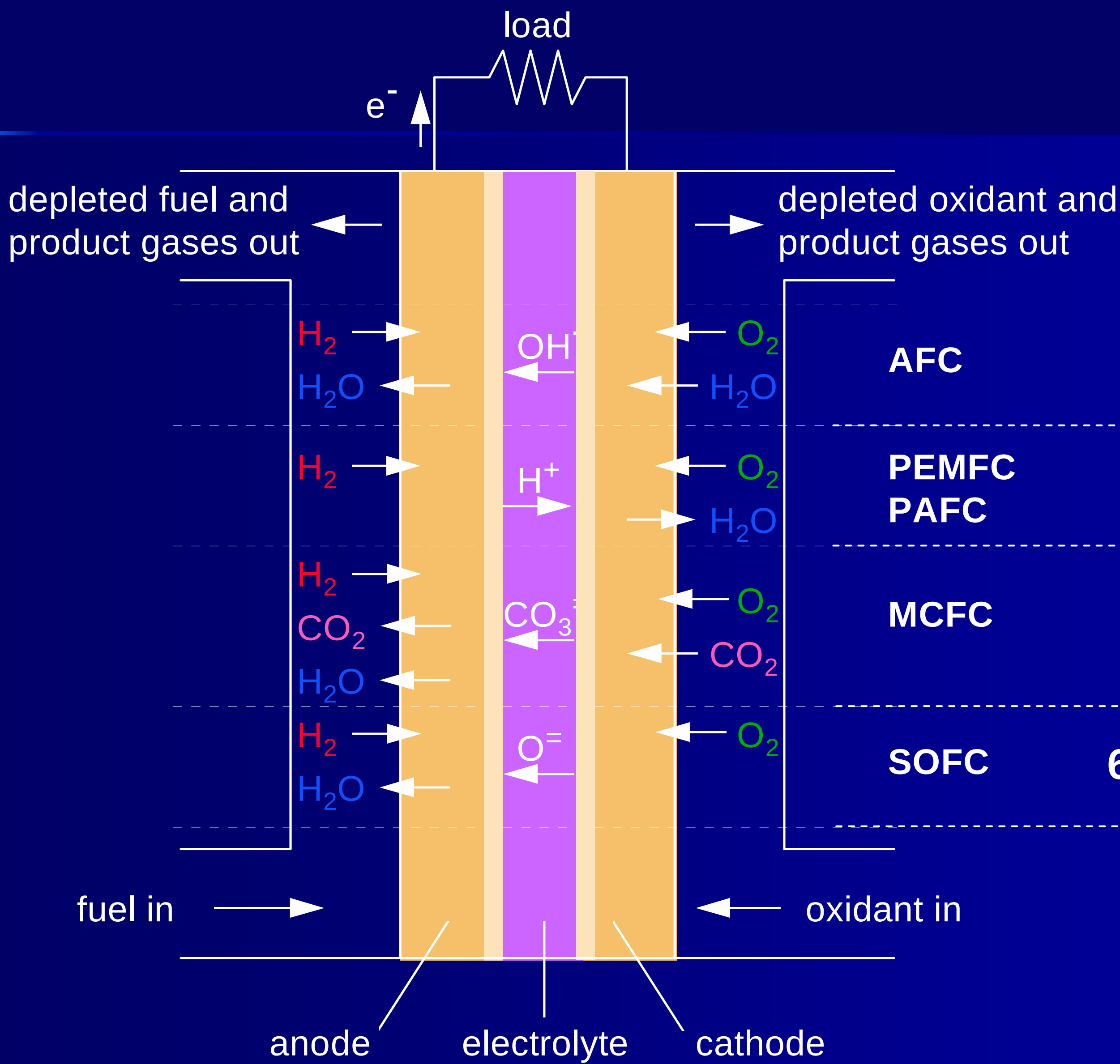
Fuel Cell Characteristics



AFC	**65-220 °C**
PEMFC	**60-80 °C**
PAFC	**205 °C**
MCFC	**650 °C**
SOFC	**600-1000 °C**

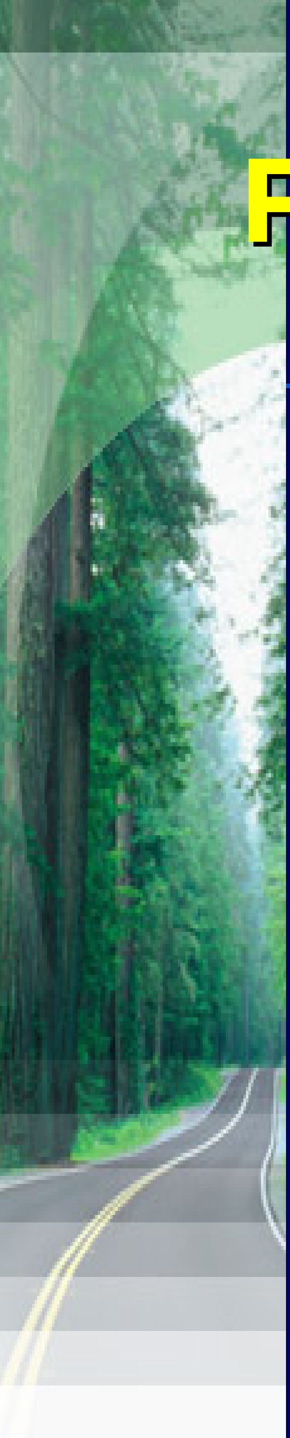
Fuel Cells Characteristics

Fuel Cell	Electrolyte	Operating Temperature (°C)	Electrochemical Reactions
Polymer Electrolyte/ Membrane (PEM)	Solid organic polymer poly-perfluorosulfonic acid	60 - 100	Anode: $H_2 \rightarrow 2H^+ + 2e^-$ Cathode: $\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$ Cell: $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$
Alkaline (AFC)	Aqueous solution of potassium hydroxide soaked in a matrix	90 - 100	Anode: $H_2 + 2(OH)^- \rightarrow 2H_2O + 2e^-$ Cathode: $\frac{1}{2} O_2 + H_2O + 2e^- \rightarrow 2(OH)^-$ Cell: $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$
Phosphoric Acid (PAFC)	Liquid phosphoric acid soaked in a matrix	175 - 200	Anode: $H_2 \rightarrow 2H^+ + 2e^-$ Cathode: $\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$ Cell: $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$
Molten Carbonate (MCFC)	Liquid solution of lithium, sodium and/ or potassium carbon-ates, soaked in a matrix	600 - 1000	Anode: $H_2 + CO_3^{2-} \rightarrow H_2O + CO_2 + 2e^-$ Cathode: $\frac{1}{2} O_2 + CO_2 + 2e^- \rightarrow CO_3^{2-}$ Cell: $H_2 + \frac{1}{2} O_2 + CO_2 \rightarrow H_2O + CO_2$ (CO_2 is consumed at cathode and produced at anode)
Solid Oxide (SOFC)	Solid zirconium oxide to which a small amount of ytrria is added	600 - 1000	Anode: $H_2 + O^{2-} \rightarrow H_2O + 2e^-$ Cathode: $\frac{1}{2} O_2 + 2e^- \rightarrow O^{2-}$ Cell: $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$

Comparison of Fuel Cell Technologies

Fuel Cell	Applications	Advantages	Disadvantages
Polymer Electrolyte/ Membrane (PEM)	electric utility portable power transportation	• Solid electrolyte reduces corrosion & management problems • Low temperature • Quick start-up	• Low temperature requires expensive catalysts • High sensitivity to fuel impurities
Alkaline (AFC)	military space	• Cathode reaction faster in alkaline electrolyte — so high performance	• Expensive removal of CO_2 from fuel and air streams required
Phosphoric Acid (PAFC)	electric utility transportation	• Up to 85 % efficiency in co-generation of electricity and heat • Impure H_2 as fuel	• Pt catalyst • Low current and power • Large size/weight
Molten Carbonate (MCFC)	electric utility	• High temperature advantages*	• High temperature enhances corrosion and breakdown of cell components
Solid Oxide (SOFC)	electric utility	• High temperature advantages* • Solid electrolyte advantages (see PEM)	• High temperature enhances breakdown of cell components

*High temperature advantages include higher efficiency, and the flexibility to use more types of fuels and inexpensive catalysts as the reactions involving breaking of carbon to carbon bonds in larger hydrocarbon fuels occur much faster as the temperature is increased.

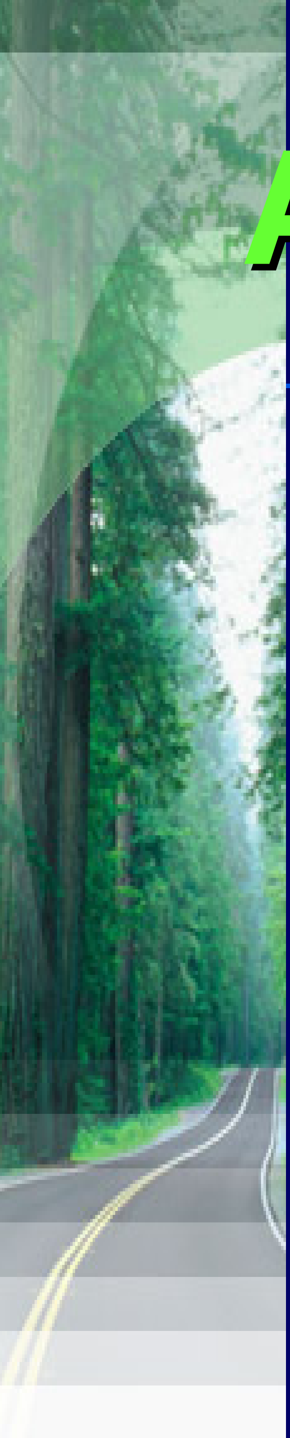


Fuels For Fuel Cell

- Hydrogen

- Methanol
- Natural gas
- Propane
- Gasoline
- Other liquid hydrocarbons
  - desulfurized gasoline
  - hydrocrackate
  - alkylate/isomerate
  - gas-to-liquid light paraffin
  - hydrotreated condensate

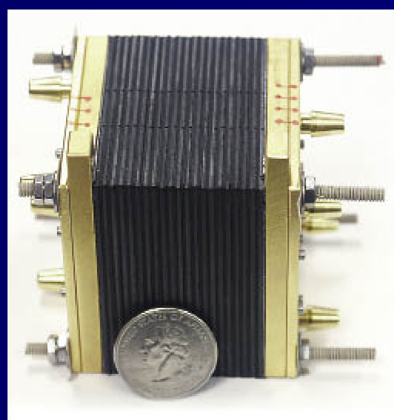
} **Reformer**

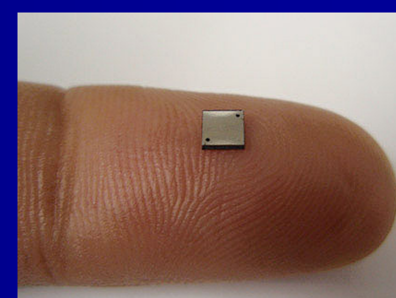


Applications

- Small appliances
- Power packs
  - Material Handling
  - Auxiliary Power Units
  - Aviation Ground Support Equipment
- Fuel cell vehicles (FCVs)
- Power generations (Plants)

Sizes to fit applications





http://newtech.aurum3.com/images/worlds-smallest-fuel-cell.jp

Small Applications

- Battery replacement
  - Cell phones, laptops, mp3
  - Powering medical sensors

Source: http://blog.megapixel.net/blog/2008/05/09/050908_methanol_fc.jpg

Power Pack Applications

- Back-up unit
- Material handling

Source: http://blog.megapixel.net/blog/2008/05/09/050908_methanol_fc.jpg

Fuel Cell Vehicles (FCVs)

- EV family
- PEMFCs
- BoP needed
- Dynamics concerned
- Hybridization

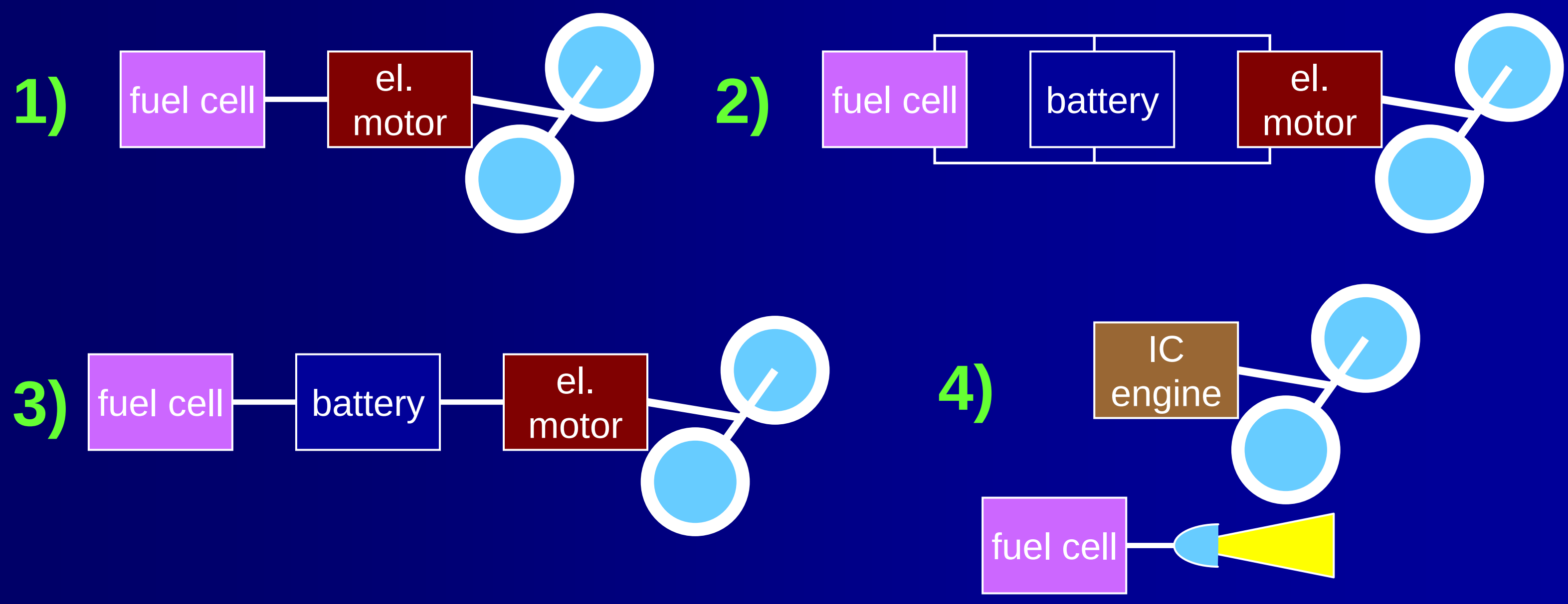
http://www.psa-peugeot-citroen-press.co.uk/

Why PEMFC for FCVs?

- Simple
- Quick start-up
- Fast response
- High efficiency
- High power density (kW/kg and kW/l)
- Zero emissions

System Configurations of Fuel Cell Vehicles

1) Fuel cell provides all the power
2) Fuel cell provides nominal power
   – battery provides peak power (parallel hybrid)
3) Fuel cell charges the batteries (series hybrid)
4) Fuel cell as an auxiliary power unit



Configurations of FCVs

- Direct hydrogen fuel cell system
- Direct methanol fuel cell system
- Fuel cell system with a reformer

Fuel

- Compressed hydrogen
- Liquid hydrogen
- Hydrogen in metal hydrides
- Hydrogen in chemical hydrides
- Ammonia
- Methanol
- Gasoline
- Other

Some of FCVs


F-Cell
driving the future

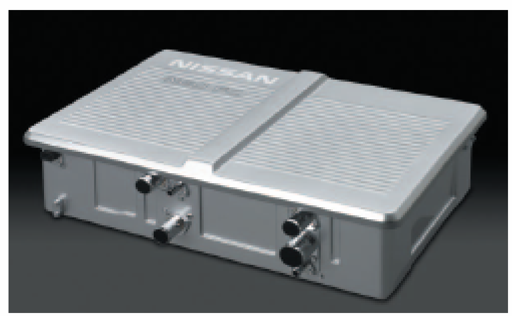

HYDROGEN
FUEL CELL ELECTRIC

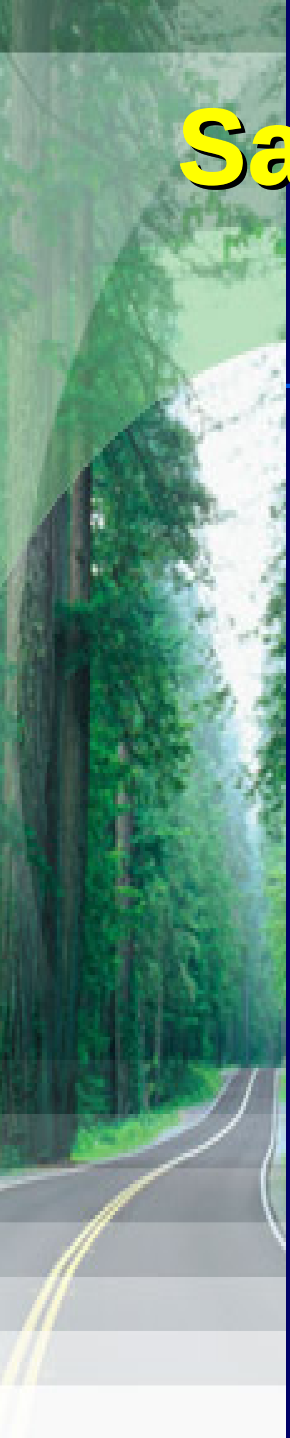

GM FUEL CELL POWER
HYDROGEN3
HYDROGEN3


FCEV
HYUNDAI
Fuel Cell Electric Vehicle

Sample of FCV (Nissan)

1. Fuel Cell Stack Developed by Nissan





Sample of FCV (Nissan)

2. Specifications

		2005 Model	2003 Model
Vehicle	Overall length/width /height (mm)	4485/1770/1745	4485/1771/1800
	Weight (kg)	1790(1860)	1960
	Seating capacity (people)	5	←
	Top speed (km/h)	150	145
	Cruising range (km)	Over 370 (over 500)	Over 350
Motor	Type	Coaxial motor integrated with reduction gear	←
	Max. power (kW)	90	85
	Max. torque (N·m)	280	←
Fuel cell stack	Fuel cell	Solid polymer type	←
	Max. power (kW)	90	63
	Supplier	Developed by Nissan	UTC Fuel Cells (USA)
Rechargeable Battery	Type	Compact lithium-ion battery	←
Fueling system	Fuel type	Compressed hydrogen gas	←
	Max. pressure (MPa)	35(70)	35

Parentheses ( ) indicates a reference value for a vehicle equipped with the 70 Mpa high pressure hydrogen tank.

Hydrogen Refueling Infrastructure

DTE/BP Power Park, Southfield, MI

ing station

Hydrogen and gasoline station, WA DC

Photo:Shell Hydrogen

Chino, CA

Photo: H2CarsBiz

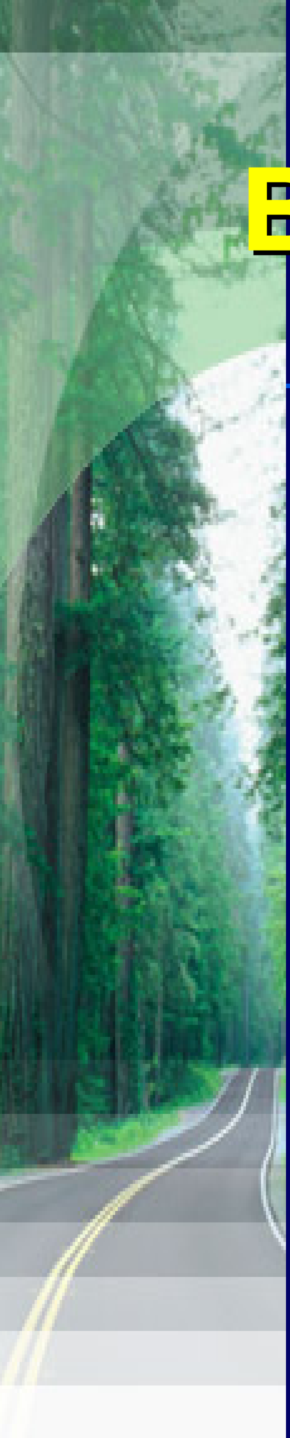
Power Generation Applications

- PEMFC
- SOFC
- MCFC
- PAFC

Source: http://blog.megapixel.net/blog/2008/05/09/050908_methanol_fc.jpg

Fuel Cell System Requirements (Depend on application)

	Automotive	Primary Power	Back-up Power
Power	50-100 kW	1-10 & >200 kW	1-10 kW
Fuel	Reformate/H_2	Reformate	Hydrogen
Life	5,000 hrs	>40,000 hrs	<2,000 hrs
High Efficiency	Critical	Critical	Not Critical
Instant Start	Very Important	Not Important	Very Important
Output Mode	Variable	Variable	Constant
Operation	Intermittent	Constant	Intermittent
Preferred Voltage	>300 V	>110 V AC	48 V DC
Heat Recovery	Not Needed	Very Important	Not Needed
Water Balance	Very Important	Very Important	Not Critical
Size and Weight	Critical	Not Critical	Not Critical
Extreme Conditions	Critical	Not Critical	Important
Cost	<$100/kW <$50/kW	<$1000/kW <$200/kW	<$1000/kW <$400/kW



Barriers To Commercialization

- Fuel infrastructure
- High cost
  - More expensive than competing technologies
  - Actual price depends on production numbers
- Insufficient durability
- Performance issues
  - Lifetime lower than competing technology
  - Need research on lifetime issues, performance is good

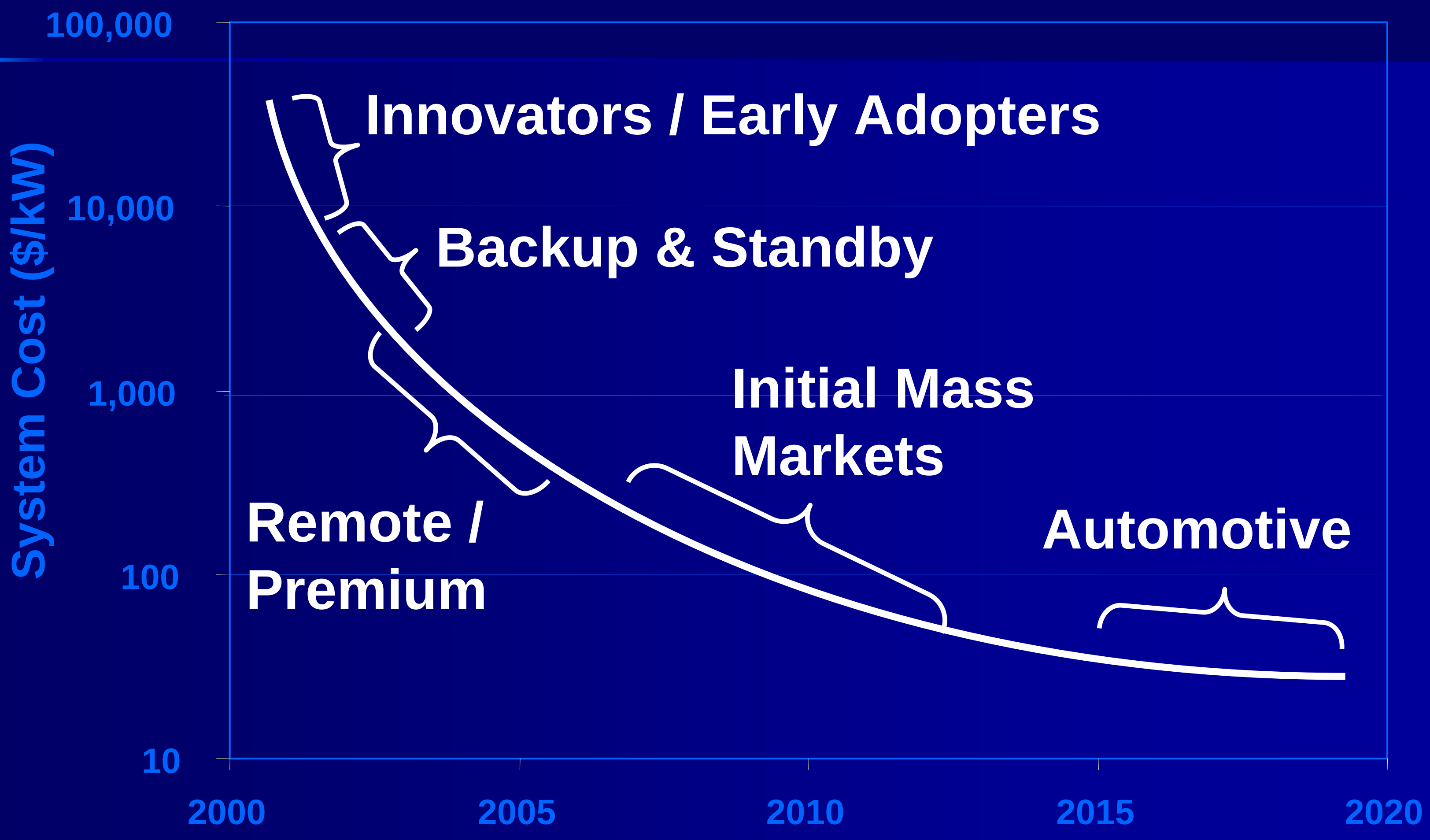
R & D Needs

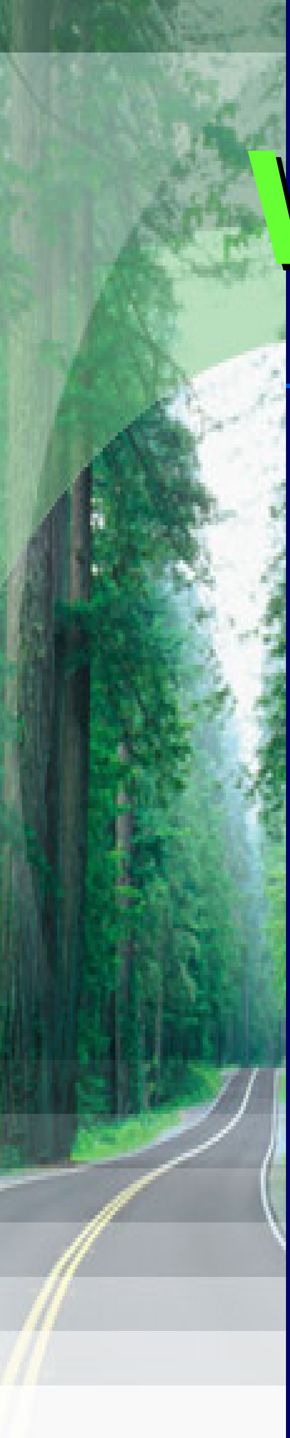
- Better performance
  - **higher voltage, better stability, transients, start-up, survivability**
- Susceptibility to contaminants
- Lower cost
  - **materials, manufacturing processes, manufacturing scale**
  - **simpler systems**
- Longer life/durability
- Hydrogen/fuels infrastructure
  - **hydrogen production, storage, transport, distribution**
  - **technical and socio-economic issues**

Some Players (PEMFCs)

Company	City	Province	Applications
Aluminum Power	Toronto	Ontario	Mobile
Angstrom Power	North Vancouver	British Columbia	Portable
Astris Energi	Mississauga	Ontario	Mobile
Ballard Power Systems	Burnaby	British Columbia	Stationary; Portable; Mobile
Cellex Power Products	Richmond	British Columbia	Stationary
DuPont Canada	Kingston	Ontario	Stationary; Portable; Mobile
Energy Visions	Mississauga/Calgary	Ontario / Alberta	Stationary; Portable; Mobile
Fuel Cell Technologies	Kingston	Ontario	Stationary
Global Thermoelectric	Calgary	Alberta	Stationary; Mobile
GreenVOLT Power	Orillia	Ontario	Stationary
Hydrogenics	Mississauga	Ontario	Stationary; Portable; Mobile
Kinectrics	Toronto	Ontario	Stationary
MagPower Systems	Delta	British Columbia	Stationary; Portable
Palcan Fuel Cells	Burnaby	British Columbia	Portable; Mobile
PEM Technologies	Vancouver	British Columbia	Portable; Mobile
PowerDisc Development	Chilliwack	British Columbia	Mobile
Siemens Canada	Mississauga	Ontario	Stationary; Portable

CURRENT STATE OF THE TECHNOLOGY (Cost projection)

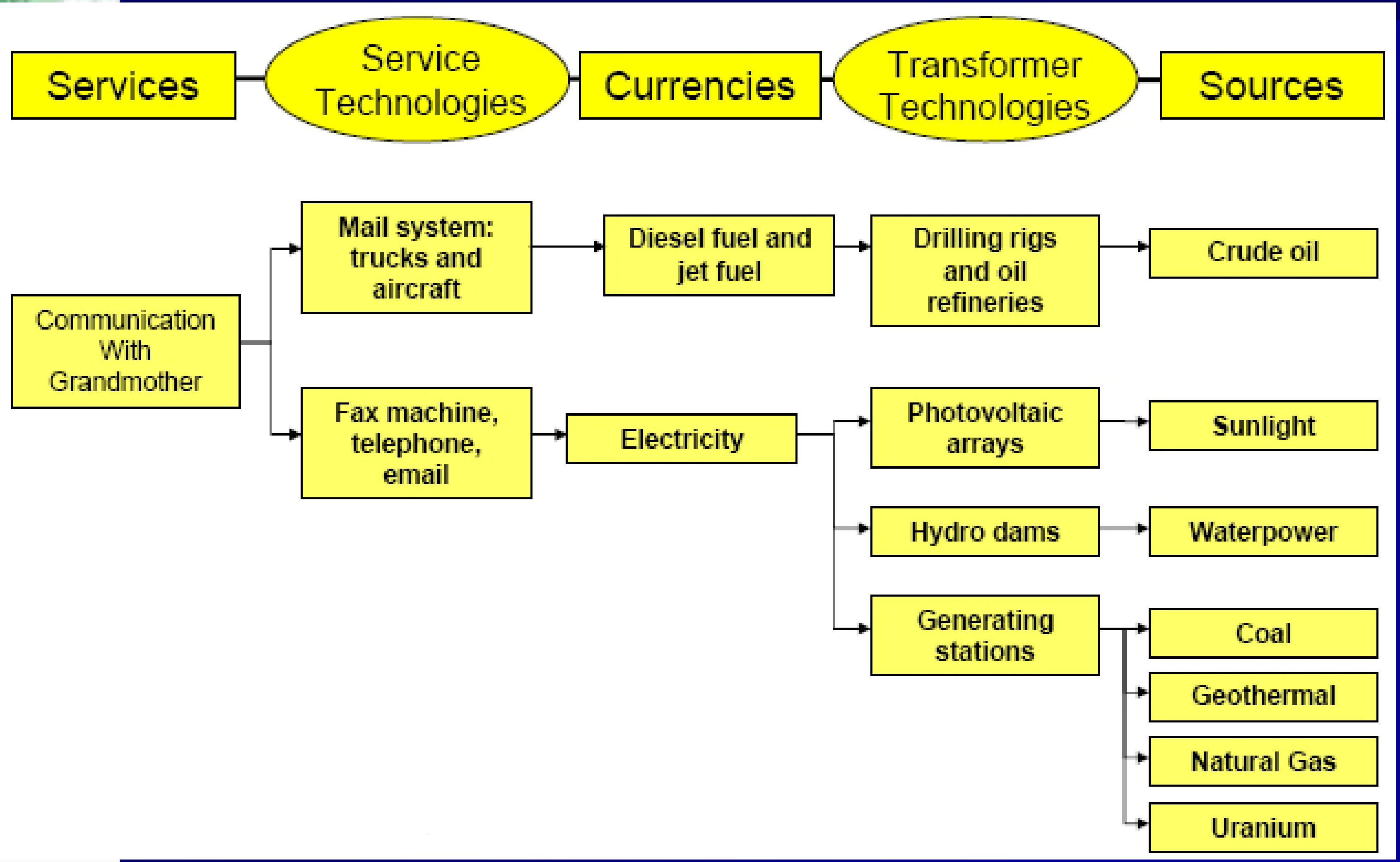




Why Fuel Cells?

- World energy crisis
- Energy system
- Hydrogen economy
- (Local) Environmental friendly technology
- Promise of high efficiency
- No moving parts/promise of long life
- Modular
- Quiet
- (Simple/promise of low cost)

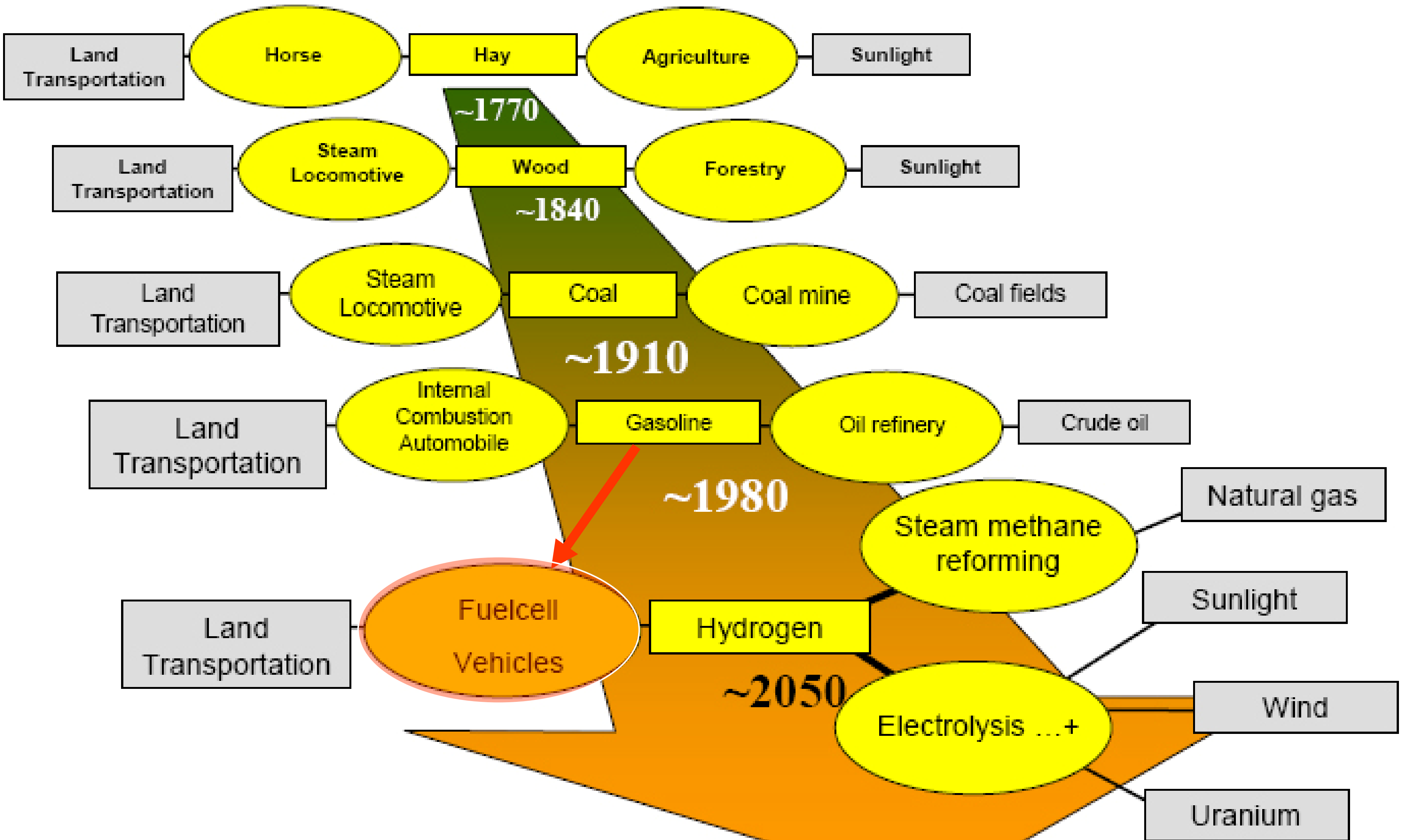
Why Fuel Cells?



Why Fuel Cells?

Services	Service Technologies	Currencies	Transformer Technologies	Sources
Transportation	Automobile	Gasoline	Oil refinery	Coal
Communication	Telephone	Electricity	Hydraulic generators	Oil
Illumination	Light bulb	Methanol	Nuclear power plants	Natural gas
Health care	NMR-scan	Methane	Anaerobic digestion	Sunlight
Keeping warm	Heat pump	Hydrogen	:	Wind
Keeping cool	Refrigerator	:	:	Uranium
Potable water	:	:		Biomass
:	:			:
:				:
What people want...	What energy system developers create			What nature provides

Why Fuel Cells?



Thank you

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