
May 23, 2019
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• CMU Energy Fellows program
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Engage with Industry and the Public Sector
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• House Centers for specific interest areas
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• High-Performance Renewables
• Transportation Energy, EVs, Infrastructure, and Electrification
• Energy Storage, Batteries, Fuel Cells, and Internet of Things
• Decarbonization, Carbon Capture, Sequestration and Utilization

Resource Efficiency, Policy, and Analysis
• Efficiency of Traditional Fuels and Resource Recovery
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• Enhanced Water Resources

High-Tech Energy and Computational Solutions
• Grid Modernization, Energy Planning, System Reliability, and Resiliency
• Building Performance, Urban Planning, Design and Analytics
• Machine Learning, AI, Autonomous Vehicles, and Robotics for Energy Systems
• High-Performance Computing and Data Centers
Expert Assessments of Fuel Cell Cost, Durability, and Viability

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Supported by: Alfred P. Sloan Foundation
Fuel cells and DOE targets

Expert Elicitation

Interview

Fuel Cell Vehicle Assessments

Solid Oxide Fuel Cell Assessments
Outline

Fuel cells and DOE targets

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Solid Oxide Fuel Cell Assessments
What is a fuel cell?

Fuel cells generate electricity

- Efficient, quiet: No combustion or moving parts (uses an electrochemical reaction)
- Scalable: Produce energy for small and large applications
Research focus: PEMFCs and SOFCs

- Proton exchange membrane fuel cells (PEMFCs): Low-temperature (<100 °C), fast start-up, compact
- Energy security and environment (hydrogen)
- Market for FCEVs: Toyota, Honda, Hyundai (3–5 minute refueling, 350+ mile range) (Honda, 2019)

- Solid oxide fuel cells (SOFCs): Temperatures > 600 °C, power and heat, fuel-flexible
- Continuous, clean, distributed power (Bloom Energy)
- “Bridge” from fossil to low-carbon fuels; new jobs
PEMFC challenges: Cost and durability

“Cost and durability are the major challenges to fuel cell commercialization.” (DOE, MYRD&D Plan, 2017)

▪ **Cost** = System cost/power output ($/kW)

▪ **Status (2017)** = $53/kW (James et al., 2017)

▪ **Target** = $30/kW (compete with ICEVs) (DOE, 2017)

▪ **Durability** = Time until 10% power reduction

▪ **Status (2015)** = 2,500 hrs (DOE, 2017)

▪ **Target** = 8,000 hrs (150,000 miles) (DOE, 2017)

Excludes H₂ storage, power electronics, electric drive, battery
SOFC challenges: Cost and degradation rate

“...efficient, low-cost electricity with intrinsic carbon capture capabilities....” (Vora, SOFC Project Review Meeting, 2018)

- **Cost** = system cost/power output ($/kW)
- **Status (2013)** = $12,000/kW (Iyengar et al., 2013)
- **Target** = $900/kW (compete with internal combustion engines and microturbines) (Vora, 2018)

- **Degradation rate** = Reduction in stack voltage
- **Status (2017)** = 1–1.5%/1,000 hrs (Vora, 2018)
- **Target** = 0.2%/1,000 hrs (Vora, 2018)
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Research questions

- What are the current and anticipated **future costs** and **durability** of fuel cell technologies?
- What are the **major barriers** to improving cost and performance?
- How much **RD&D funding** and what **policies** are needed?
Expert elicitation

- **Formal** and **systematic** procedure for gathering experts’ assessments

  - Mitigate biases and **heuristics**
  - 95% CI
  - Lower bound
  - Best guess
  - Upper bound

- **Previous studies** used expert elicitation to assess:

  - Solar: (Curtright et al., 2008)
  - Biofuels: (Fiorese et al., 2013)
  - Wind: (Wiser et al., 2016)
  - Gas turbines: (Bistline et al., 2014)
  - Carbon capture: (Baker et al., 2009)
  - Nuclear: (Abdulla et al., 2013)
Project timeline

2016
*Project launch*
- Literature review
- Protocol development

2017
*Individual interviews*
- 64 interviews (in-person, phone)
  - PEMFC: 18 yrs experience
  - SOFC: 19 yrs experience

2018
*Elicitation workshops*
- Group discussion
  - 16 PEMFC experts
  - 21 SOFC experts

2019
*Dissemination*
- CMU Energy Week
- Policy Briefing
Outline

- Fuel cells and DOE targets
- Expert Elicitation

Fuel Cell Vehicle Assessments

Solid Oxide Fuel Cell Assessments
Cost and durability targets met by 2035–2050

- **Cost:** 51% of experts said target met by 2050 (median = $30/kW)
- **Durability:** 48% said target met by 2050 (median = 7,500 hrs)

(Whiston et al., 2019a)
# Pt loading, instability, and sintering are barriers

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<td>Gas diffusion layer cost</td>
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(Whiston et al., 2019a)

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(Whiston et al., 2019a)

- **Reducing cost:** Platinum loading, bipolar plate manufacturing, coating cost
- **Improving durability:** Pre-leaching, annealing, particle size
Governmental actions to advance FCEV viability

- **Hydrogen storage**: Compressed gas viable in 2035; 44% experts anticipated material storage by 2050
- **Refueling stations**: 500 stations by 2030 and 10,000 by 2050
Outline

1. Fuel cells and DOE targets
2. Expert Elicitation
   - Interview
3. Fuel Cell Vehicle Assessments
4. Solid Oxide Fuel Cell Assessments
Cost and degradation rate targets met by 2035–2050

- **Cost:** 25% of experts said target met by 2035; 52% said target met by 2050 (median = $800/kW)

- **Degradation:** 36% said target met by 2035; 58% said target met by 2050 (median = 0.2%/1,000 hrs)
Stack cost and chromium poisoning considerable

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(Whiston et al., 2019b)

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<td>Ni particle agglomeration</td>
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<td>Sulfur poisoning</td>
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(Whiston et al., 2019b)

- **Reducing stack cost**: Operating temperature, production volume
- **Chromium poisoning**: Chromium getters, interconnect coatings
Experts recommended **$70 million (median)** in total funding for FY 2018

Experts identified **medium** and **small-scale** applications as the most favorable entry-level markets
Conclusions

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