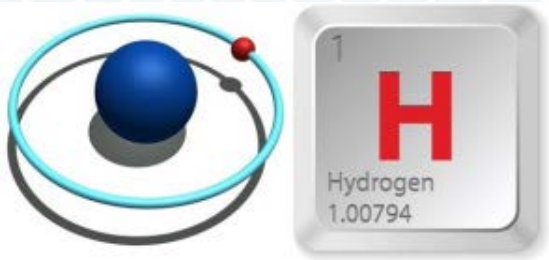
Getting From Here to There

Moving to a Hydrogen Economy



Domenico Grasso
Provost & Professor of Engineering

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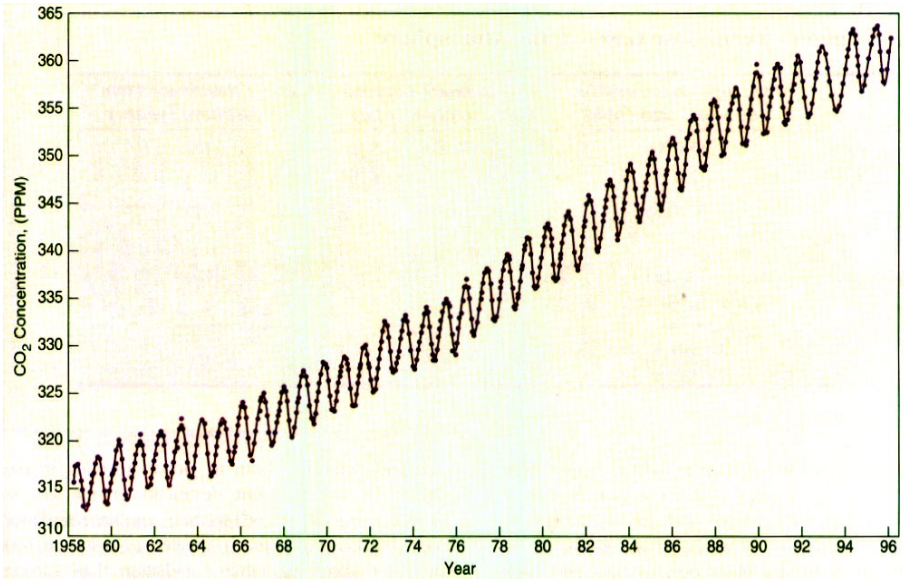
[1]Professor of Chemical Engineering
[2]Professor of Mechanical Engineering

University of Delaware
April 21, 2016

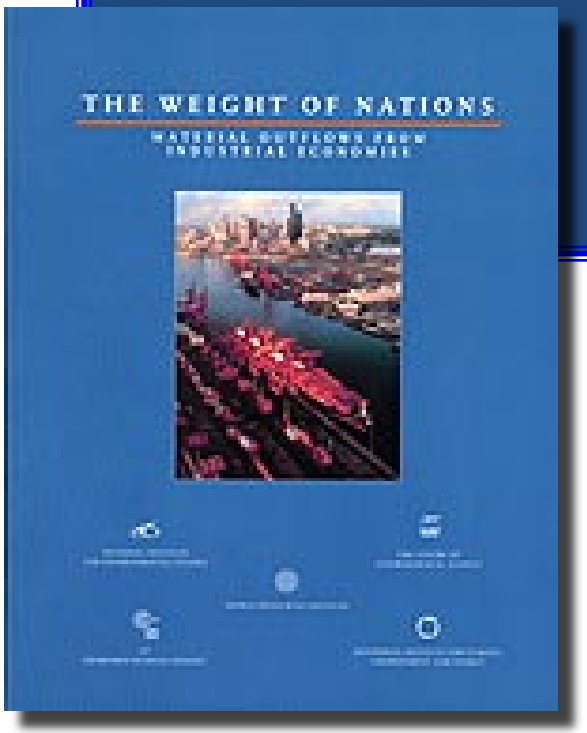
CO_2 Emissions

Released (10^9 ton/year)		Removed (10^9 ton/year)	
Combustion (HCs)	6.0	Bio-uptake (plants)	1.2
Deforestation	1.2	Uptake by oceans	2.5
Sum:	*7.2*	*Sum:*	*3.7*

Accumulation: 3.5 x 10^9 ton/year



Austria
Germany
Japan
Netherlands
United States



Selected Key Findings:

•Between ½ and ¾ industrial inputs are returned to the environment as waste within ***1 year!***

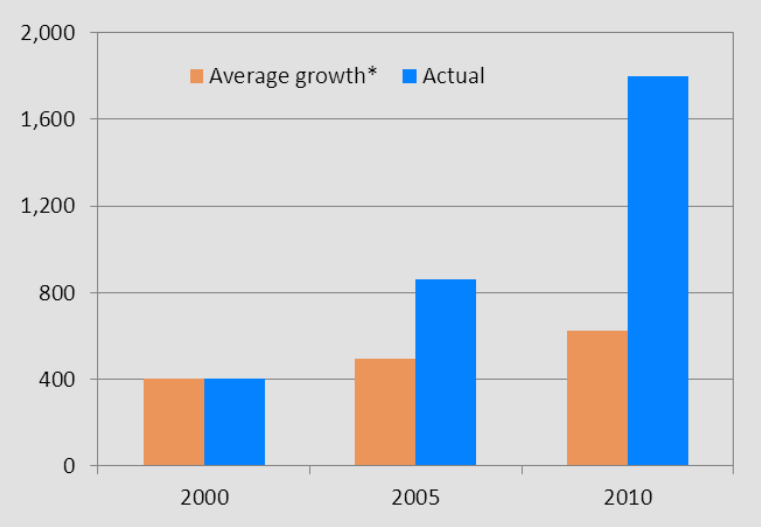
•Total annual ***per person*** material outputs to the environment:

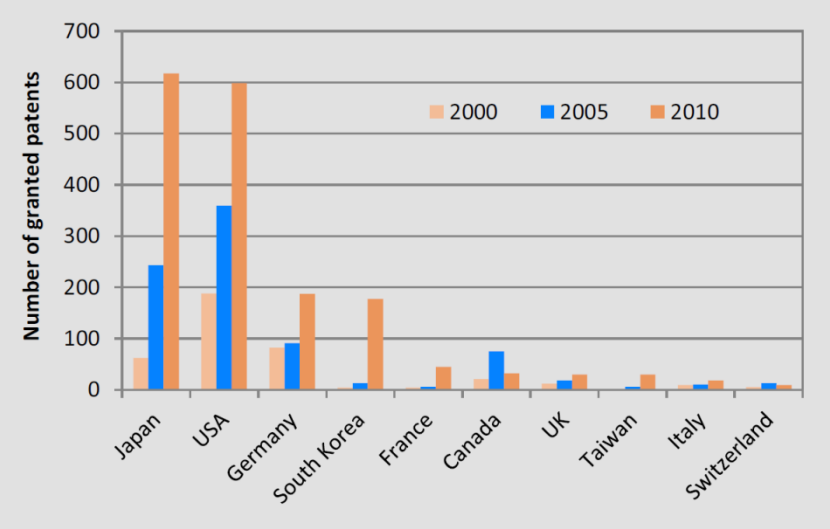
Japan	21 metric tons
United States	86 metric tons

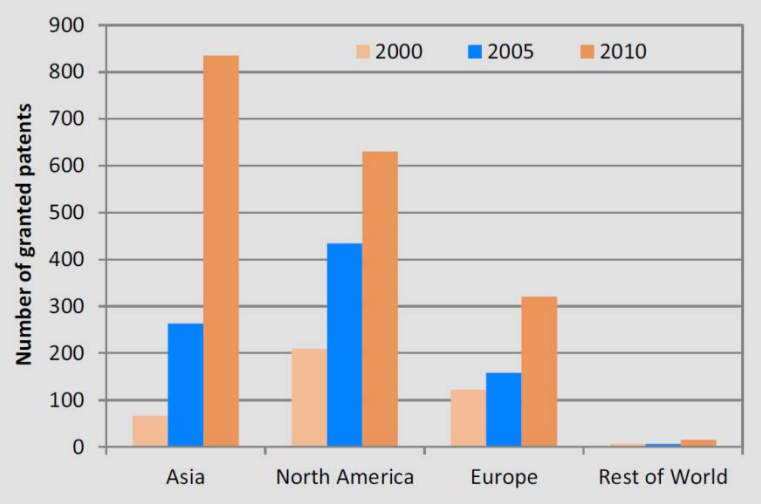
Pros and Cons of Fuel Cells

Advantages of Fuel Cells	1. Higher efficiency compared to IC engines
	2. Zero emissions at the point-of-use
	3. No moving parts in the stack, so quieter
Challenges Facing Fuel Cells	1. Cost (materials, labor, economy of scale)
	2. Durability (membrane, catalyst)
	3. Lack of H2 Infrastructure: H2 is difficult to produce, transport, and store

Fuel cell patents granted







Rank	2010 Applications	
1	Toyota	381
2	Panasonic	141
3	UTC[a]	118
4	Honda	103
5	General Motors	103
6	Samsung	79
7	Daimler	75
8	Toshiba	61
9	Nissan	52
10	Sony	52

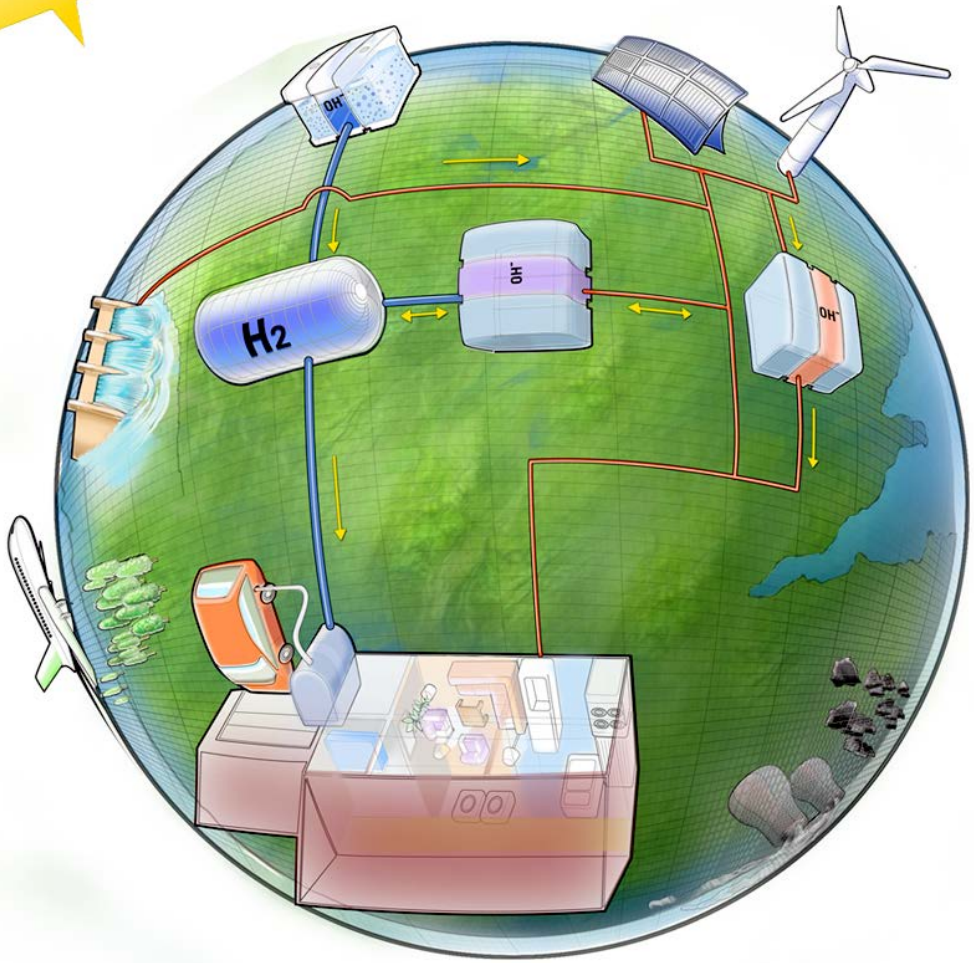
The 2011 Fuel Cell Patent Review, Fuel Cell Today

Current fuel cell car prototypes

Vehicle	Year Shown	Fuel Cell Size/Type	Range (km)	Fuel Type
Audi Q5 HFC	2010	98 kW PEM	N/A	CH_2 (700 bar)
Daimler EcoVoyager	2008	45 kW PEM	483	CH_2 (700 bar)
Daimler Mercedes-Benz B-Class F-Cell	2009	100 kW PEM	385	CH_2 (700 bar)
Fiat Panda	2007	60 kW PEM	200	CH_2
GM Provoq	2008	88 kW PEM	483	CH_2 (700 bar)
GM HydroGen4/Equinox	2007	93 kW PEM	320	CH_2 (700 bar)
Honda FC Clarity	2007	100 kW PEM	386	CH_2 (350 bar)
Hyundai Tucson ix	2011	100 kW PEM	650	CH_2 (700 bar)
Intelligent Energy Black Cab	2011	30 kW PEM	400	CH_2 (350 bar)
Kia Borrego/Mojave	2008	115 kW PEM	685	CH_2 (700 bar)
Kia Sportage II	2008	100 kW PEM	328	CH_2 (350 bar)
Morgan LIFEcar	2008	22 kW PEM	402	N/A
Nissan X-Trail FCEV	2008	130 kW PEM	N/A	CH_2 (700 bar)
Suzuki SX4-FCV	2008	80 kW PEM	250	CH_2
Toyota FCV-R	2011	N/A	700	CH_2 (700 bar)
Toyota FCHV-adv	2008	90 kW PEM	830	CH_2 (700 bar)
VW Passat Lingyu	2008	55 kW PEM	300	N/A
VW Tiguan HyMotion	2008	80 kW HTFC	200	CH_2 (700 bar)

http://www.fuelcells.org/info/charts/carchart.pdf

Only vehicles introduced since 2007 are included.



University of Delaware Centers and Institutes

UD Energy Institute

Institute for Energy Conversion
- *Solar power*

Center for Carbon-free Power Integration
- *Wind power*
- *Vehicle-to-grid*

Center for Fuel Cell Research
- *Fuel cells*
- *Solar hydrogen*
- *Lithium-ion batteries*

Center for Catalytic Science & Technology
- *Catalysts for fuel cells, electrolyzers, and flow batteries*

April 9, 2007

November 16, 2009

Bus #	Size	Stack	Batteries	Operation
1	22-ft	20 kW	Ni-Cad	2007
2	22-ft	40 kW	Ni-Cad	2009
3	40-ft	60 kW	Li-Ti	2016

Center for Fuel Cell Research

Active research in:

- Polymer Electrolyte Membrane fuel cells (PEM) – automotive
- Direct Methanol Fuel Cells (DMFC) – portable electronics
- Solid Oxide Fuel Cells (SOFC) – stationary power
- Hydroxide Exchange Membrane (HEM) Fuel Cells

Center for Fuel Cell Research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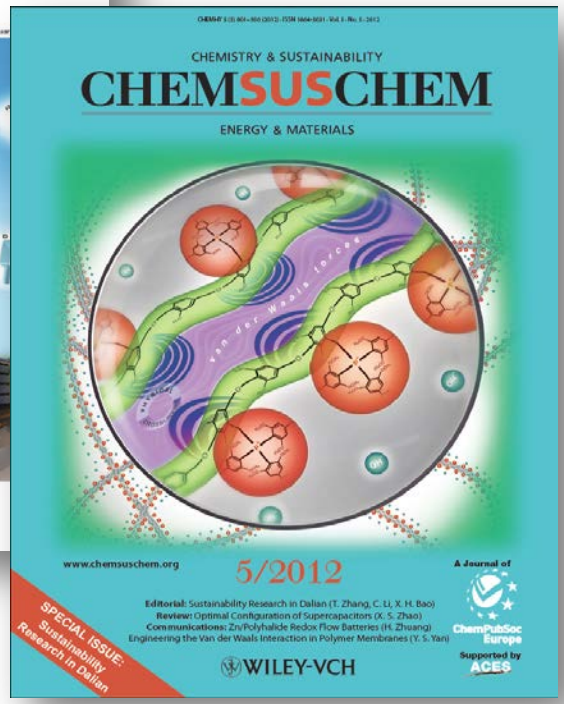
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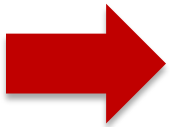
Computing Revolution

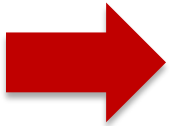
Yesterday – Centralized
Large mainframe computers



Today – Distributed
Networked personal computers

Energy Revolution

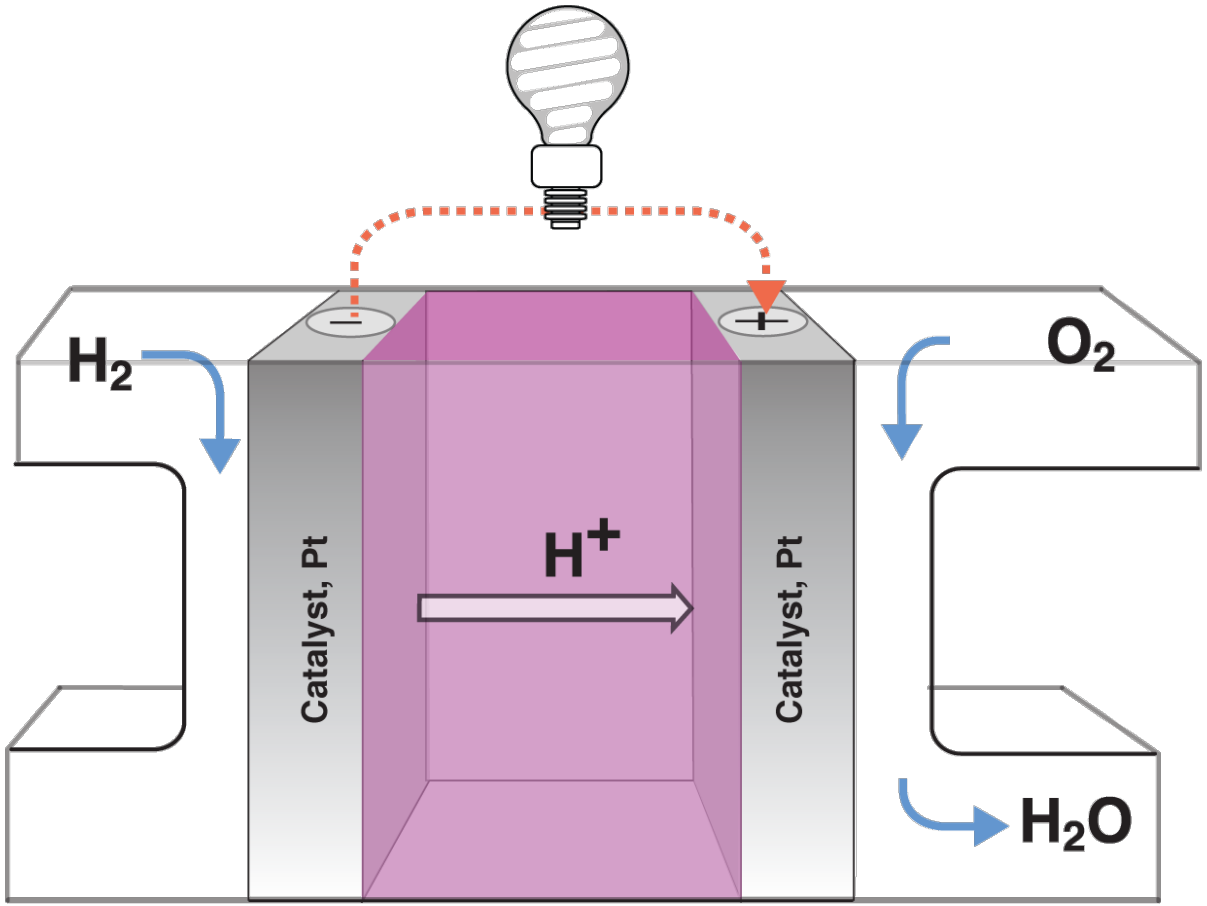
Today – Centralized
Large combustion power plants



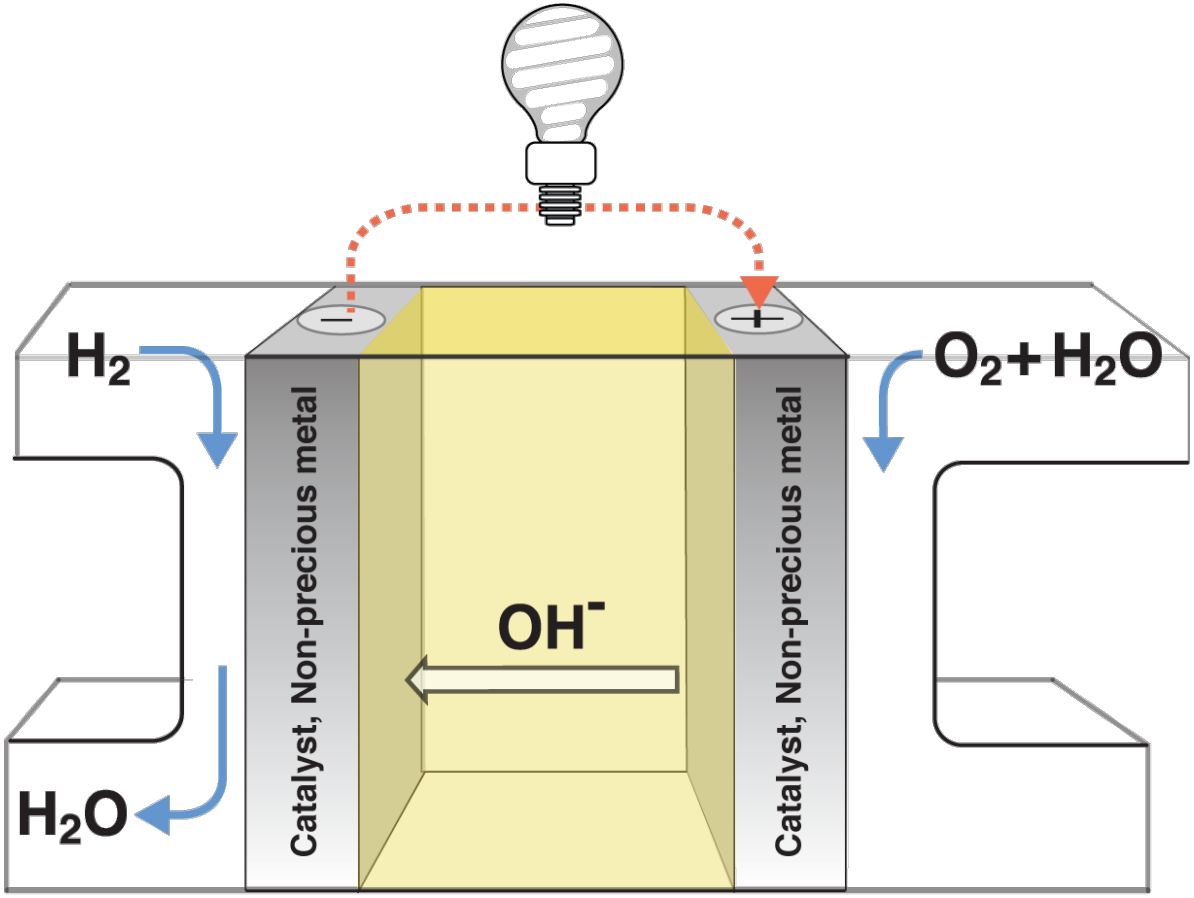
Tomorrow – Distributed
Networked electrochemical devices

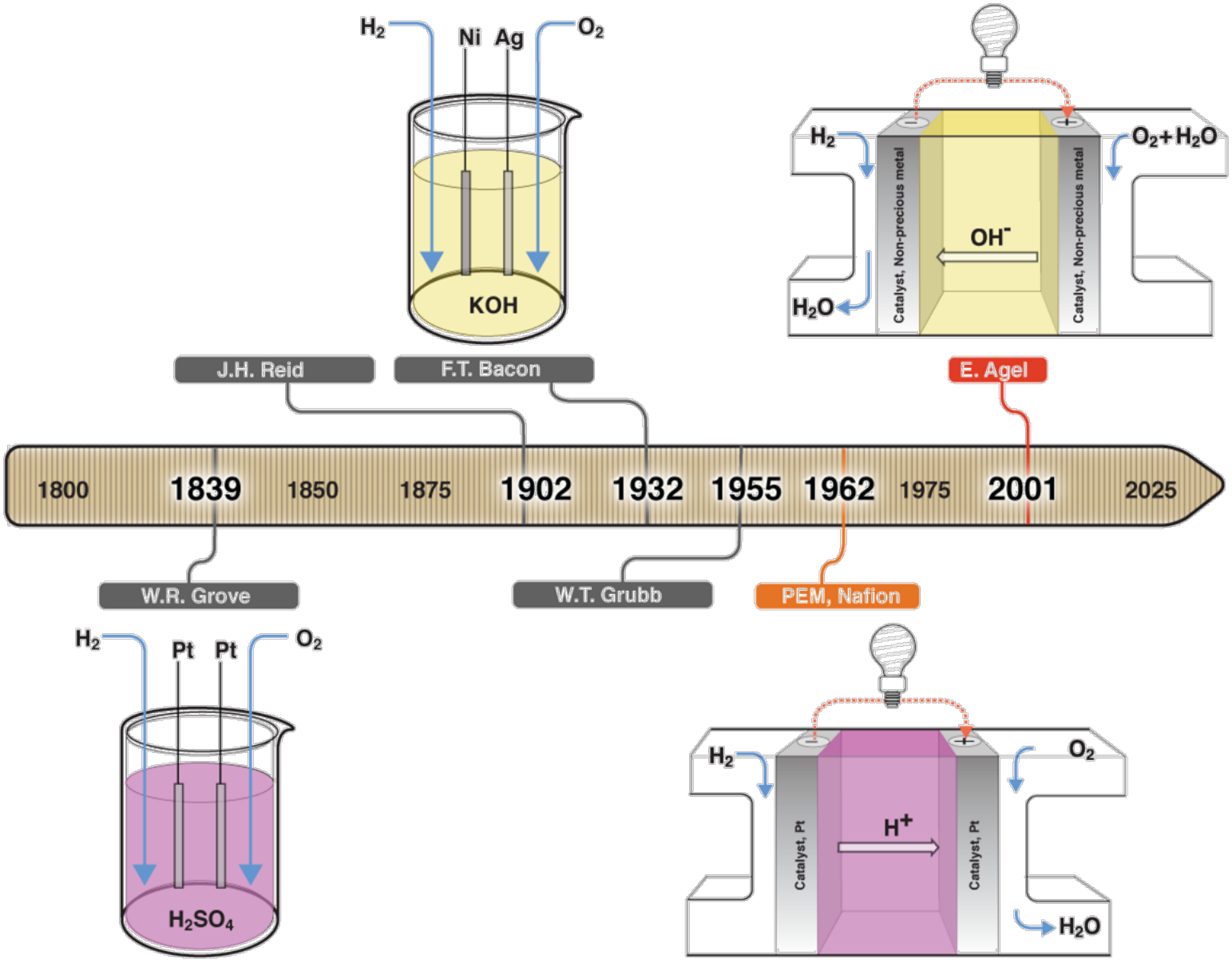
Toyota Mirai – *$57,000*

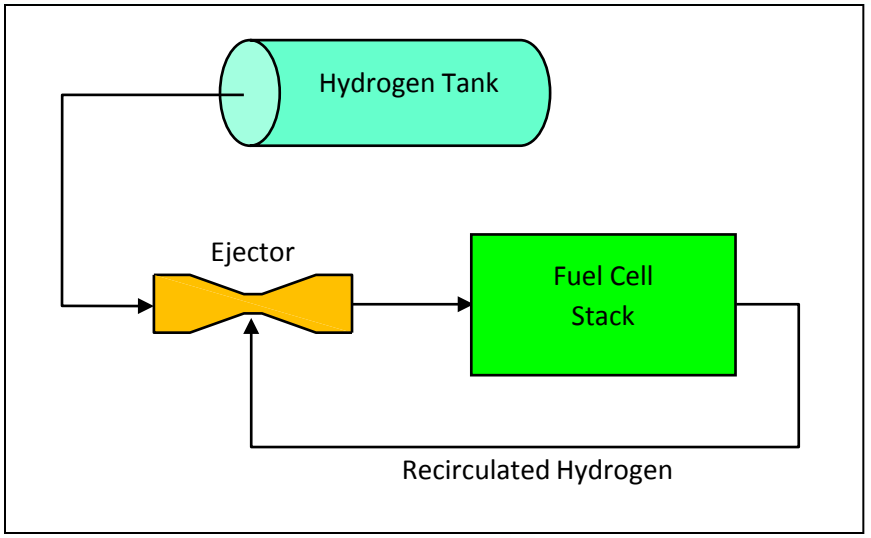
Proton Exchange Membrane Fuel Cell (PEMFC)



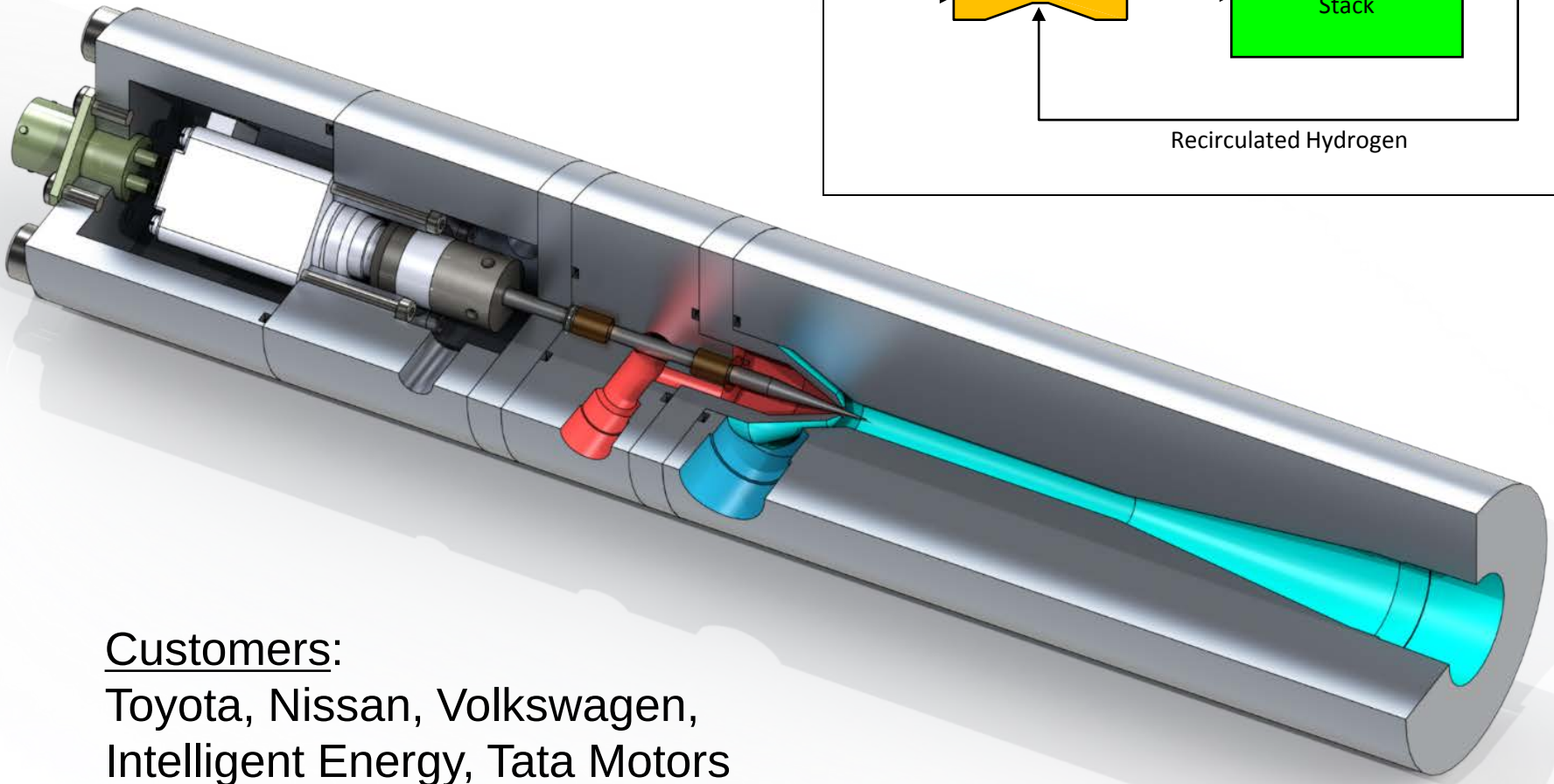
Hydroxide Exchange Membrane Fuel Cell (HEMFC)




H2
Ni
Ag
O2
KOH
H2
O2+H2O
Catalyst, Non-precious metal
OH-
Catalyst, Non-precious metal
H2O
J.H. Reid
F.T. Bacon
E. Agel
1800
1839
1850
1875
1902
1932
1955
1962
1975
2001
2025
W.R. Grove
W.T. Grubb
PEM, Nafion
H2
Pt
Pt
O2
H2SO4
H2
H+
O2
Catalyst, Pt
Catalyst, Pt
H2O



Start-up Company:
Sonijector LLC



Customers:
Toyota, Nissan, Volkswagen, Intelligent Energy, Tata Motors

The best way to predict the future is to create it…