New Generation of Fuel Cells: Fast, Furious and Flexible

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Increasing demand for electrification of transportation

- Economics: fewer oil imports, higher efficiency
- Emissions reduction, especially while idling
- More power for computing, entertainment, auxiliary power
- Lower noise, thermal signature
- More fun to drive…

Electrification increasingly benefits transportation

https://youtu.be/1qFV5i8tBhs

Pros and Cons of Current Options

Battery Electric Vehicle (BEV)

85 kWh battery
~265 mi.

Fuel Cell Vehicle (FCEV)

113 kW FC
1.6 kWh battery
~312 mi.

	BEV	FCEV
Strengths	• **High round trip efficiency** • **High power** • Grid connected infrastructure • Short range, fleet operations	• **High energy density – large driving range** • **Fast charging time comparable to ICE** • Power and energy separated • Long range, heavy duty
Weaknesses	• **Limited range** • **Recharging time** • **Lithium battery safety** • Infrastructure (urban) • **Battery cost**	• **Infrastructure** • **Less mature technology** • **Lower round trip efficiency** • Hydrogen safety • **Fuel cell cost**

Overdesigned for energy **Overdesigned for power**

Solution: Hybridization with Direct Liquid Fuel Cells

Combination of a plug-in EV with fuel cell range extender could be the optimal solution

- Smaller battery provides power for acceleration at low cost
- Fuel cell stack provides energy for desirable driving range
- Liquid fuels allows for smaller tank sizes and using existing infrastructure

Critical needs

- **Fast**: short time for start-up/shut down
- **Furious**: high power density
- **Flexible**: capable to use a variety of sustainable liquid fuels

Fuels for Direct Liquid FCHEVs

Fuel	B.p., deg C	Energy density, kWh/L	Driving range (miles)*	
			Primary (16 gal)	Extender (8 gal)
Synthetic gasoline	69-200	9.7	682	307
Biodiesel	340-375	9.2	581	291
Methanol	64.7	4.67	554	249
Dimethyl ether (DME)	-24	5.36	**632**	**284**
Ethanol	78.4	6.30	**750**	**338**
Formic acid (88%)	100	2.10	272	123
Ammonia	-33.3	4.32	**470**	**212**
Hydrazine hydrate	114	3.40	418	188
Liquid hydrogen	-252.9	2.54	259	116
Compressed hydrogen (700 bar)	gas	1.55	158	71

* - Fuel cell efficiency 55%, battery round trip efficiency 90%, energy consumption 0.3 kWh/mile

Trailblazers

12 kW hydrazine hydrate fueled PGM-free AEMFC by Daihatsu Motor Co. www.electrical-cars.net

3kW diesel fueled SOFC APU by Delphi www.7ms.com/fct/

3kW diesel fueled SOFC APU by AVL, Eberspächer, Topsoe Fuel Cell, Volvo and Forschungszentrum Jülich http://www.desta-project.eu/partners/

5kW ethanol fueled SOFC range extender (375+miles) by Nissan www.greencarcongress.com

Viking Lady 250 kW methanol fueled Convion SOFC APU www.lngworldshipping.com

90kW liquid H2 FC APU for A320 aircraft by Airbus www.asdreports.com

Potential Requirements: Feedback Sought!

Component Requirements

- Power density comparable with hydrogen fuel cells
- Combining electrocatalysis and fuel reforming catalysis working below 550 C with no coking issues
- Non- or extremely low Pt catalysts adaptable to different liquid fuels
- No membrane crossover

System Requirements

- Power output > 3 kW/L
- Start up time less than 3 minutes
- 5,000 thermal cycles with degradation less 5%
- Internal fuel reforming
- Fuel flexibility

Potential Applications: Niche to Broader Markets

Military: unmanned vehicles

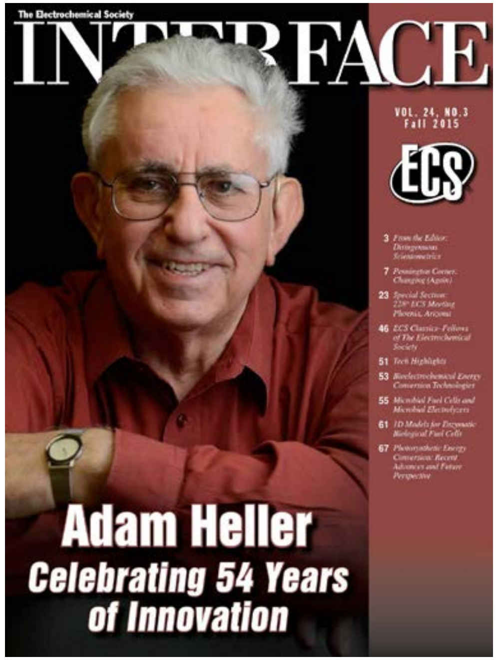
Heavy duty, long range auxiliary power units (APUs)

Range extenders

Airplane APUs

Primary propulsion

Quotes of the day



Adam Heller (a prominent electrochemist in interview to ECS, 2015)
“Pretty soon—on a historical scale of 100 years—there’s no question in my mind that we will drive **liquid fuel-based fuel cell powered cars.”**

Let’s make it in 10 years!

arpa·e
CHANGING WHAT'S POSSIBLE