MECA0527: FUEL CELL VEHICLES
Part 2: Applications

Pierre Duysinx
LTAS-Automotive Engineering
University of Liege
Academic year 2021-2022

References

- C.C. Chan & K.T. Chau. Modern Electric Vehicle Technology. Oxford Sciences publications. 2001.
- I. Husain. Electric and hybrid Vehicles. Design Fundamentals. 2nd edition. CRC Press. 2011
- M. Ehsani, Y. Gao, S. Gay & A. Emadi. Modern Electric, Hybrid Electric, and Fuel Cell Vehicles. Fundamentals, Theory, and Design. 2nd edition. CRC Press, 2010
- J. Larminie & A. Dicks. Fuel Cell Systems Explained. J. Wilez & sons. 2001.
- J. Pukrushpan, A. Stephanopoulou & H. Peng. Control of Fuel Cell Systems. Springer. 2004.
- Les Piles à Combustibles http://www.annso.freesurf.fr/index.html#plan
- Fuel cell org: www.fuelcell.org

Comparison of FC and ICE

Efficiency of FC vs ICE

- High electrical efficiency:
  - FC efficiency is about 50 to 60% with the perspective of further improving the performance, nearly no limitations
  - ICE: effective efficiency of 20 to 25% in road vehicle in urban and highway driving conditions, limited by Carnot efficiency
- Efficiency in terms of nominal power:
  - FC: efficiency is nearly independent of the size of the FC
  - ICE: minimum and maximum size to achieve satisfactory performance
- Cogeneration favored with FC

Efficiency of FC vs ICE

- Number of conversion steps to produce electricity
  - FC: single stage process
  - ICE: a least two stages : 1/ combustion and thermodynamic conversion 2/ generator

CO_2 emissions of FC and ICE

- Reduction of CO_2 emissions and pollutants
  - FC have a higher energy efficiency
  - ICE exhaust emissions produces CO_2, CO, NO_x, sulfur oxides SO_x (acid rains) and unburnt hycarbon (HC) (cancer risk)
  - Hydrogen FC emits solely steam water
  - Methane FC (CH_4) are characterized by a reduction of CO_2, CO, HC, and NO_X emissions

CO_2 emissions of FC and ICE

- Reduction of CO_2 emissions and pollutants
  - Nowadays inconvenient : H_2 is produced from fossil fuels so they yield indirect CO_2 emissions: Research to find new production paths of H_2 (biomass for instance)
  - FC are fitting the hydrogen route as an alternative energy vector and on the impetus of Hydrogen as corner stone for decentralized production
  - Allows for a low carbon society, weakly dependent on fossil fuels in centralized production using poly generation schemes
  - FC allows valorizing renewable energy sources (geothermal, hydroelectricity, wind energy….)

Advantages of FC

- Higher energy conversion efficiency
- Low emissions or even zero emissions (NO_x, SO_2, PM, CO)
- Silent operation
- Reliability
- Reduced maintenance
- Flexibility in usage
- Efficiency is high even for low rate of power generation

Future trends

- Domestic applications : non centralized production of electricity
- Applications in transports : road vehicle and urban transports such as busses, cars, bikes,…
- Partial substitution of heavy batteries in mobile applications: Mobile phones, PC, portable electronics, cameras…

- To this end, it is necessary to further improve the robustness, the durability and the cost!

Advantages of FC

FOR STATIONARY APPLICATIONS

- High electrical efficiency, nearly independent of the size of the power plant
- FC close to consumers (decentralized energy production)
- Cogeneration is easier (electricity + heat / air conditioning)
- High overall efficiency
- Electricity supply of isolated sites
- Circumvent the necessity to develop expensive and difficult high voltage transmission lines

Advantages of FC

FOR MOBILE APPLICATIONS

- Compared to traditional vehicle based on ICE:
  - Better environmental score

    (Higher conversion efficiency, emissions reduction)
  - Reduction of noise
- Compared to electric vehicles equipped with batteries
  - Longer range because of higher specific energy
  - Improvement of available power
  - Easier refueling

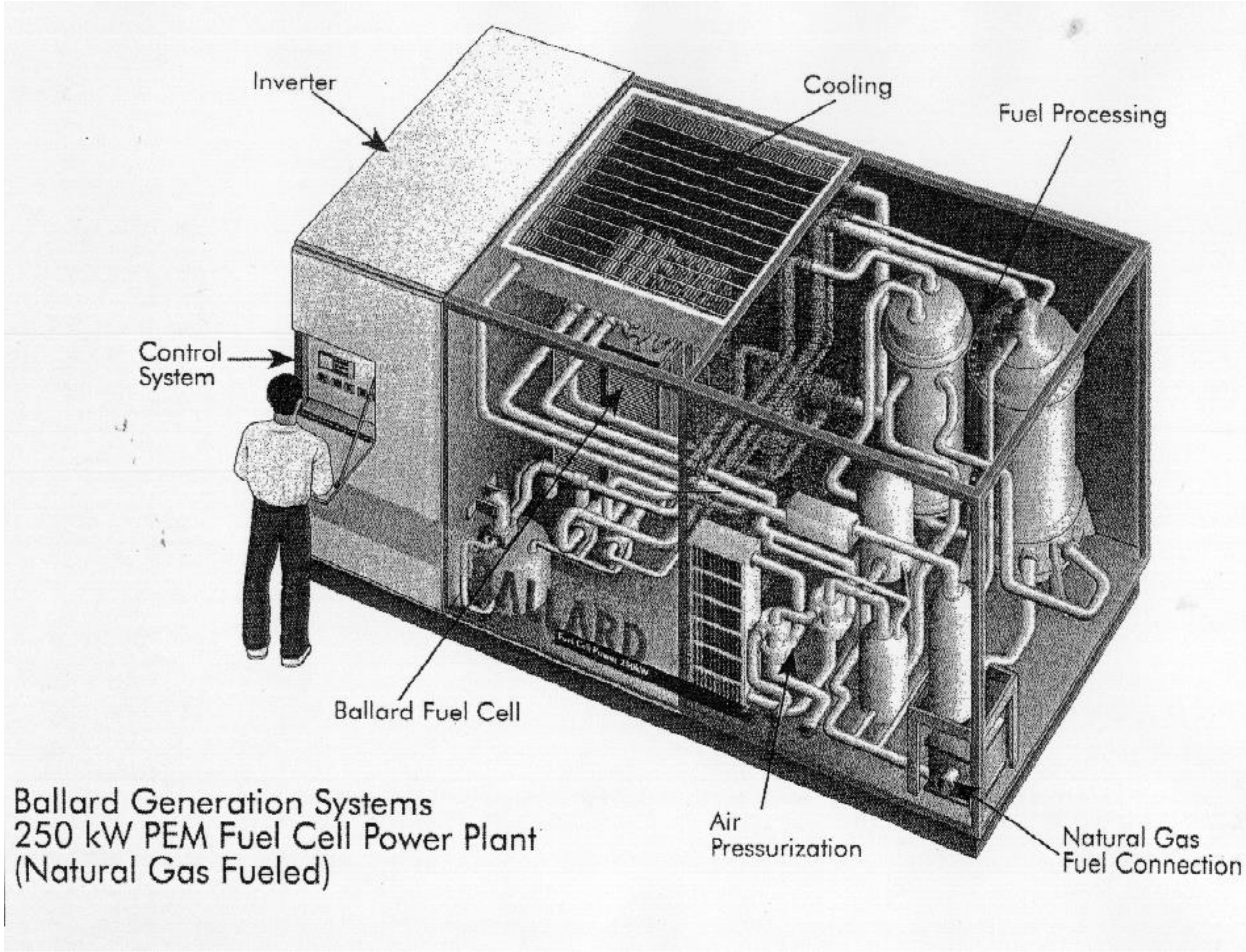
Problems of Fuel Cells

Shell Hydrogen Refueling Station (HRS) in Reykjavik to fuel the Fc busses involved in ECTOS demonstration program since 2003

- Fuel:
  - Hydrogen storage (high pressure or low temperature)
  - Liquid fuel: reforming
  - Distribution network
- Presently, one is just moving the emissions
- Robustness and reliability of fuel cells
- Cost is still high

Applications

Market of stationary applications



Market of stationary applications

Mobile applications

- **Niche markets:**
  - Electric bikes, golf karts, two wheelers…

- **Automobile:**
  - Market is slowly taking off
  - Fuel cell powered vehicle: market after 2020, probably 2030
  - Electric supply of electric vehicles and hybrid electric vehicles
  - Hybrid vehicles: Series hybrid vehicle with a fuel cell prime mover
  - Strongly related to the availability of H_2 network and hydrogen refueling stations
  - Storage problems
  - Fuel technology: PEMFC

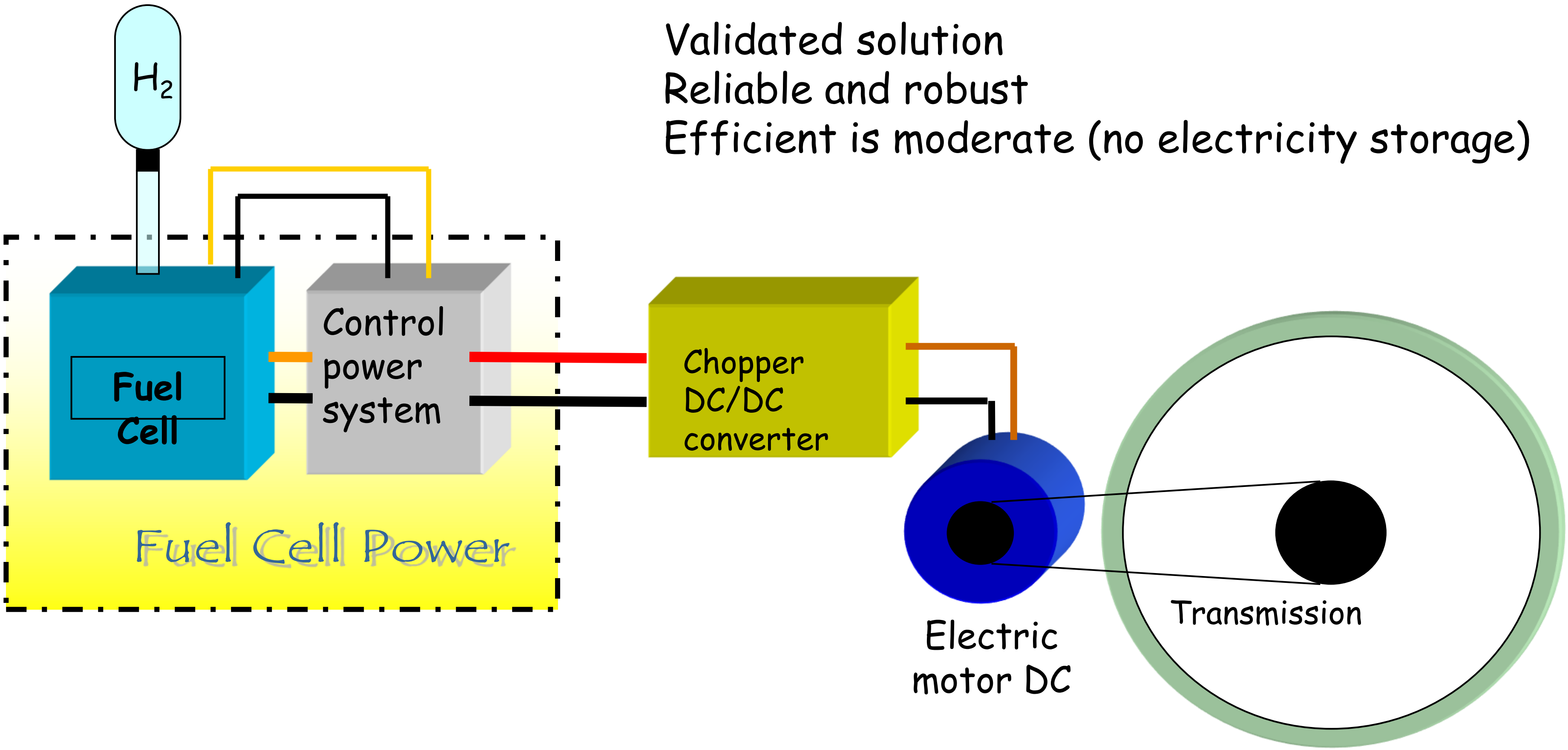
Mobile applications

- **Bus:**
  - Few dozens of fuel busses fabricated up to now (44 in Europe). Several have been operated in demonstration and prestige projects
  - Marketing restricted because of the availability of large power fuel cells (200 kW) and by the cost (~1.5 M€)
  - Fuel cell technologies: PEMFC
  - Fuel: compressed gas

- **Military vehicles :**
  - UAV (unmanned planed)
  - Submarines
  - etc.

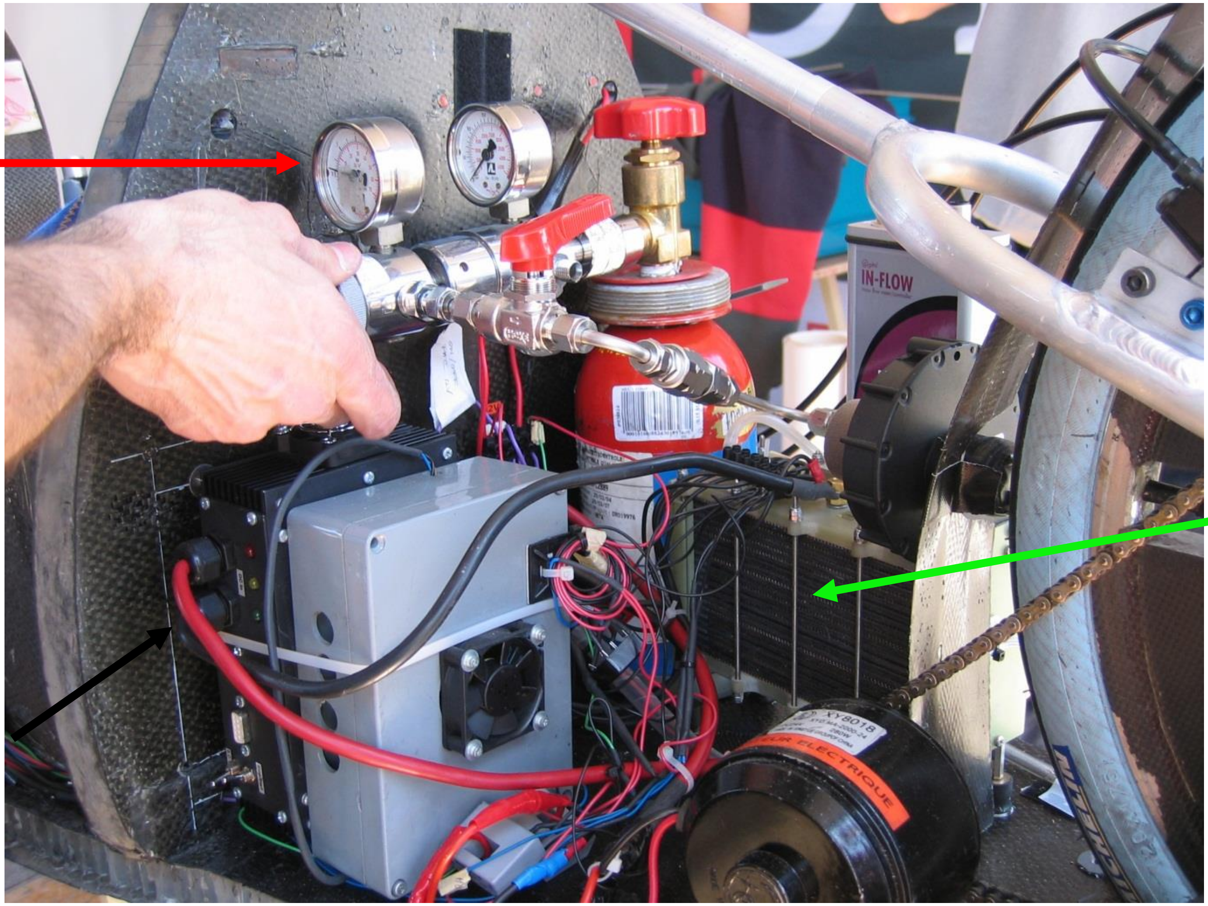
Fuel cell powered vehicles

Validated solution
Reliable and robust
Efficient is moderate (no electricity storage)



Fuel cell powered vehicles: PAC2FUTURE

H2



Fuel cell

Fuel Cell
Controller
And Chopper

Electric motor

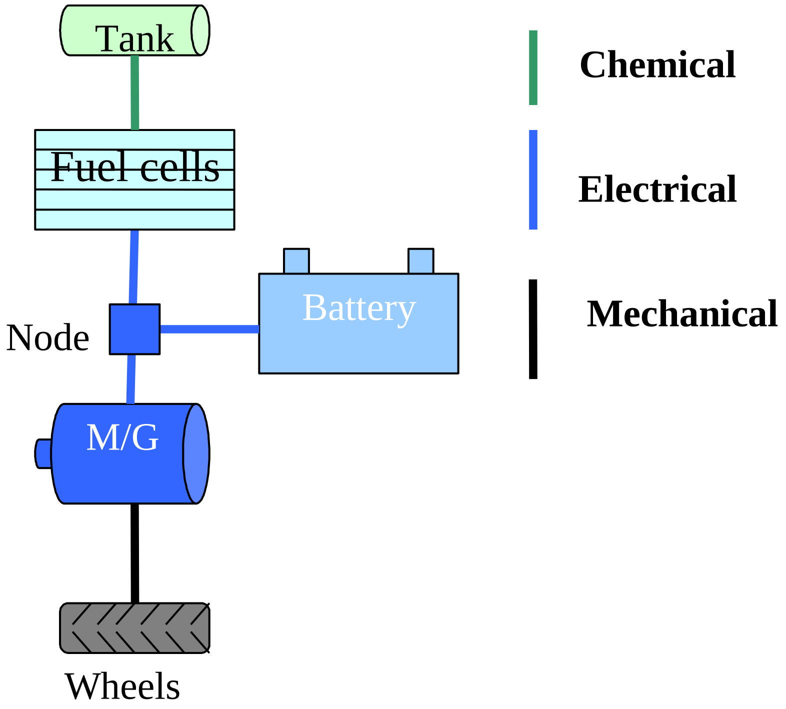
Fuel cell powered vehicles: PAC2FUTURE

- Advantages:
  - Advantages of pure battery electric vehicles :
    - Zero emission mode
    - Silent operation
    - Large torque at low speed
    - Comfort during urban driving conditions

- Disadvantages:
  - Important voltage variation of power supply with current output
  - Requires a good quality power electronics and a complex control systems to carry out the energy management
  - Hydrogen storage
    - Limitation of range
    - Careful manipulation, e.g. refueling
    - Volume constraints

Fuel cell powered hybrid vehicles

- Based on series hybrid architecture
  - Battery or supercap power storage system levels the energy demand
  - Improvement of vehicle performance
  - Braking energy recovery
  - Downsizing of the fuel cell
- Pure H_2 or dual energy systems (electric network + H_2)
- H_2 production and retail network ?
- H_2 stockage ⇨ reduction of the range



Mercedes Story

Mercedes NECAR 1, 2, 3

Mercedes NECAR 5

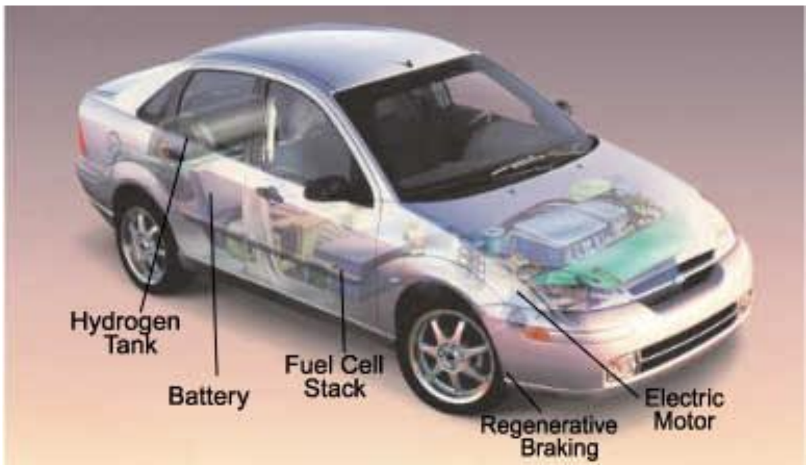
- Prototype released in 2005
- 5 seats
- Fuel: Ballard® Mark 900 of 75 kW
- Maximum speed: 150 km/h
- Fuel: methanol from on board reforming provided by XCELLSIS

Ford FCV HEV


Focus FCV-Hybrid
Hydrogen Fuel Cell
Electric Vehicle
FUEL CELL

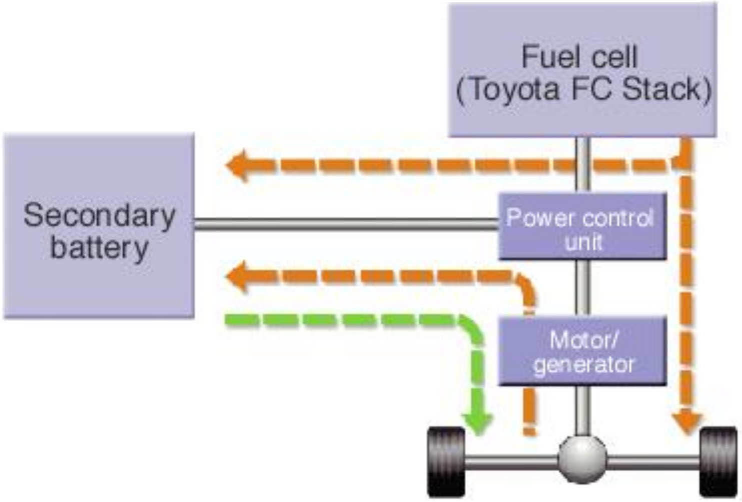

fuel cell vehicle
K FC 1300

Ford FCV HEV



- Fuel Cell: Ballard Mark 902 Fuel Cell with high reliability, designed for a better maintenance and easier fabrication. Output power 85 kW (117 CV).
- Integrated powertrain combining a converter, an electric motor and differential / gear box
- Batteries: made of 180 batteries « D », placed between the rear seats and the hydrogen reservoir
- Reservoir containing four kilos of compressed hydrogen
- Maximum speed: 125 km/h

Toyota FCHV-4



- Series Hybrid architecure
- Fuel cell power: 90 kW
- Batteries: NiMH
- Hydrogen storage: Compressed gaseous H_2 @ 250 bars
- Electric motor: Permanent magnets synchronous machine: 80 kW / 260 Nm
- Top speed > 150 km/h
- Range: 250 km

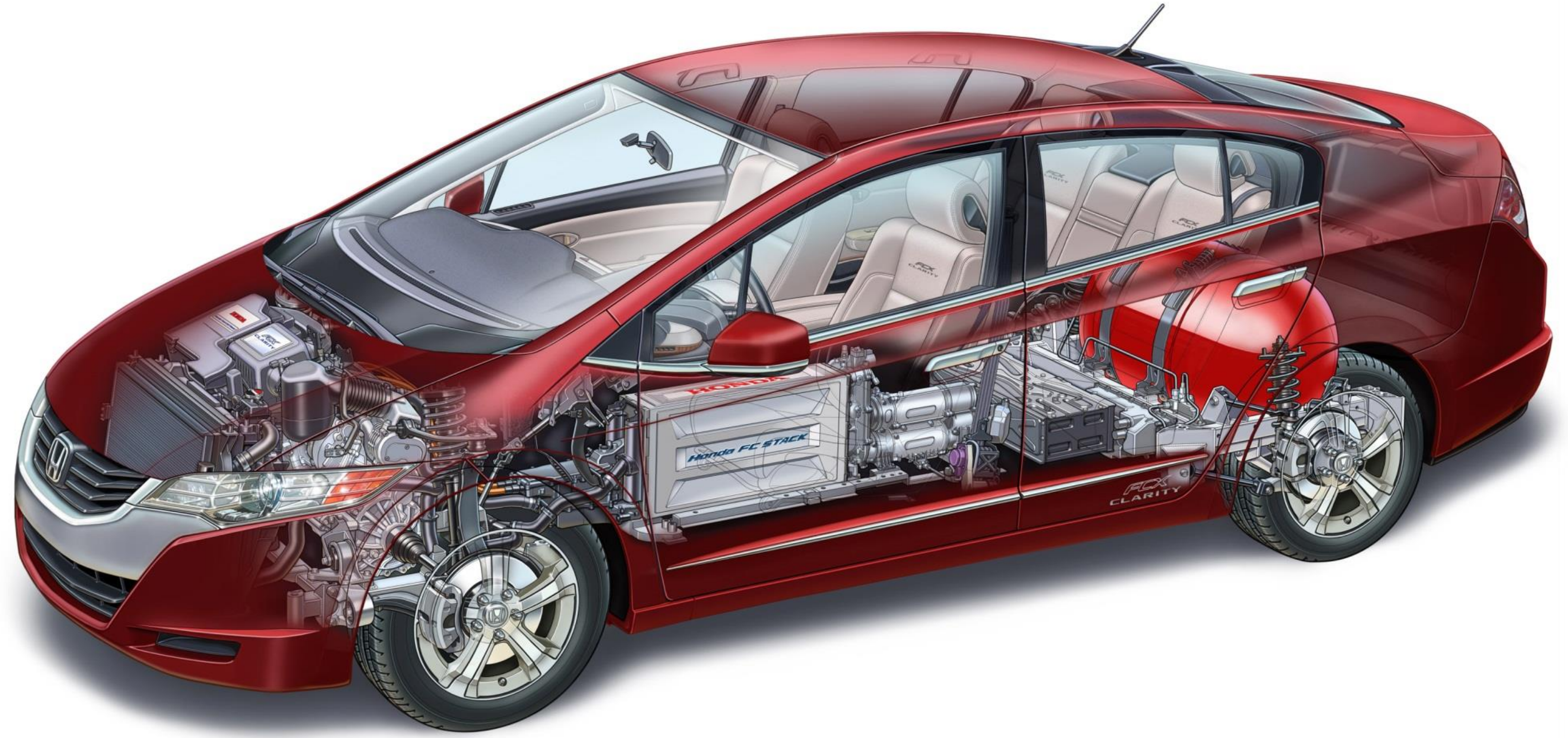
Honda Clarity

- Performance:
  - Max speed: 100 mph ~ 140 km/h
  - Acceleration: 0-60 mph (96 km/h) : 10 sec
  - Curb weight: 1625 kg
- Major characteristics: http://automobiles.honda.com/fcx-clarity/specifications.aspx

Honda Clarity

- Electric motors: Synchronous Permanent Magnets with output power 100 kW / max torque: 256 Nm
- Fuel cell: PEM type V-flow (patent by Honda) 100 kW
- Li-ions batteries: 288 V (capacity?)
- Suspensions : Double wishbone at front / Five points suspension at rear
- Range : 240-270 miles
- Leasing cost : 600 $ per month
- Major characteristics: http://automobiles.honda.com/fcx-clarity/specifications.aspx

Honda Clarity



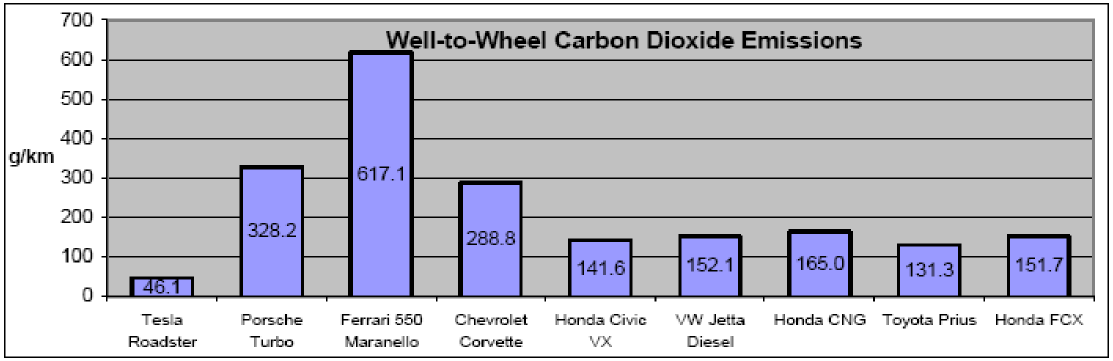
Honda Clarity

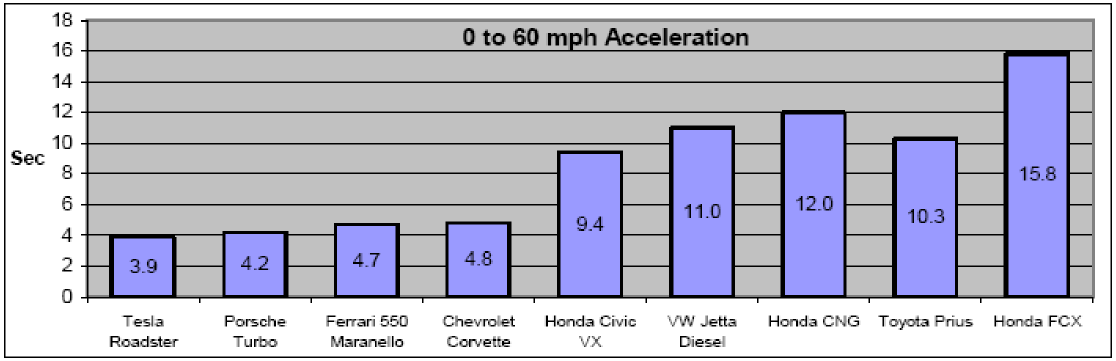
Powertrain	Drive method		Front-wheel drive
	Motor	Type	AC synchronous electric motor (permanent magnet)
		Max. output (kW [HP])	100 [134]
		Max. torque (N·m [kg·m])	256 [26.1]
	Fuel cell stack	Type	PEMFC (Proton Exchange Membrane Fuel Cell)
		Max. output (kW)*	100
	Lithium-ion battery	Voltage (V)*	288

Fuel	Type	Compressed hydrogen gas
	Storage	High-pressure hydrogen tank
	Tank capacity (L)	171
	Max. pressure when full (MPa)	35

Honda Clarity

Technology	Example Car	Gas mileage	Well-to-Wheel Efficiency	Well-to-Wheel CO_2 Emissions	0 to 60 mph Acceleration
Electric	Tesla Roadster	110 Wh/km	1.15 km/MJ	46.1 g/km	3.9 sec
Gasoline Engine (Turbo 6-cyl)	Porsche Turbo	22.0 mpg	0.22 km/MJ	328.2 g/km	4.2 sec
Gasoline Engine (V12)	Ferrari 550 Maranello	11.7 mpg	0.12 km/MJ	617.1 g/km	4.7 sec
Gasoline Engine (V8)	Chevrolet Corvette	25.0 mpg	0.25 km/MJ	288.8 g/km	4.8 sec
Gasoline Engine (VTEC 4-cyl)	Honda Civic VX	51.0 mpg	0.52 km/MJ	141.6 g/km	9.4 sec
Diesel Engine (4-cyl)	VW Jetta Diesel	50.0 mpg	0.48 km/MJ	152.1 g/km	11.0 sec
Natural Gas Engine (4-cyl)	Honda CNG	35.0 mpg	0.32 km/MJ	165.0 g/km	12.0 sec
Hybrid (3-cyl Gas/Electric)	Toyota Prius	55.0 mpg	0.56 km/MJ	131.3 g/km	10.3 sec
Hydrogen Fuel Cell	Honda FCX	64 mi/kg	0.35 km/MJ	151.7 g/km	15.8 sec





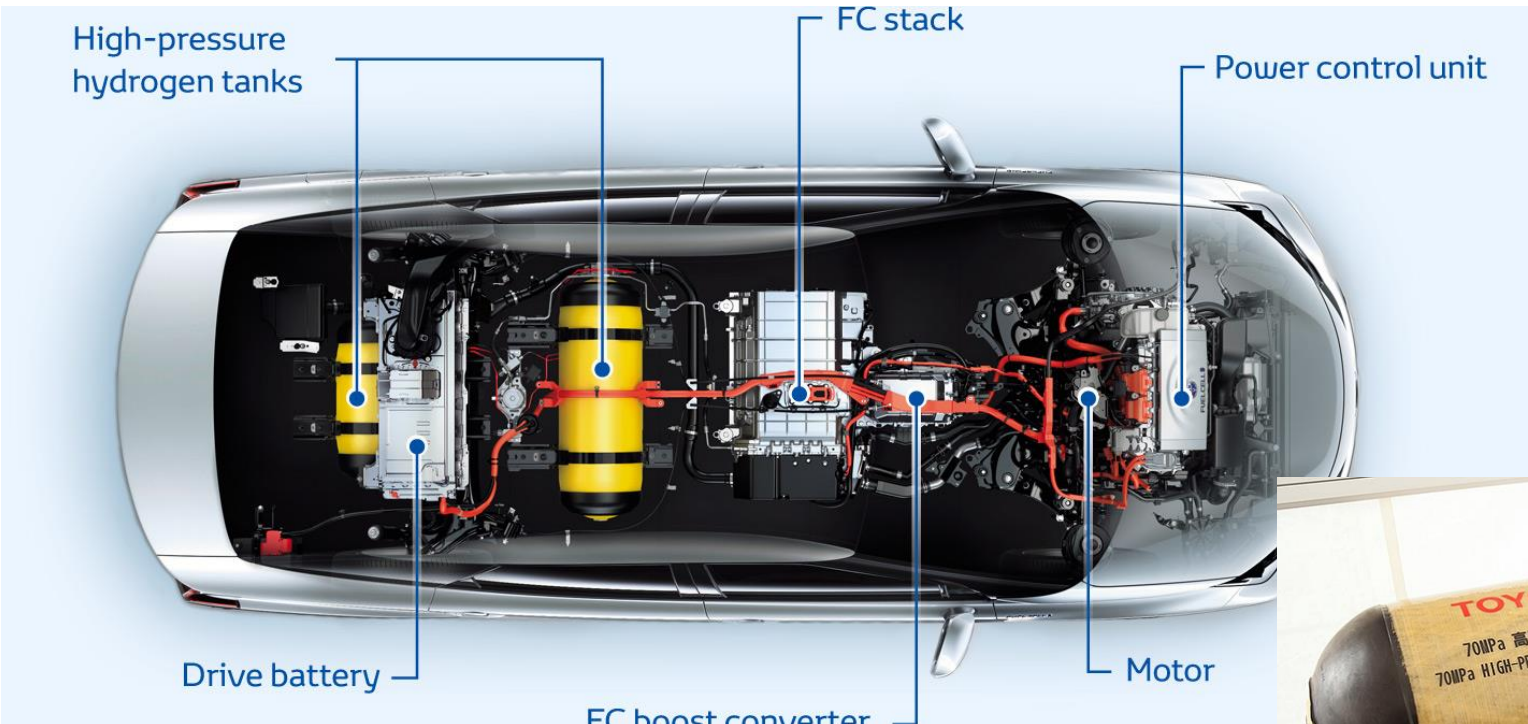
http://www.teslamotors.com/learn_more/white_papers.php?js_enabled=1

TOYOTA Mirai

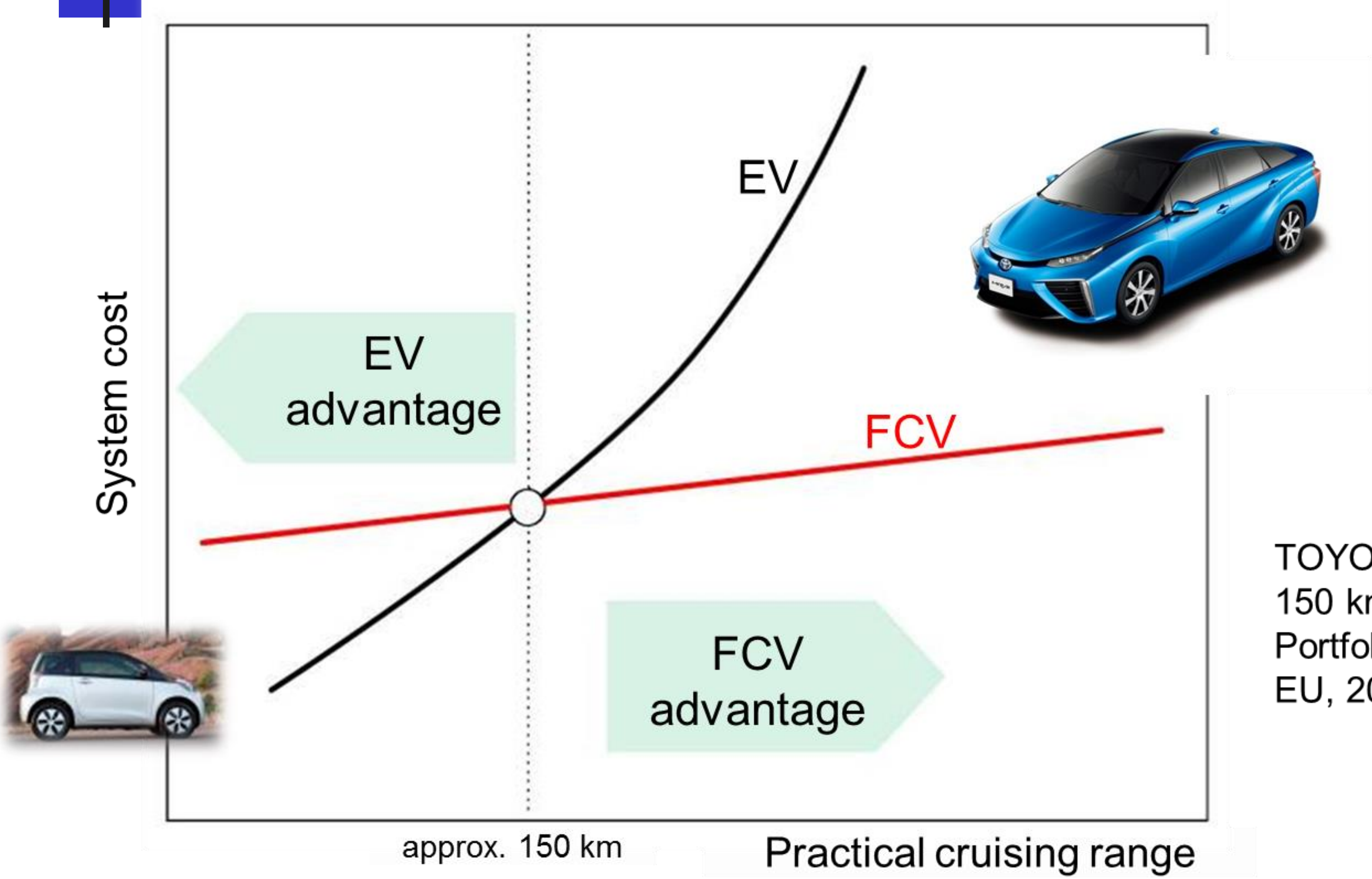
Toyota Mirai
Released in 2015 (Japan)

http://www.toyota-global.com/innovation/environmental_technology/fuelcell_vehicle/index.html

Fuel cell vehicle: case studies



Fuel cell vehicle: case studies



TOYOTA estimation:
150 km, Joint study on a Portfolio of Powertrains for EU, 2010: 140 km

Source: Toyota

TOYOTA

Development of MIRAI

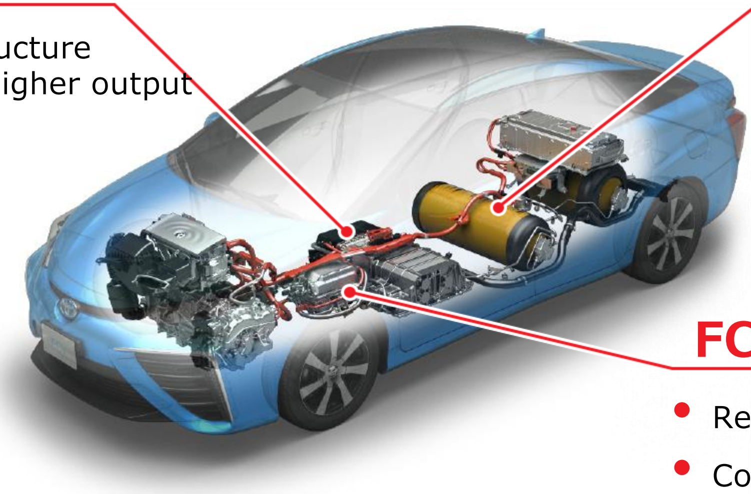
★FC stack

- Innovative flow channel structure and Electrodes of cells for higher output
  Output/volume; 3.1kW/L

world top level

Humidifier less

- Internal circulation



★High pressure hydrogen tank

- The light weight structure of carbon fiber reinforced plastic enabled
  Storage; 5.7 wt%*

world top level

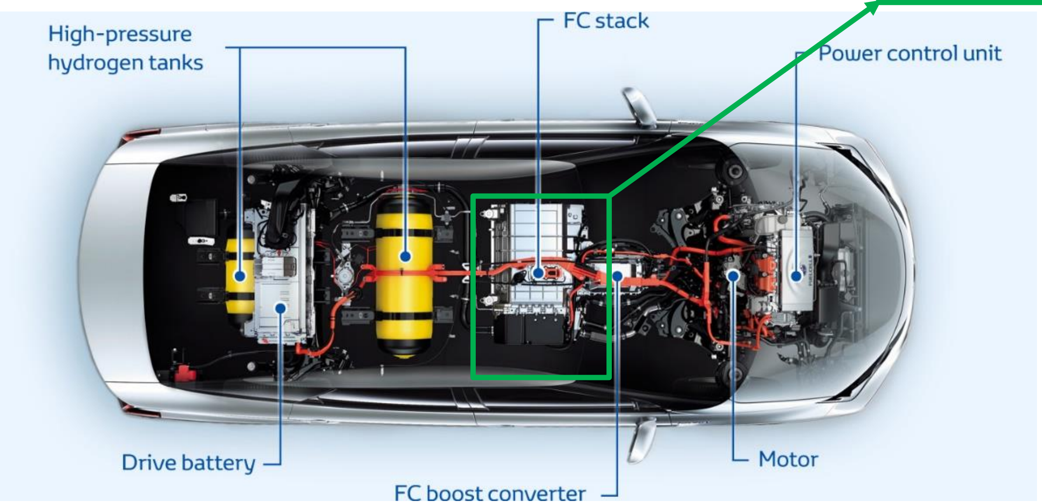
FC boost converter

- Reduced number of cells in FC stack
- Common use of hybrid units

*Hydrogen mass/Tank mass

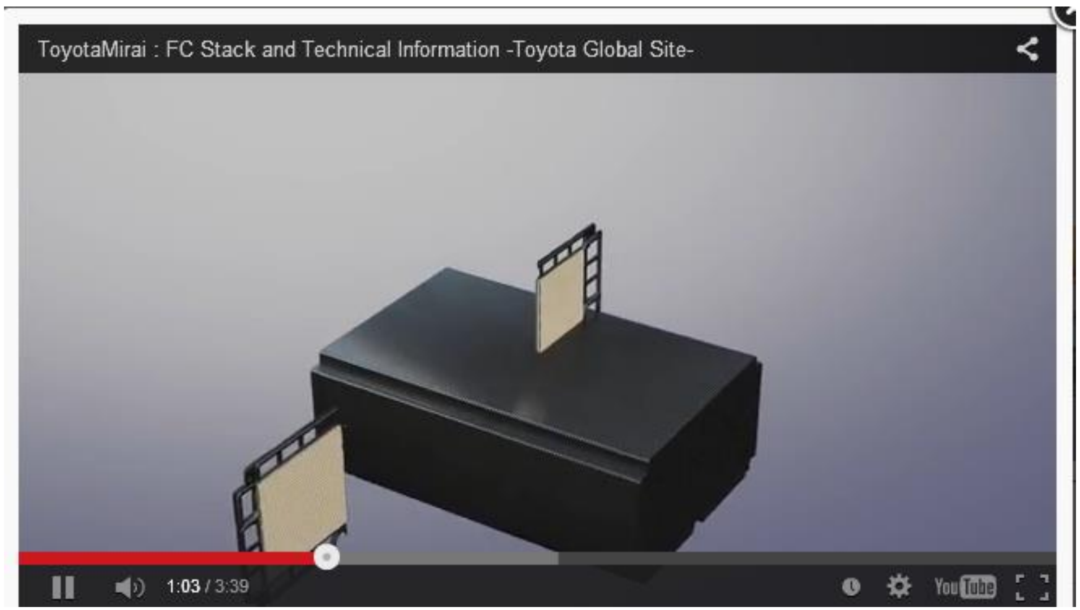
FC main components developed in-house to achieve world leading performance

TOYOTA Mirai



http://www.toyota-global.com/innovation/environmental_technology/fuelcell_vehicle/index.html

TOYOTA Mirai

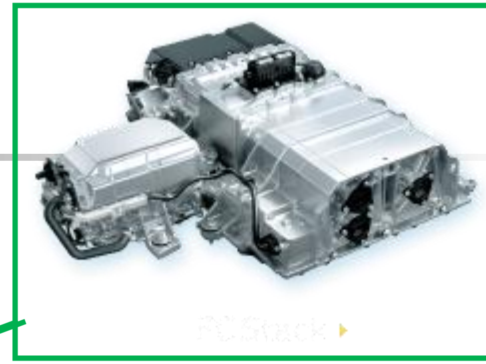


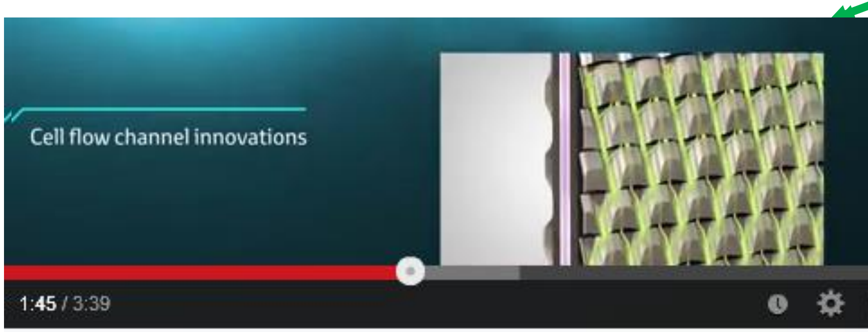
http://www.toyota-global.com/innovation/environmental_technology/fuelcell_vehicle/index.html

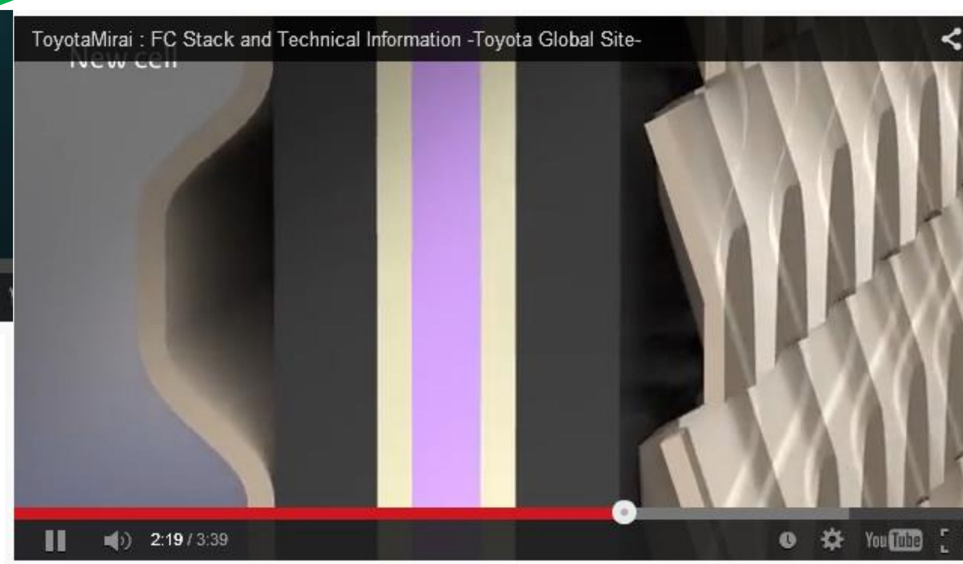
TOYOTA Mirai

http://www.toyota-global.com/innovation/environmental_technology/fuelcell_vehicle/index.html

TOYOTA Mirai



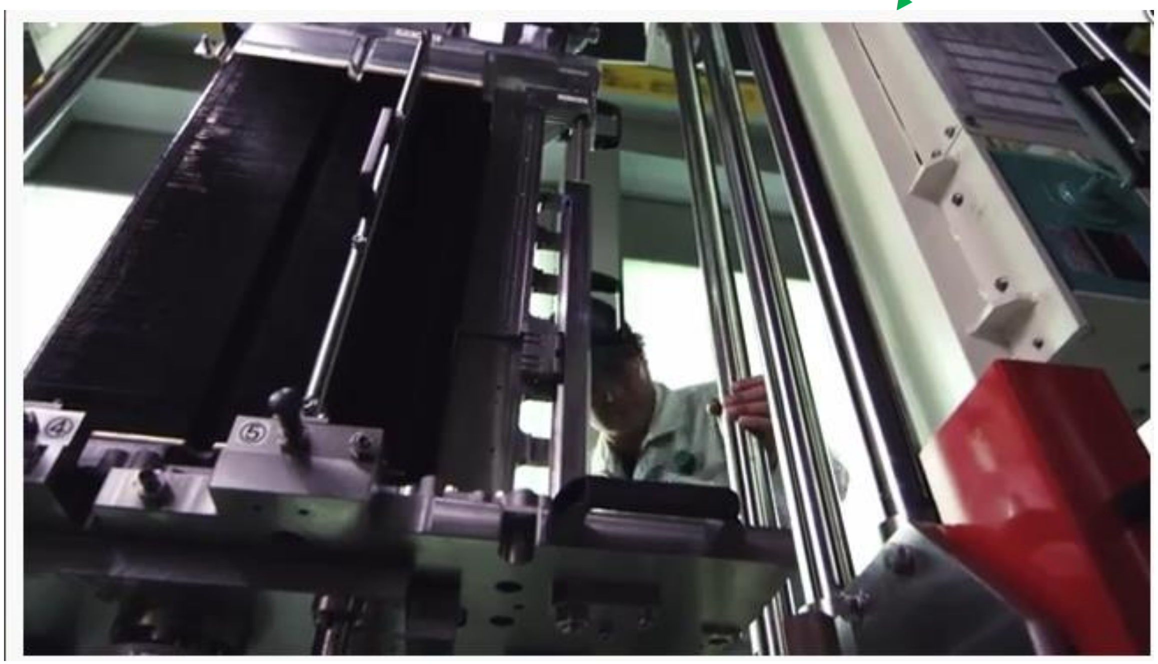




Complex geometries!
→ Thermal management??

http://www.toyota-global.com/innovation/environmental_technology/fuelcell_vehicle/index.html

TOYOTA Mirai



Manual assembly!

http://www.toyota-global.com/innovation/environmental_technology/fuelcell_vehicle/index.html

TOYOTA Mirai

- Challenges:
  - Materials with given properties
  - Mass manufacturing of components?
  - Stacking?
  - Mass manufacturing of devices?

http://www.toyota-global.com/innovation/environmental_technology/fuelcell_vehicle/index.html

Toyota FCHV-Bus 1/2

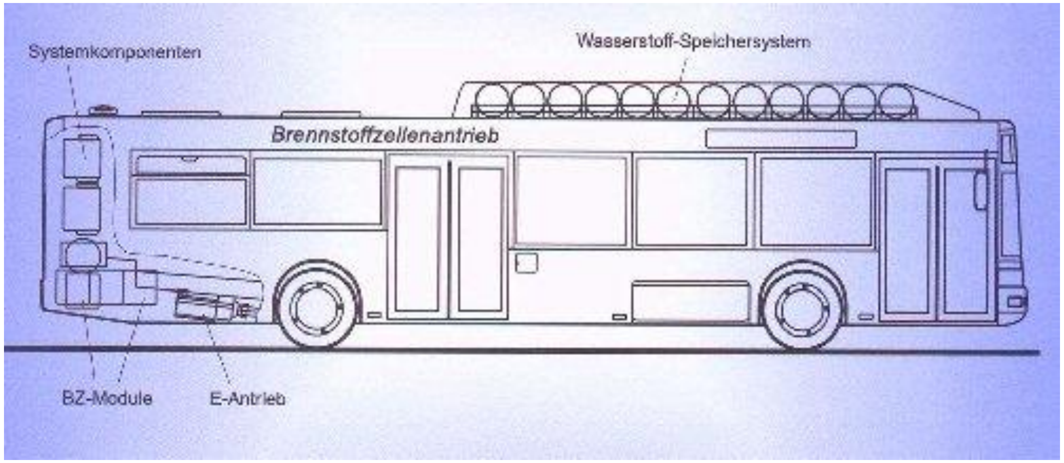
- Hybrid series configuration
- Fuel cells: 2 fuel cells of 90 kW
- Batteries: NiMH
- Hydrogen storage: compressed H_2 compressed @ 250 bars
- Electric motor: PM synchronous machine

Mobile applications: niche markets

Motor bikes and electric bikes

Fuel Cell busses

Programme CUTE: clean Urban Transport
NEBUS de Daimler Benz



Mobile applications

Market for portable equipment

- PC, GSM, etc.
- Mainly based on Direct methanol Fuel Cells

Many thanks for your kind attention

All the best in your futur professionall life