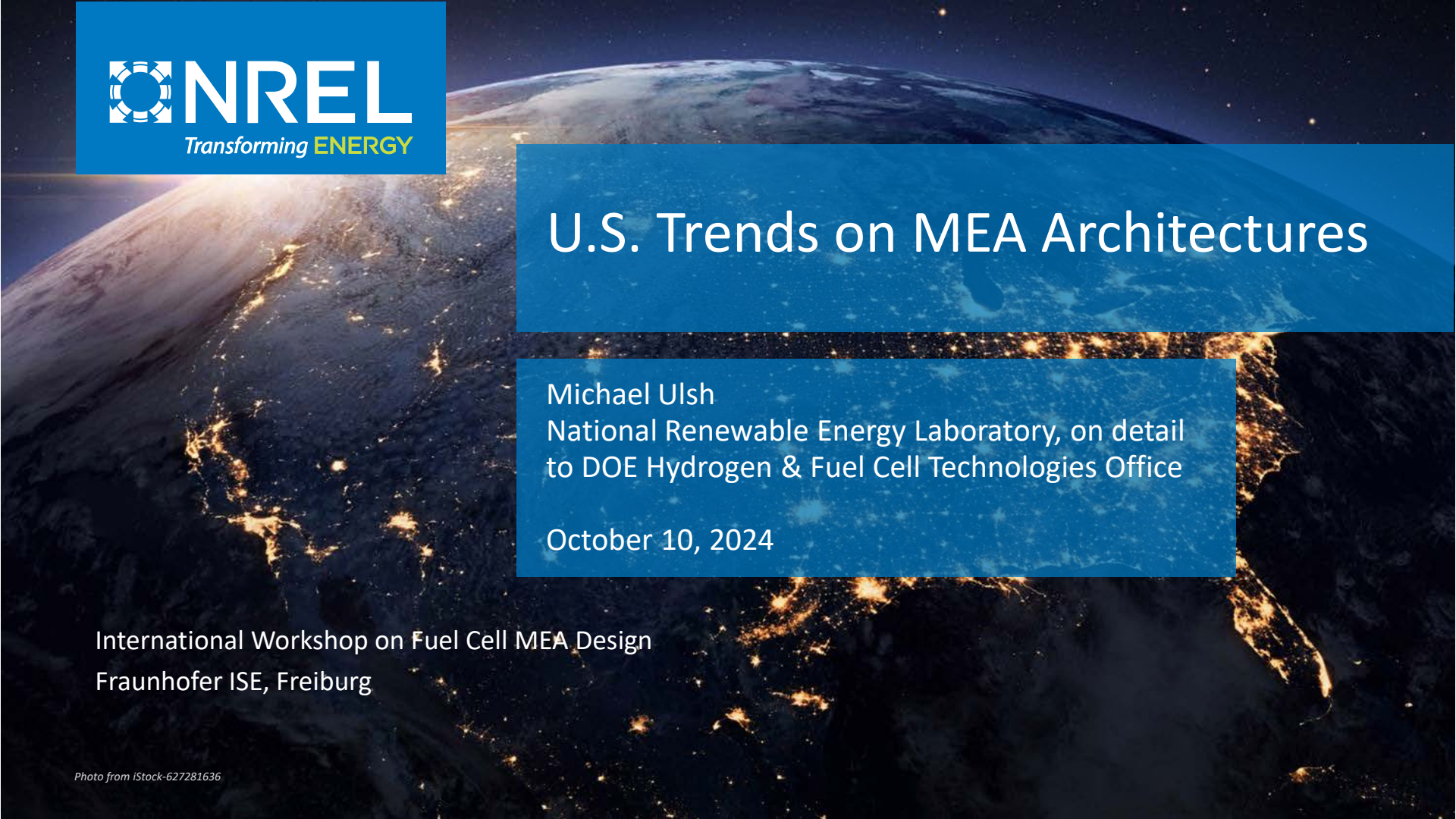


U.S. Trends on MEA Architectures

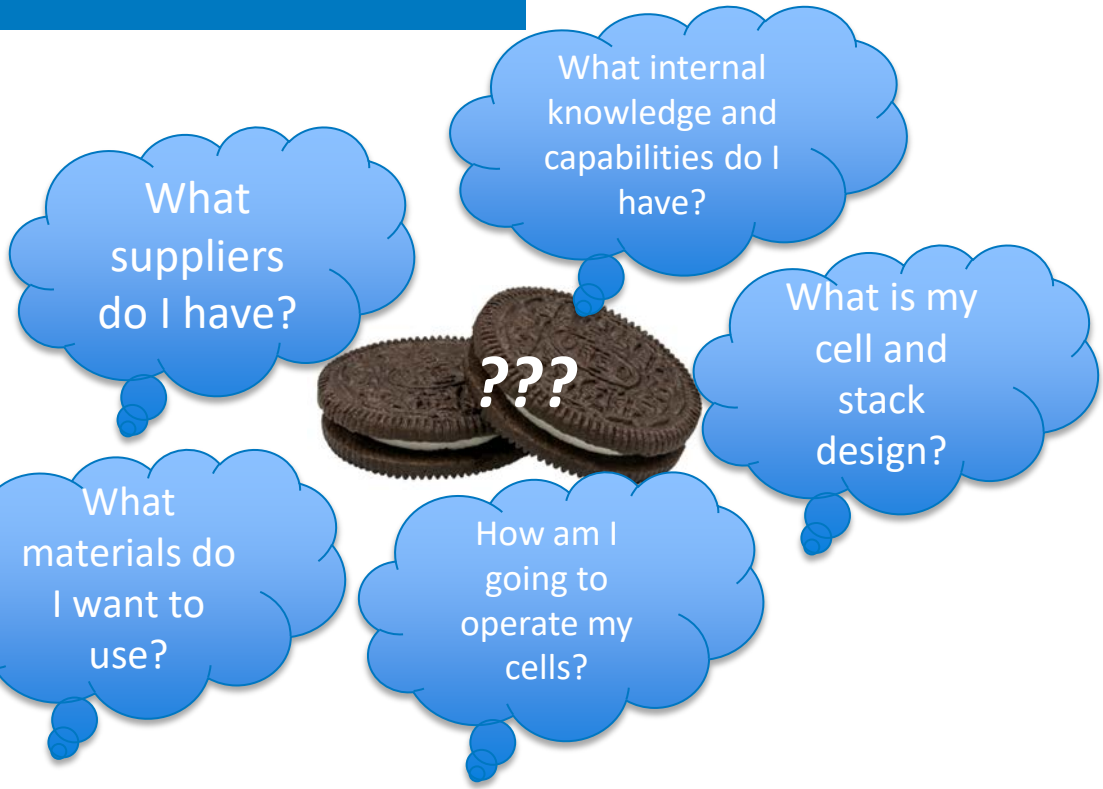
Michael Ulsh
National Renewable Energy Laboratory, on detail to DOE Hydrogen & Fuel Cell Technologies Office

October 10, 2024

International Workshop on Fuel Cell MEA Design
Fraunhofer ISE, Freiburg

Photo from iStock-627281636

Overview



Industry status → **Novel pathways** → **Challenges**

Architecture Commentary

CCM

- Probably ideal due to critical membrane-electrode interface
- Difficult due to membrane mechanical stability when wetted
- Precision tension controls needed

Decal

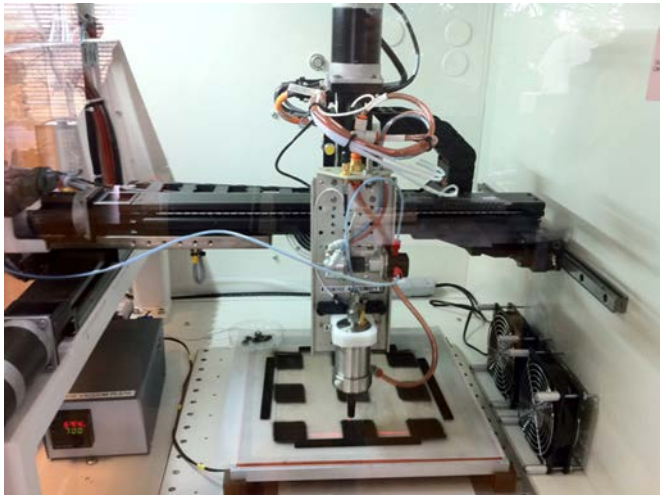
- Well-known
- Low-risk vs higher cost
- In-line lamination not well understood
- Ink needs to transfer but also provide good electrode

GDE

- Possibly easiest from coating perspective
- Possible to achieve comparable performance to CCM
- Must ensure good membrane-electrode interface

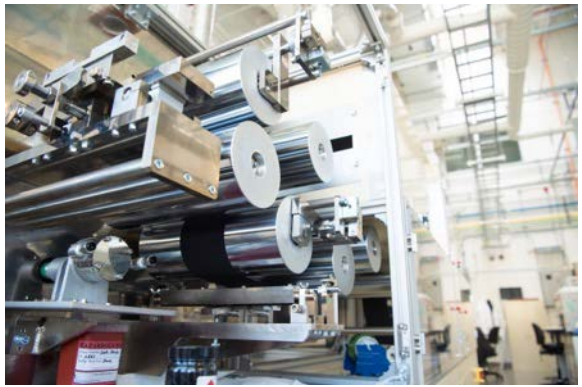
Lab Fabrication

- In the U.S., ultrasonic spray is the typical R&D scale fabrication technique
- Can fabricate decal, CCM, GDE
- Leads to layers coated as multiple (~6-20) very thin layers that are deposited and dried prior to the next layer
- Fabrication time ~O many minutes



Scaled Fabrication

- Efforts focused on R2R or other continuous or high-volume capable methods
- Typical R2R coating and drying methods, such as slot die or gravure coating, appear at first glance to be able to reproduce lab-scale electrodes, in terms of performance and durability
- Fabrication time ~O second (or less)



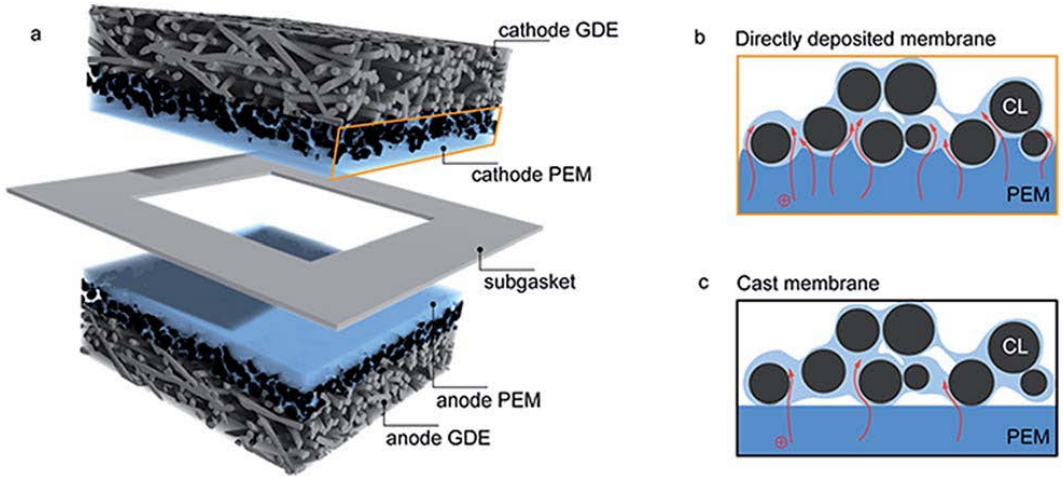
U.S. Industry Status

- No consensus at this point on the way to build a 5-layer MEA
  - All of them are being used and pursued for scale-up
- Why?
  - Different combinations of selected catalyst, ionomer, membrane, and diffusion media may be differently amenable to one or another architecture, or
  - Different process expertise (e.g., via acquisition) leads to preference of one or another, or
  - Stack/system design and operational strategies could lead to one or another architecture being optimal

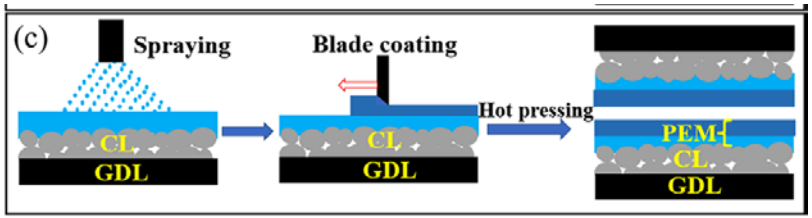
Novel Pathways

Direct jet/spray +membrane structures

- Several ways to make
- Optimize interfaces and interactions
- How to scale up



Breitwieser et al., AdvEnergyMater, 2017; Klingele et al., JMaterChemA 3, 2015

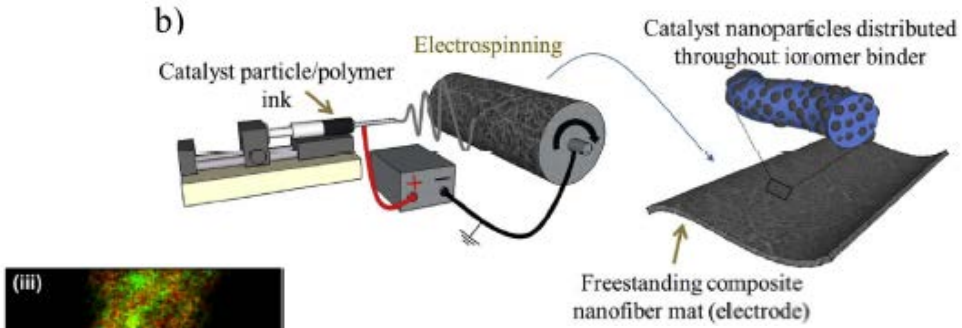


Xing et al., FuelCells 23, 2023

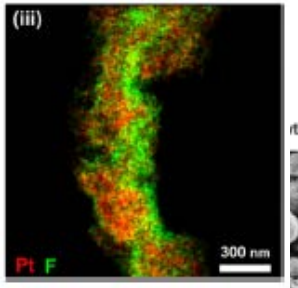
Novel Pathways

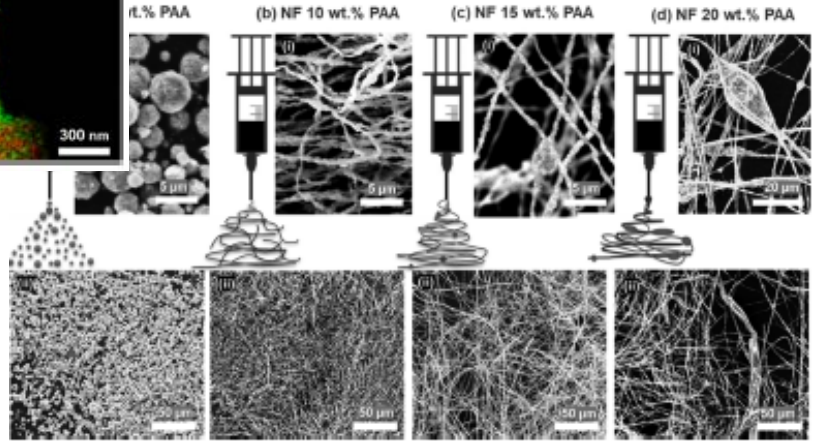
Electro-spun structures

- Novel incorporation of catalyst and ionomer
- Design porosity
- Scaled for certain products (filtration), but more work needed to develop and validate for MEA structures



Waldrop et al., CurrentOpinionElectrochem 21, 2020



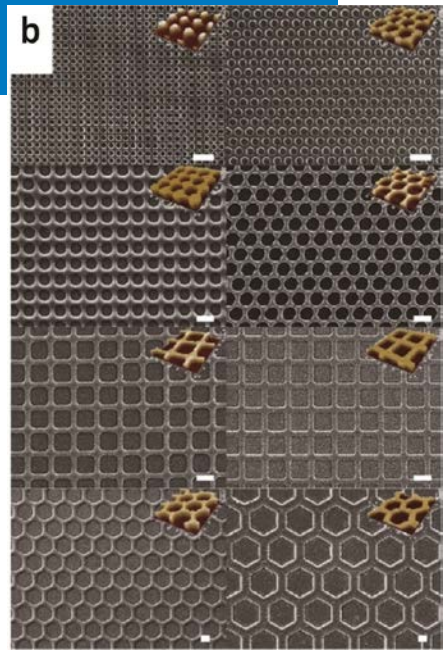


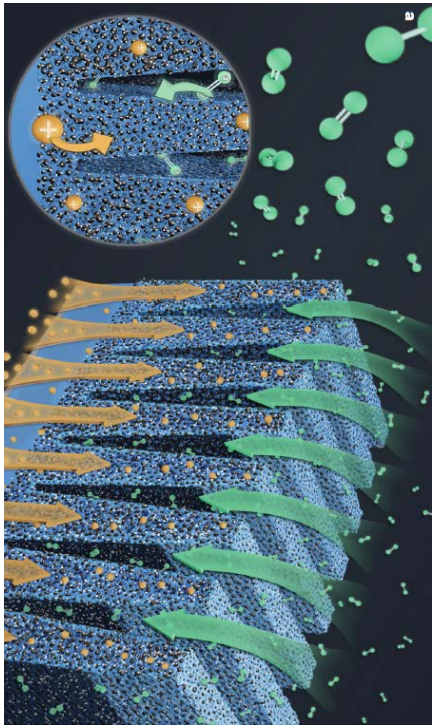
Kabir et al., ACSApplEnergyMater 4, 2021

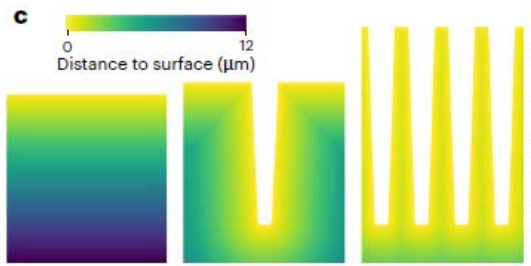
Novel Pathways

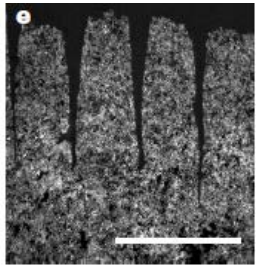
Micro-structured electrodes/membranes

- Novel control of transport
- Fabricated at lab scale with complicated methods
- How to scale up







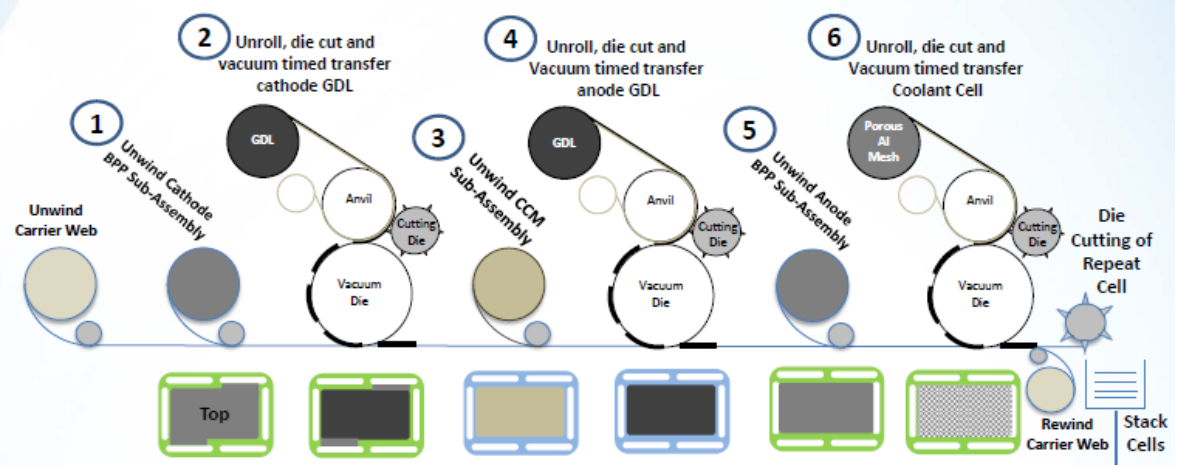


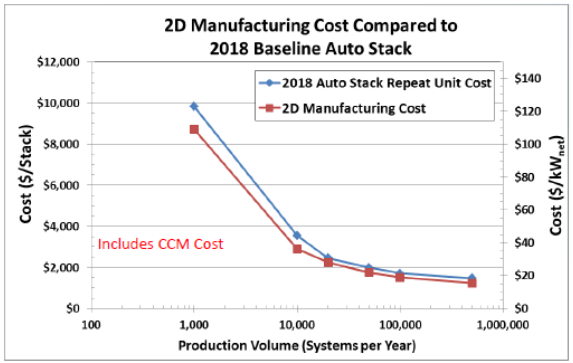
Yang et al., ElectrochemEnergyRevs 7(9), 2024; Lee et al., NatureEnergy, 2023

Novel Pathways

Roll-to-piece (R2P) methodologies

- Several similar concepts
- Equipment being designed and built
- Need at-scale demonstration and validation





Huya-Kouadio et al., Fuel Cell Seminar & Energy Exposition, 2019

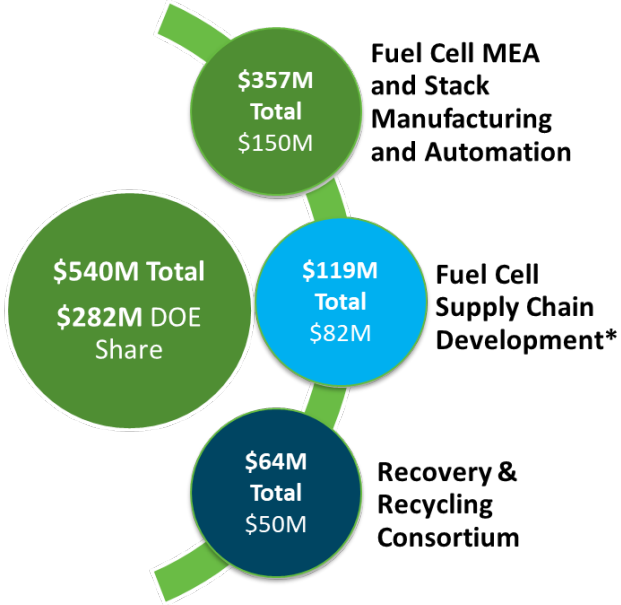
Challenges

- Co-optimization of catalyst inks for process-ability and optimal electrode structure
- Optimization and validation of high-volume equipment
- Optimal integration of new materials into MEAs
  - PFAS-free materials in all components
  - PGM-free catalysts
- Development of new at-scale processes for novel structures

The solutions created and the experience gained in all these efforts will impact decisions about MEA architecture going forward

Relevant Activities in the U.S.

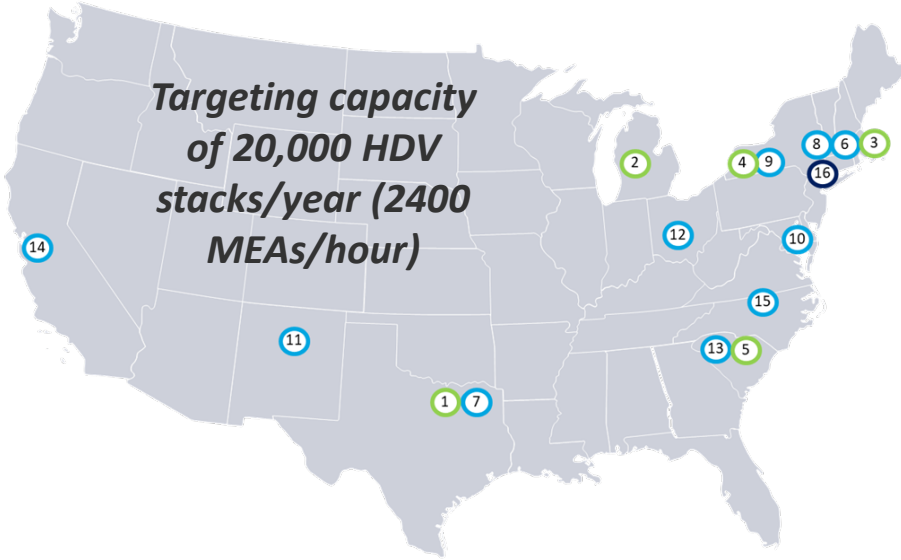
Fuel cell manufacturing, supply chain, and recycling projects from BIL



1. Ballard Power Systems
2. General Motors
3. Nuvera Fuel Cells
4. Plug Power
5. Robert Bosch

6. AvCarb Material Solutions
7. Ballard Power Systems
8. Cabot Corporation
9. Ionomr Innovations
10. Materic
11. Pajarito Power
12. pH Matter
13. Robert Bosch
14. Robert Bosch
15. Saueressig

16. American Institute of Chemical Engineers



**GDLs, Catalysts, Bipolar Plates, Non-PFSA Membranes*

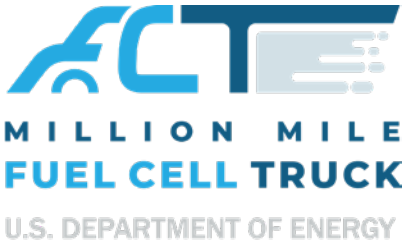
Papageorgopoulos, Hydrogen Program Annual Merit Review, 2024

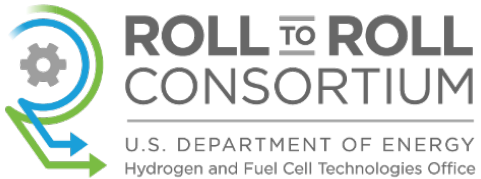
Enabling fuel cell manufacturing of 14 GW/yr

https://www.energy.gov/articles/biden-harris-administration-announces-750-million-accelerate-clean-hydrogen-technologies

Relevant Activities in the U.S.

- M2FCT Consortium studying materials and MEA integration toward DOE efficiency and durability targets for HDV fuel cells
  - New catalysts, ionomers, structures may influence decisions on an architecture
- R2R Consortium studying process science fundamentals and cutting-edge processes for electrodes and membranes
  - Process-based understandings could influence decisions on an architecture





Conclusion

- No consensus on optimal MEA architecture
- Many parameters impact decisions – new activities will contribute to increased understanding and validation
- Novel structures may make selection clearer in the future
- New materials, to reduce cost, reduce supply chain or environmental concerns, are still in development in terms of reaching target performance, and little work done to date to understand optimal integration into MEAs that may clarify an optimal architecture

Thank You

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