trends

- Dependence on fossil fuels
  - Climate change
  - CO₂ emissions
  - Pollution/ecological consequences
    - SO₂, NOₓ, soot
  - Finite resource
  - Energy dependence on foreign resources
Energy Carriers
Solution for fluctuation and portability of renewables

- Are a fuel or system
- Store energy for future use
- Examples:
  - Fossil fuels
  - Batteries
  - Hydrogen

LIB recycling is a challenge
With high growth in hydrometallurgy and pyrometallurgy

Metals recovered from Li-ion batteries
Recycling of LIBs high commercial value

China and patent publications are leading the way driven by the future potential

Green hydrogen has different challenges

Driven by lack of infrastructure

- **Production**
  - Cost of Catalysts (Pt, Pd)
  - Hydrogen Evolution Reaction

- **Storage**
  - Safety
  - Costs
  - Transportation
  - Materials Based

- **Fuel Cell Utilization**
  - Cost of Catalysts
  - Oxygen Reduction Reaction
China leads green hydrogen publications
Japan in 2nd place and the US comes in 3rd

Publications by Country

Publication Trends by Country

Audience Survey Question

Among the three research topics listed below, which one do you think need more research attention than what it has currently?

• Hydrogen production
• Hydrogen storage
• Hydrogen fuel cells
• Not sure
• Other (Let us know more in the chat!)

* If your answer differs greatly from the choices above tell us in the chat!
Solar Cell and Rechargeable Battery Technologies

Yiying Wu, Ph.D

Department of Chemistry & Biochemistry
The Ohio State University
Columbus, Ohio
Organic-Inorganic Hybrid Perovskite Solar Cells (PSCs)

A: Organic cation, such as \( \text{CH}_3\text{NH}_3^+ \)
M: Metal ion, such as \( \text{Pb}^{2+} \)
X: Halogen ion, such as \( \Gamma \)

Hole transport material (HTM)
Electron transport material (ETM)

In collaboration with Prof. Jing Cao, *J. Am. Chem. Soc.*, 2019, 141, 6345

Large area processing & hole transporting

Morphology control and reduction of defects formation

In collaboration with Prof. Jing Cao, *J. Am. Chem. Soc.*, 2019, 141, 6345

“They created a rechargeable world”
--- nobelprize.org

Critical Elements Scalability

Cite this: RSC Advances, 2012, 2, 7933–7947

www.rsc.org/advances

Addressing the terawatt challenge: scalability in the supply of chemical elements for renewable energy†
Peter C. K. Vesborg* and Thomas F. Jaramillo

An estimate based on 1 TW x 24 hr:
For Pb-acid batteries, need 100 yrs worth of current lead production;
For Li-ion batteries, need 160 yrs worth of current lithium production;
What % of the world electricity generation comes from renewable energy in the year of 2020?

• 2%
• 10%
• 29%
• 40%

* If your answer differs greatly from the choices above tell us in the chat!
Role for hydrogen in future low-carbon energy systems: insights from systems modeling

Dharik S. Mallapragada

ACS-CAS presentation

May 4, 2022
There have been previous waves of interest in the hydrogen economy, so what might be different this time?

Fuel cell cars sold and leased in US as of December 1, 2021: 12,187

Recent renewed interest in H\textsubscript{2} or H\textsubscript{2}-derived carriers appears to focus on enabling decarbonization of across multiple end-uses where direct electricity use may be challenged

Department of Energy vision for H\textsubscript{2} use in low-carbon system\textsuperscript{1}

Recent U.S. government initiatives:
- Hydrogen Earthshot $1/kg "clean hydrogen" by 2030
- Defining "clean" hydrogen \(\leq 2\text{kgCO2eq/kg H2}\)
- US DOE hydrogen hubs - $8 Billion
- US Nuclear fleet credit program

Regional initiatives:
- California Low-carbon fuel standard

\textsuperscript{1} https://www.energy.gov/eere/fuelcells/h2scale
H₂ value proposition influenced by its interactions with other energy related infrastructure (electricity, gas, CO₂) as well as its potential uses across multiple sectors

**Sectoral interactions with multiple energy vectors**

- How does sector coupling influence least-cost infrastructure outcomes?
- What are the implications for the design of emerging low-carbon technologies?
- With increased inter-dependency, what are the trade-offs between cost-saving and system resilience and reliability

**Questions of interest**

Impact of sector coupling - flexible electrolysis + H₂ storage reduces role of dispatchable low-carbon generation (gas) and battery storage in power sector under carbon constraints

**Coupled approach**

- Min CAPEX + OPEX + Emission Cost
- Power System
- H₂ to Power
- Hydrogen infrastructure
- Transportation energy demand

**Decoupled approach**

- Min CAPEX + OPEX + Emission Cost
- Power System
- Baseline electricity demand
- Transportation energy demand

**Power system generation change due to sector coupling**

- More generation in coupled approach

Northeast case study, $300/kW electrolyser capital cost

Systems analysis can support innovation in emerging H₂ technologies for production, storage and transport: liquid H₂ vs. liquid organic hydrogen carriers

### Liquid organic hydrogen carriers (LOHC)

- **H₂-rich molecule (methylcyclohexane)**
- **Heat**
- **Hydrogenation**
- **Dehydrogenation**
- **H₂-lean molecule (toluene)**

### Liquid H₂ (LH₂)

- **Electricity Input**
- **Liquefaction**
- **Liquid Storage**
- **Evaporation**
- **Boil-off losses**

Some important areas for hydrogen deployment at scale needing further research

- **Scalability and durability of electrolysis systems under dynamic operation**
  - Catalyst loadings for currently PEM electrolyzers: 700 kg Ir/GW $\rightarrow$ 9 X global production to meet projected electrolyzer deployment in 2030 a net-zero scenario
  - Degradation under dynamic operation

- **Thermo-electrochemical methane reforming for compressed H₂ (and capture ready CO₂) production**

- **Methane pyrolysis**

- **Advances in low-carbon natural gas based H₂ production**
  - Reducing methane emissions from gas supply chain
  - Improving capture rate, co-product generation, process flexibility

Hydrogen storage in geological formations (e.g. salt deposits, depleted oil and gas reservoirs) to provide large-scale energy storage

- 5 facilities existing today use salt deposits

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3. https://arts-e.energy.gov/sites/default/files/1%20Marc%20Von%20Keitz..pdf

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1. Salt deposits and used/unused known salt domes in the US
Thank you

dharik@mit.edu
@dhariksm

Relevant publications
Can Industrial-Scale Solar Hydrogen Supplied from Commodity Technologies Be Cost Competitive by 2030
Decarbonization synergies from joint planning of electricity and hydrogen production: A Texas case study
Sector coupling via hydrogen to lower the cost of energy system decarbonization
Hydrogen Supply Chain Planning with Flexible Transmission and Storage Scheduling

Q&A
Please submit your questions in the "Questions" Panel.
Continue exploring
To learn more about green hydrogen’s emerging trends

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