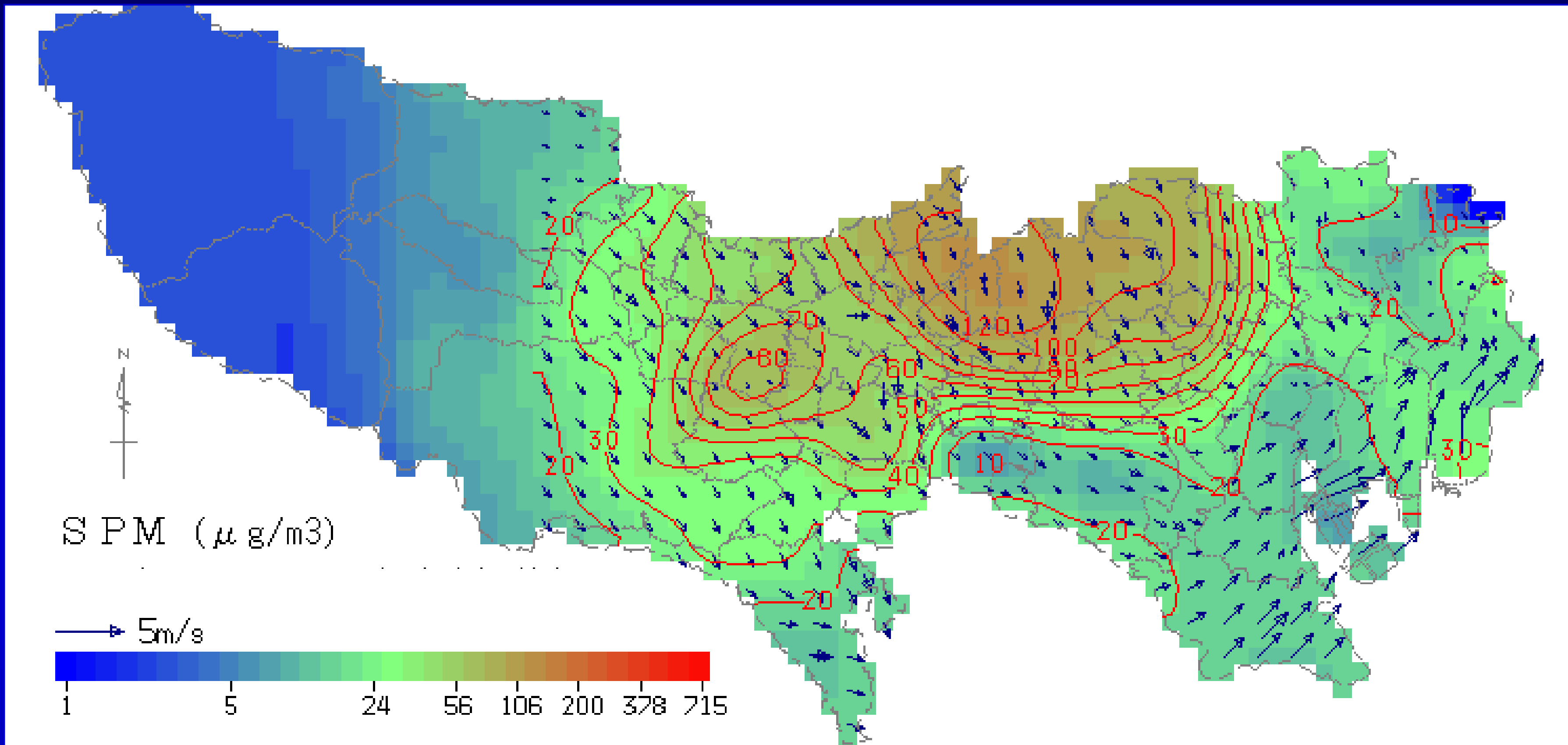
The 2003 RIETI-Hosei-MIT IMVP Meeting

September 12, 2003

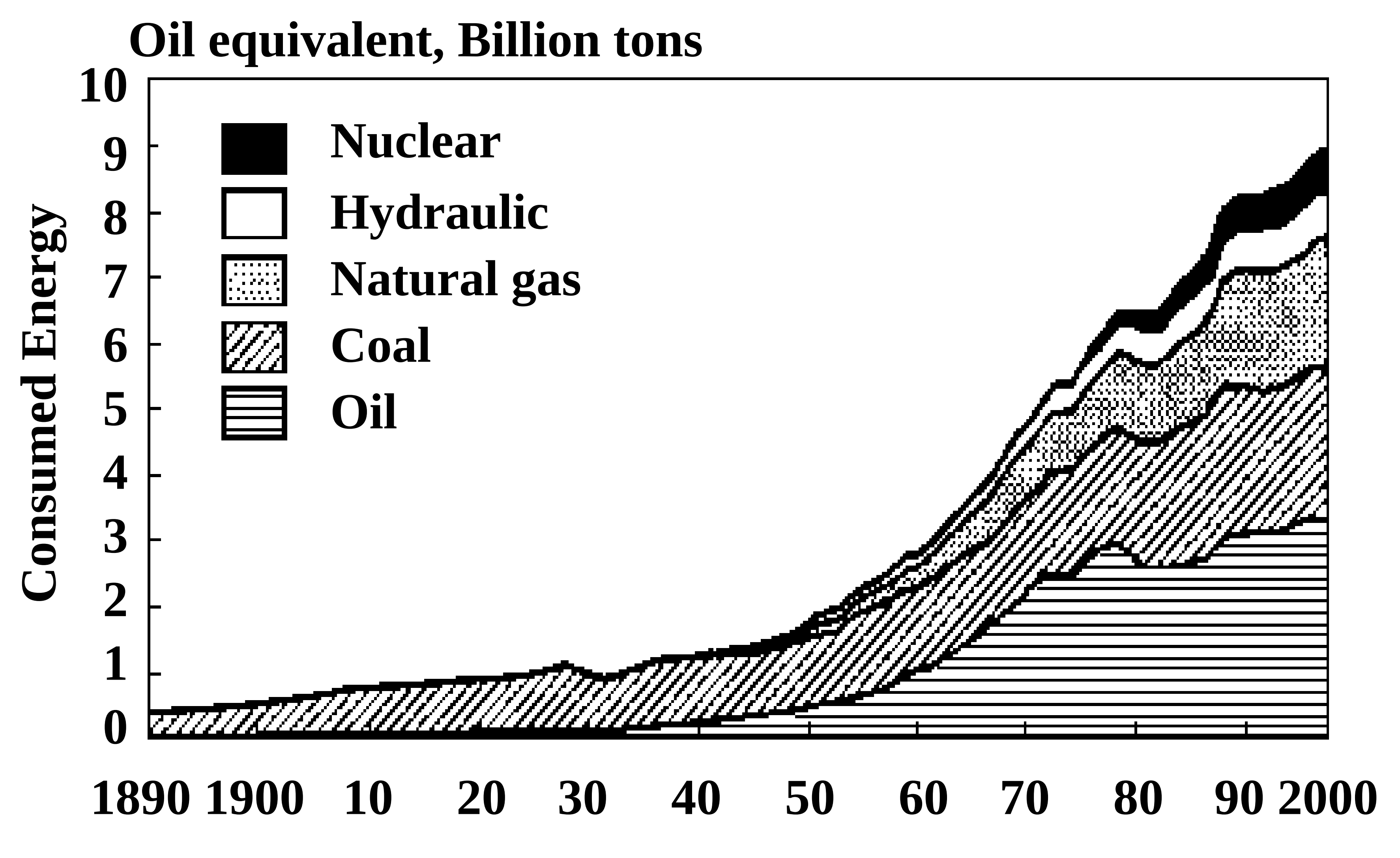
Recent Development of Fuel Cell Vehicles and Related Issues in Japan

Yasuhiro Daisho
Dept. of Mech. Eng., Waseda University
daisho@waseda.jp

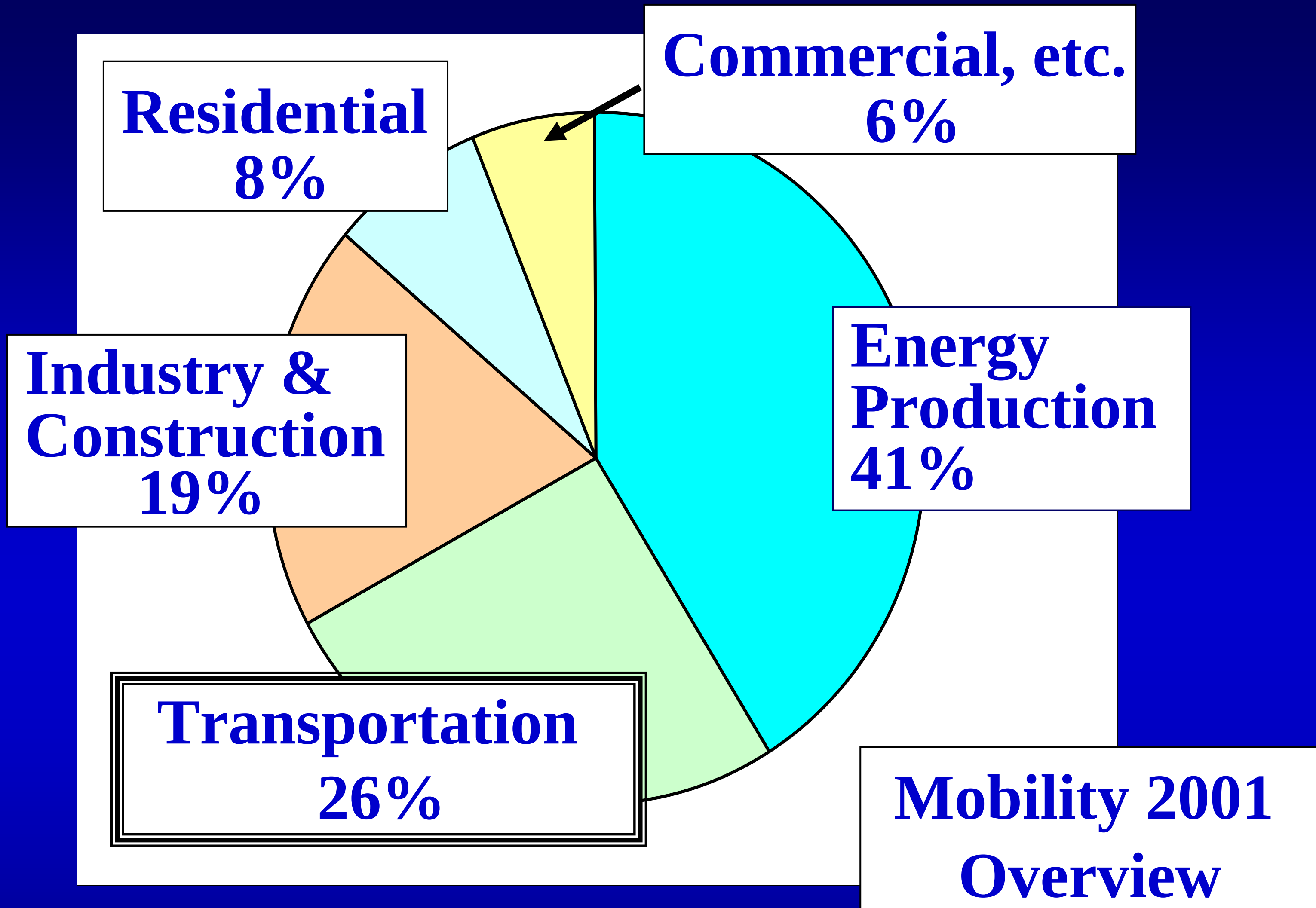


An Example of Monitored SPM Concentration and Wind Velocity Map on the Tokyo Metropolitan Web-site (23 p.m., Feb. 28, 2001)

Hear no diesel. See no diesel. Smell no diesel.



Estimated Annual Energy Consumption in the 20th Century



Worldwide CO_2 Emission Caused by Combustion, 1998

“The Action Plan for Developing and Disseminating Low Emission Vehicles”

~ MOLIT, METI and MOE in July, 2001 ~

- ☆ Disseminating 10 million LEVs for practical use by the year 2010. Included are:
  - a) CNG, Electric, Hybrid and Methanol Vehicles
  - b) Vehicles meeting the 2010 fuel economy standard and 2000 LEV guideline.
- ☆ Developing “Next-Generation LEVs” including:
  - a) FC Vehicles (50,000 FCVs introduced by 2010)
  - b) Super clean diesel, advanced hybrid system and DME engine for heavy duty vehicles
- ☆ Policy measures will be taken to achieve the targets.

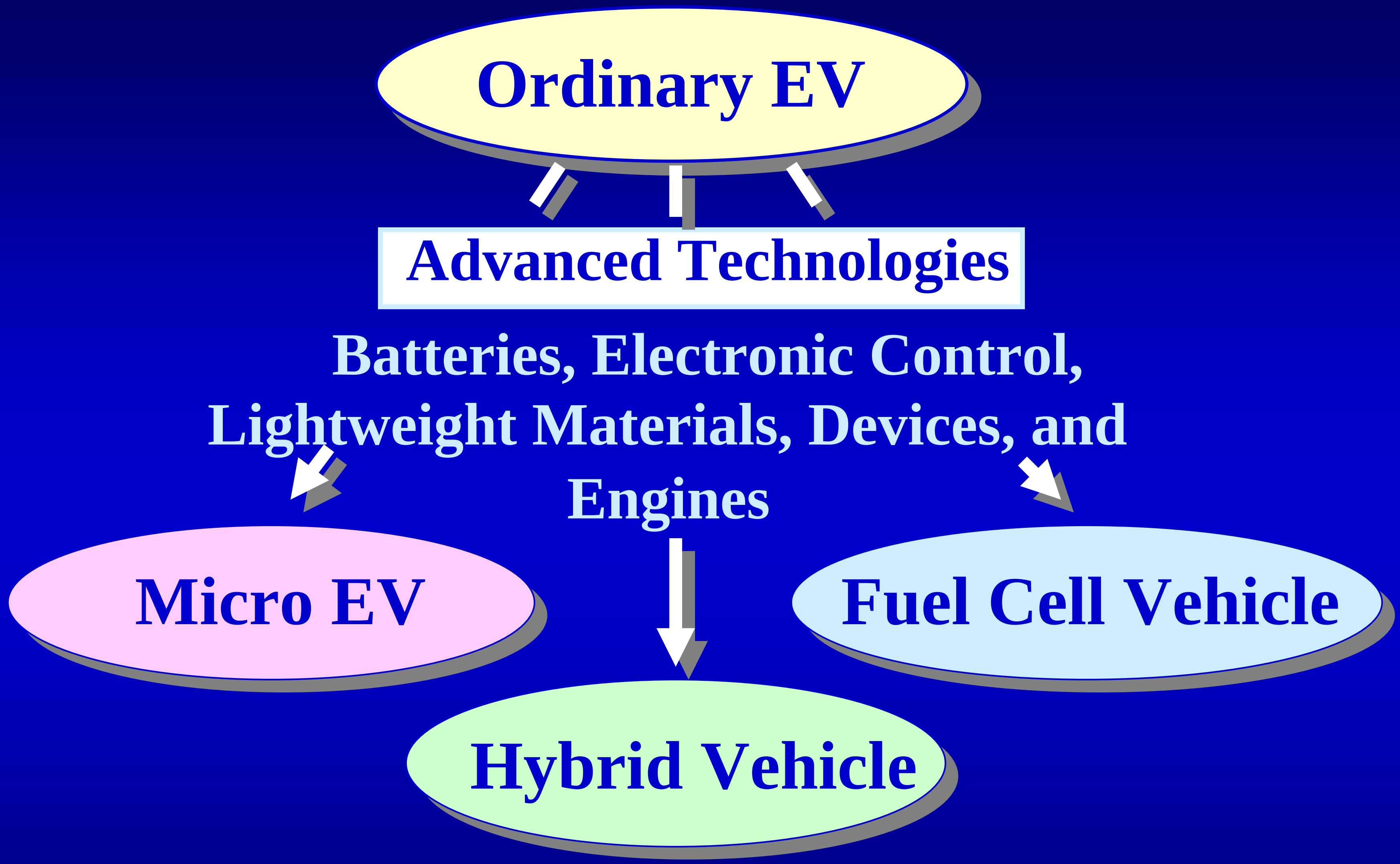
Expected Clean Energy Vehicles in 2010

Vehicle Type	2010 (present)
Electric Vehicles	110,000 (3,800)
Hybrid Electric Vehicles (including 50,000 FCVs)	2,110,000 (80,000)
Natural Gas Vehicles	1,000,000 (12,000)
LPG Trucks	260,000 (21,000)
Total	3,480,000 (117,000)

(Agency of Natural Resources and Energy, Japan, 2001)

Roles of Alternative Vehicles and Fuels

- ☆ Low or Zero Emissions,
- ☆ High Fuel-Efficiency,
- ☆ Low CO_2 Emission,
- ☆ Energy Diversity,
- ☆ Renewable and/or
- ☆ Symbolic



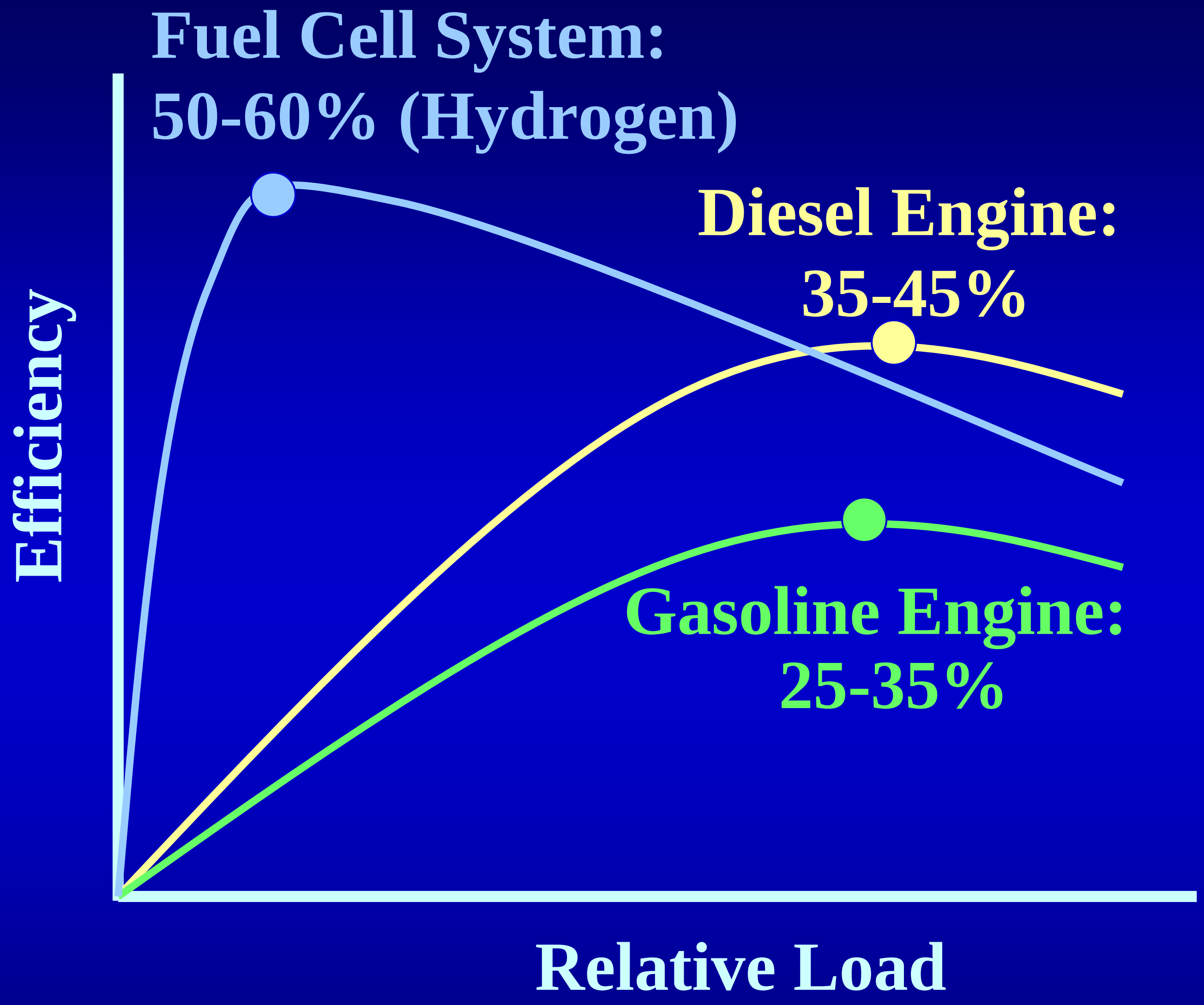
Variations of the Electric Vehicle

Toyota's e-com

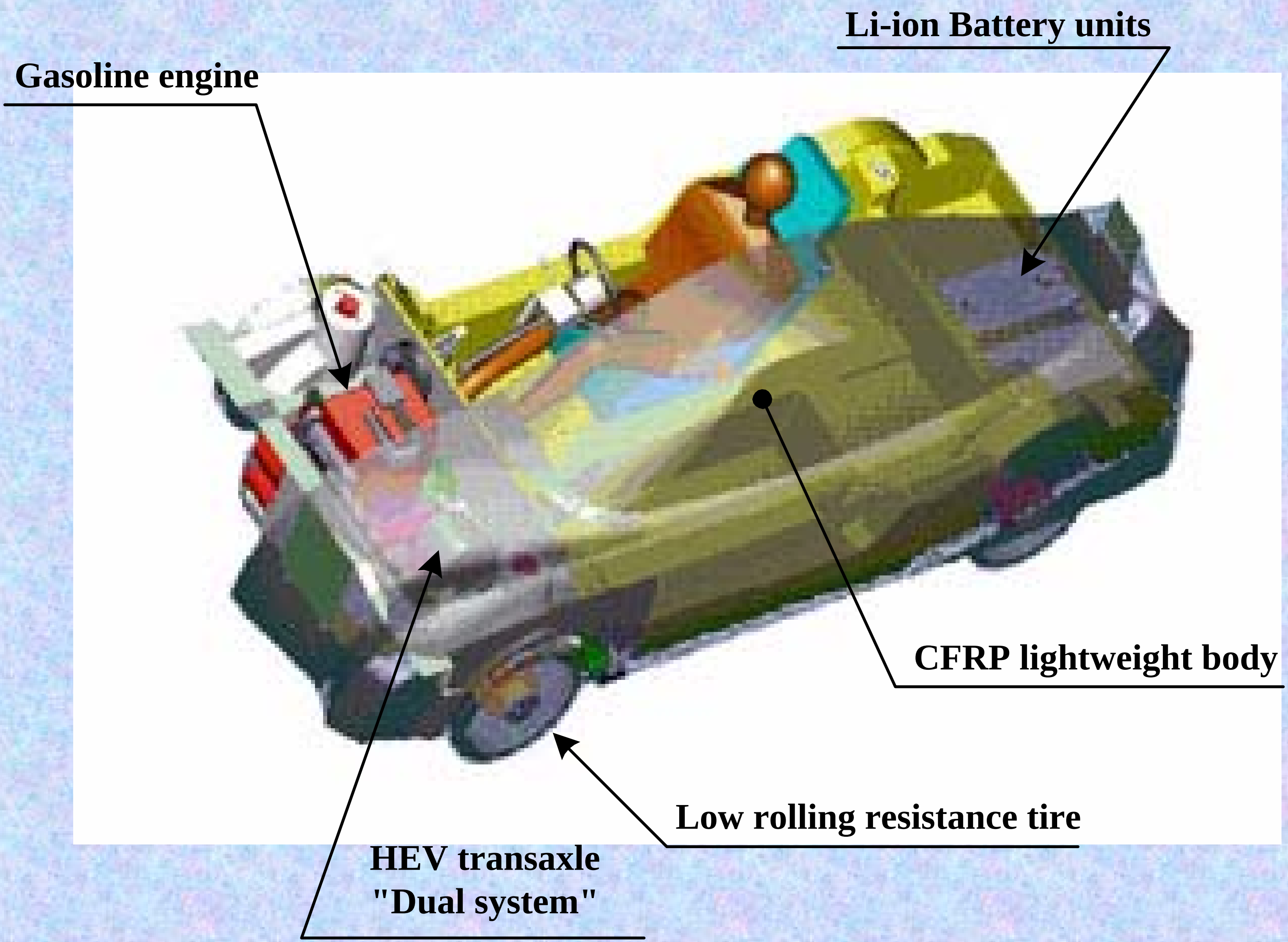
Honda's City pal

Nissan's Hypermini

Micro Electric Cars for Urban Use



Efficiency as a Function of Load



“Waseda Future Vehicle”

"WFV on a Proving Ground"

“WFV on a Chassis Dynamometer”

Vehicle mass: 740 kg
Fuel economy: 34.1 km/L (10-15 mode)

Toyota's Hybrid "Prius" (Dual Type)

L×W×H: 4.275 X 1.695 X 1.490 m   Vehicle curb mass: 1,240 kg

Riding capacity: 5   Hybrid system: Dual

Fuel economy: 31 km/L (10-15 mode)   Engine displacement: 1,496 cc

Motor controller: IGBT inverter

Motor type: A.C. synchronous motor   Maximum power: 58 kW

Battery type: Nickel-metal hydride

Number of batteries*voltage: 38*288V   Battery capacity: 6.5 Ah

Price: ¥2,150,000

Toyota's "New Prius" in September, 2003

- L×W×H: 4.445 X 1.725 X 1.490 m — Vehicle curb mass: 1,250 kg
- Riding capacity: 5 — Hybrid system: Dual
- Fuel economy: 35.5 km/L (10-15 mode) — Engine displacement: 1,496 cc
- Motor controller: IGBT inverter
- Motor type: A.C. synchronous motor — Maximum power: 50 kW
- Battery type: Nickel-metal hydride
- Number of batteries: 28 — Battery capacity: 6.5 Ah
- Price: ¥2,150,000-2,570,000

Honda's Hybrid "Insight" (Parallel Type)

L×W×H: 3.940 X 1.695 X 1.355m Vehicle curb mass: 820 kg

Riding capacity: 2 Hybrid system: Honda IMA(parallel)

Fuel economy: 35 km/L (10-15 mode) Engine displacement: 1,000 cc

Transmission: 5MT (or AT achieving 32 km/L)

Motor type: A.C. synchronous motor Maximum power: 10.0 kW/3000 rpm

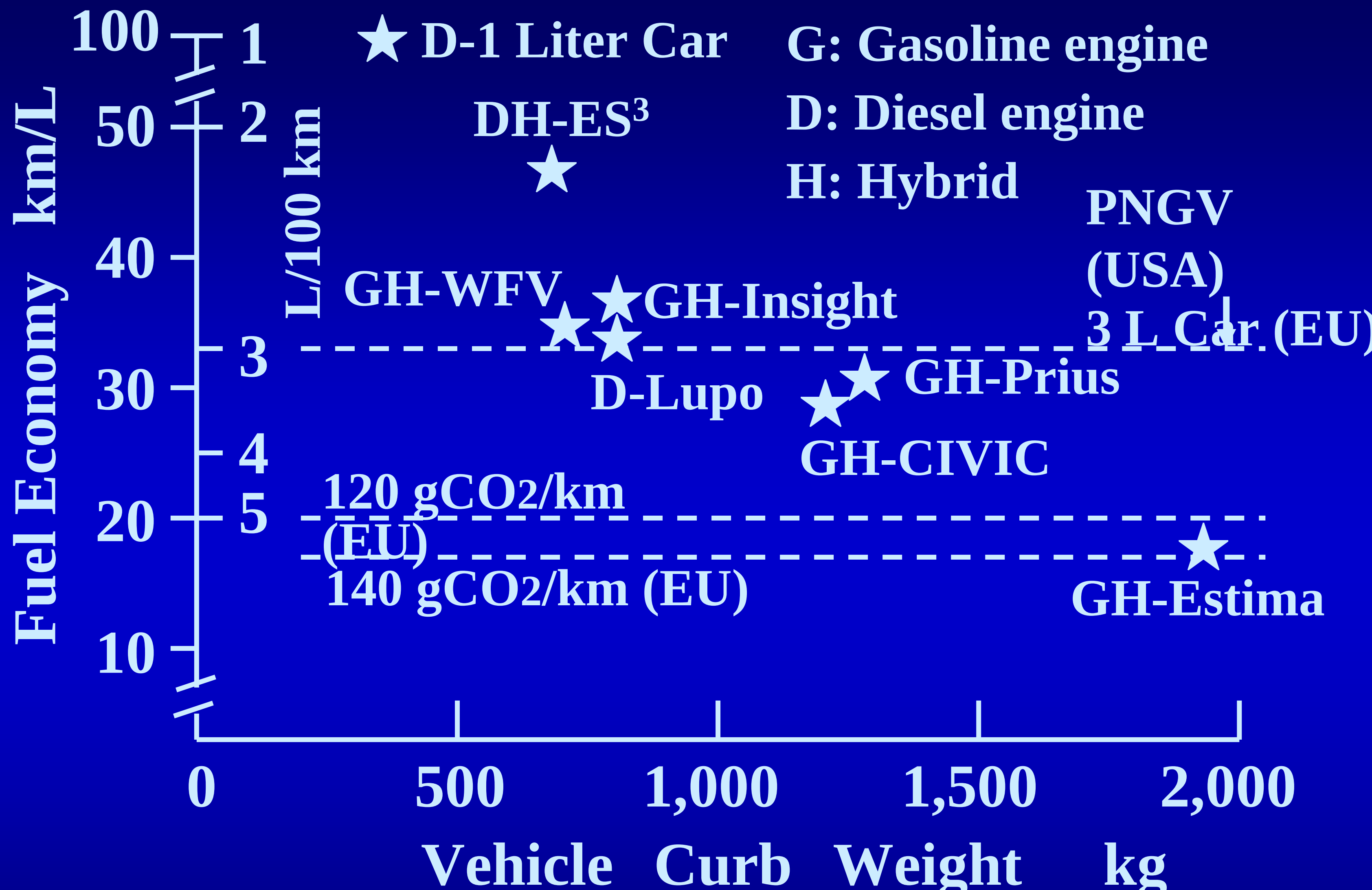
Battery type: Nickel-metal hydride Battery capacity: 6.5 Ah

Number of batteries*voltage: 20*144V

Price: ¥2,100,000

Engine: 1.364 L Turbocharged DI Diesel
Fuel Economy:
47 km/L (Japanese 10-15 mode)
2.7 L/100 km (37 km/L, EC mode)
L×W×H: 3.52×1.63×1.46 m
Vehicle Weight: 700 kg, Occupancy: 4

Toyota's Prototype Diesel Hybrid Passenger Car "ES^3" (Oct., 2001)



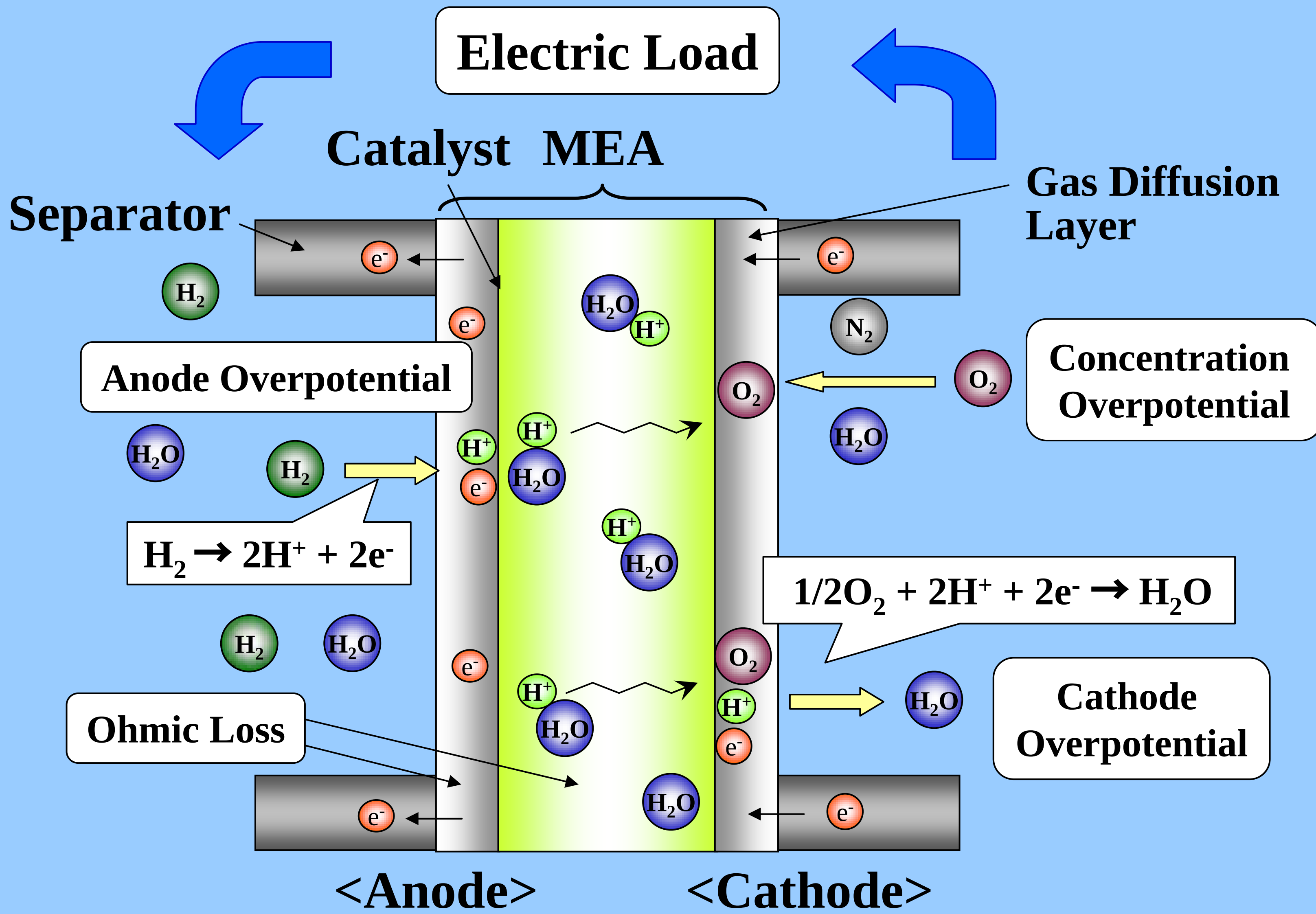
Fuel Economy of Advanced Diesel and Hybrid Passenger Cars

Hybrid Vehicles Developed and Sold in Japan

Source: JEVA, 2002

Type	Size	Name	Maker	Range	Battery	Motor/System
PC	Compact	Prius	Toyota	31 km/L	Ni-MH	AC Synch/ P/S
		Insight(MT)	Honda	35	Ni-MH	AC Synch/ P
		Insight(AT)	Honda	32	Ni-MH	AC Synch/ P
		CIVIC-H	Honda	29.5	Ni-MH	AC Synch/ P
	Medium	(Tino-H)	Nissan	20	Li-ion	AC Synch/ P
		Estima-H	Toyota	18	Ni-MH	AC Synch/ P/S
		Crown(Mild)	Toyota	15	Lead	AC Synch/ P
Truck	(3.5 t)	Ranger	Hino	8 (60km/h)	Lead	AC Induct/ P
Bus	Micro	Coaster	Toyota	5.3	Lead	AC Induct/ S
	Transit	Blue Ribbon city	Hino	30%↑	Ni-MH	AC Induct/ P

Note: Micro hybrid PCs and HD hybrid trucks are being developed by Japanese automakers



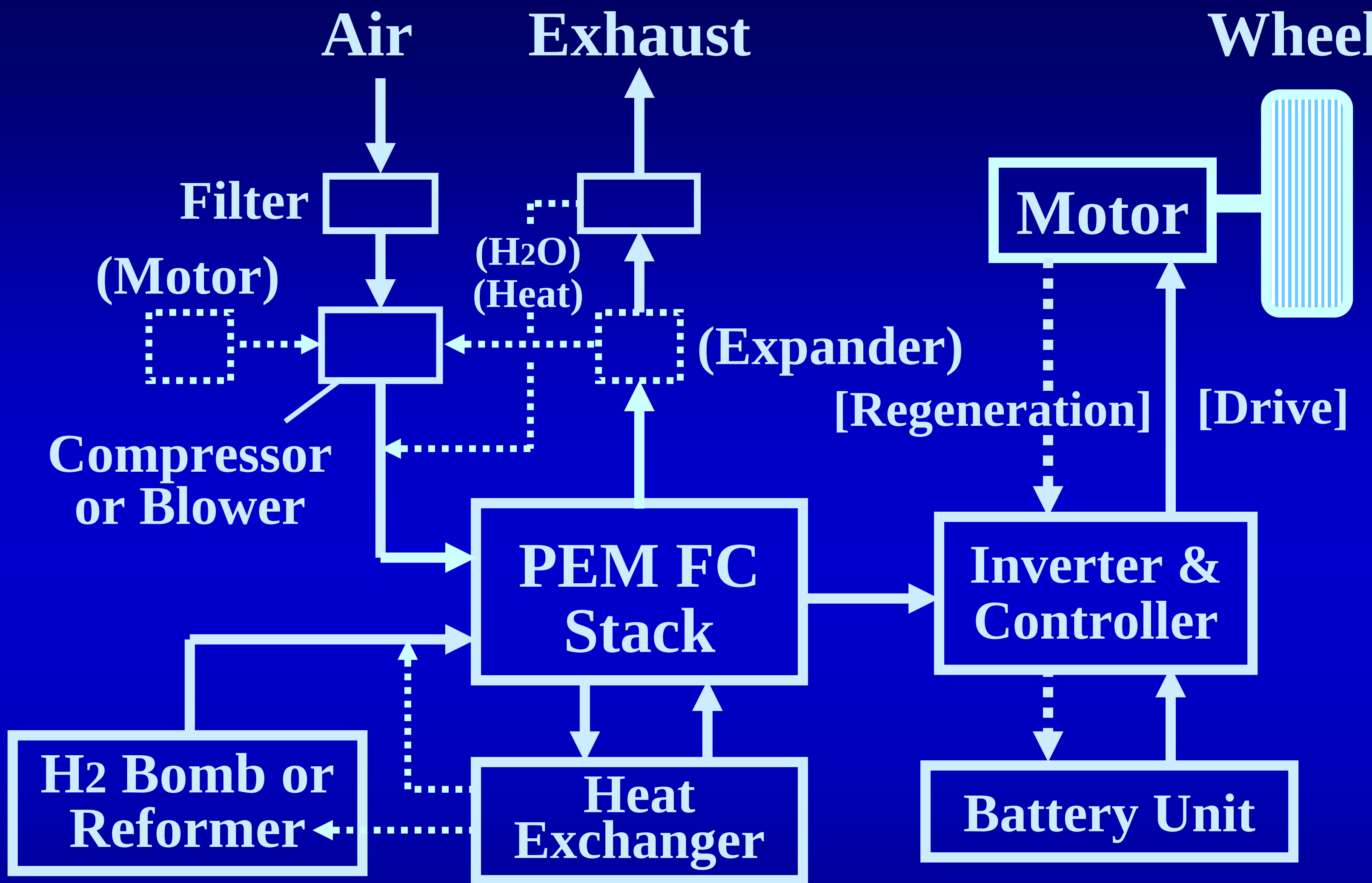
The Inside of a PEM Fuel Cell

Prototype FCVs Developed in Japan

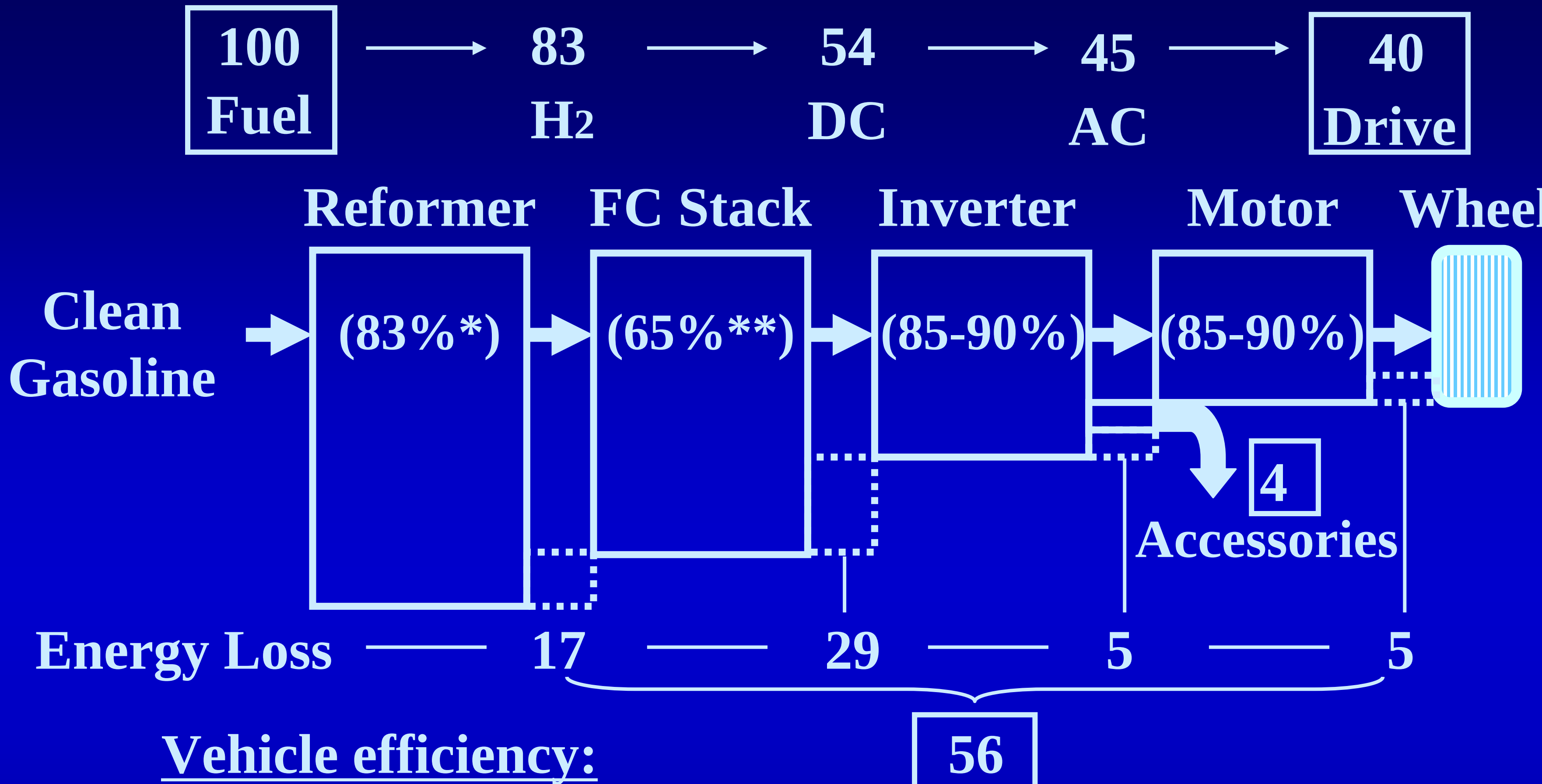
1996-2001 Source: JEVA, 2002

Automaker	1996	1997	1998	1999	2000	2001	2002
Daihatsu				M		M	
Toyota	H	M				H H B C	H B
Nissan		M		M	H		H
Fuji						M	
Honda				M H M	H	H H	H
Mazda		H		H		M	
Mitsubishi				M		(M)	

Fuels- M: Methanol, H: Hydrogen,
C: Clean Hydrocarbon B: FC Bus (Hydrogen)



A Typical Fuel Cell System and Key Components



Vehicle efficiency:

a) 48% for on-board reforming with a hybrid system

b) 60% for a) on H_2 basis (LHV)

* : Efficiency target

**: Efficiency target (LHV)

Tank-to-Wheel Efficiency in the FC System

(The Committee Report on FC Development Strategies, Agency of Natural Resources and Energy, August, 2001)

Technical Targets for Developing FCVs (1)

Time Frame: Prototype Demonstration in 2003-2004
Commercialization after 2010

Component	Targets
FC Stack	Efficiency: >65% at 25% load (LHV) (Vehicle based efficiency: >60%) Power Density: >1.3 kW/L Durability: >5000 hours for passenger cars 10,000-20,000 hours for buses 30,000-60,000 cycles for 10 years
Reformer	Efficiency: 83% (LHV), Higher load response Volume: <30 L/unit, Cost<¥1,000/kW
H_2 Storage	H_2: 5kg, Driving Range: >500 km Volume: <80 L, Weight: <90 kg
System Cost	<¥5,000/kW including a reforming system

(The Committee Report on FC Development Strategies,
Agency of Natural Resources and Energy, August, 2001)

Technical Targets for Developing FCVs (2)

Material	Present → Future target (2010)
Membrane	Temp. resistance: 80℃ → 120-150℃ Cost: ¥50,000-150,000/m^2 → ¥3,000-5,000/m^2 Lower humidification
Electrode Catalyst	Pt: 2-4 g/kW → 0.2-0.4 g/kW Cost: ¥4,000-8,000/kW → ¥400-800/m^2 CO resistance: 10 ppm → 10-50 ppm Higher durability, Low cost alternatives
Gas Diffusion Layer	Carbon paper Cost: >¥1,000/m^2 → ¥500/m^2
Separator	Carbon graphite Thickness: 1-5 mm → <1.0 mm Cost: >¥4,000/sheet → ¥100-200/sheet

(The Committee Report on FC Development Strategies, Agency of Natural Resources and Energy, August, 2001)

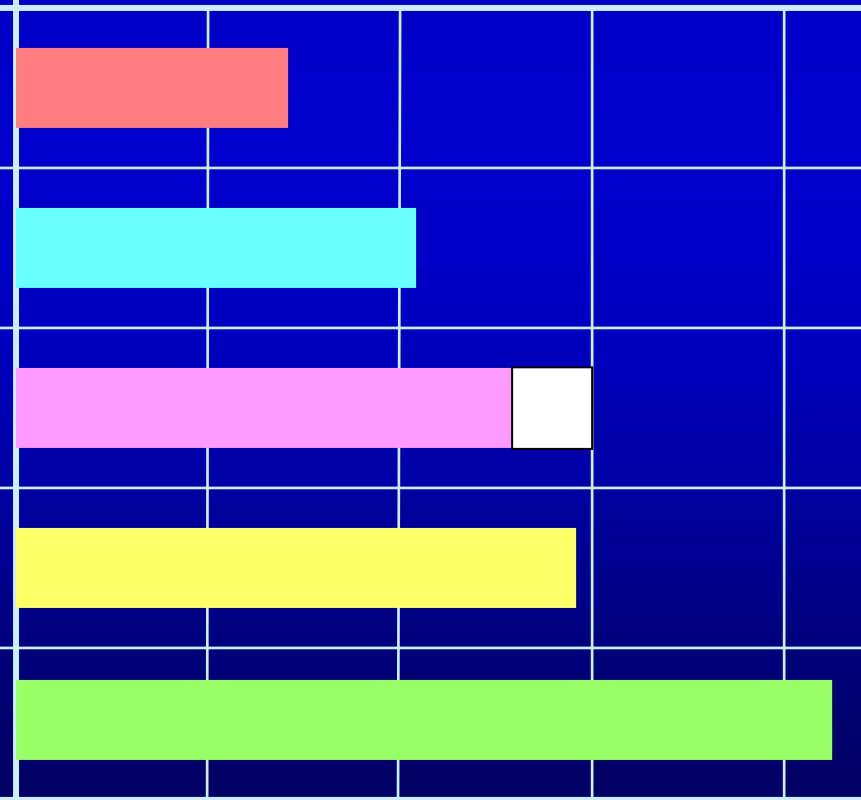
"Fuel Efficiencies in PEM Fuel Cell"

Fuel Source	Natural Gas	Natural Gas	Crude Oil
Product	H_2	Methanol	Gasoline
Production %	60～72	67～71	85～90
Reforming % (Temperature℃)	—	78～85 (200～300)	75～83 (700～800)
Fuel Cell %	55～60	50～55	45～50
Net %	33～43	26～33	29～37

(ExxonBobil)

Overall Efficiencies (estimated by Toyota)

Type (passenger car)	Fuel well-to-tank %	Vehicle tank-to-well %	Overall well-to-wheel % (0 10 20 30 40)
Gasoline V	88	16	
Electric V	26	80	
Gasoline HEV	88	30	
FCV (present)	58	50	
(target)	70	60	



How to store H_2?

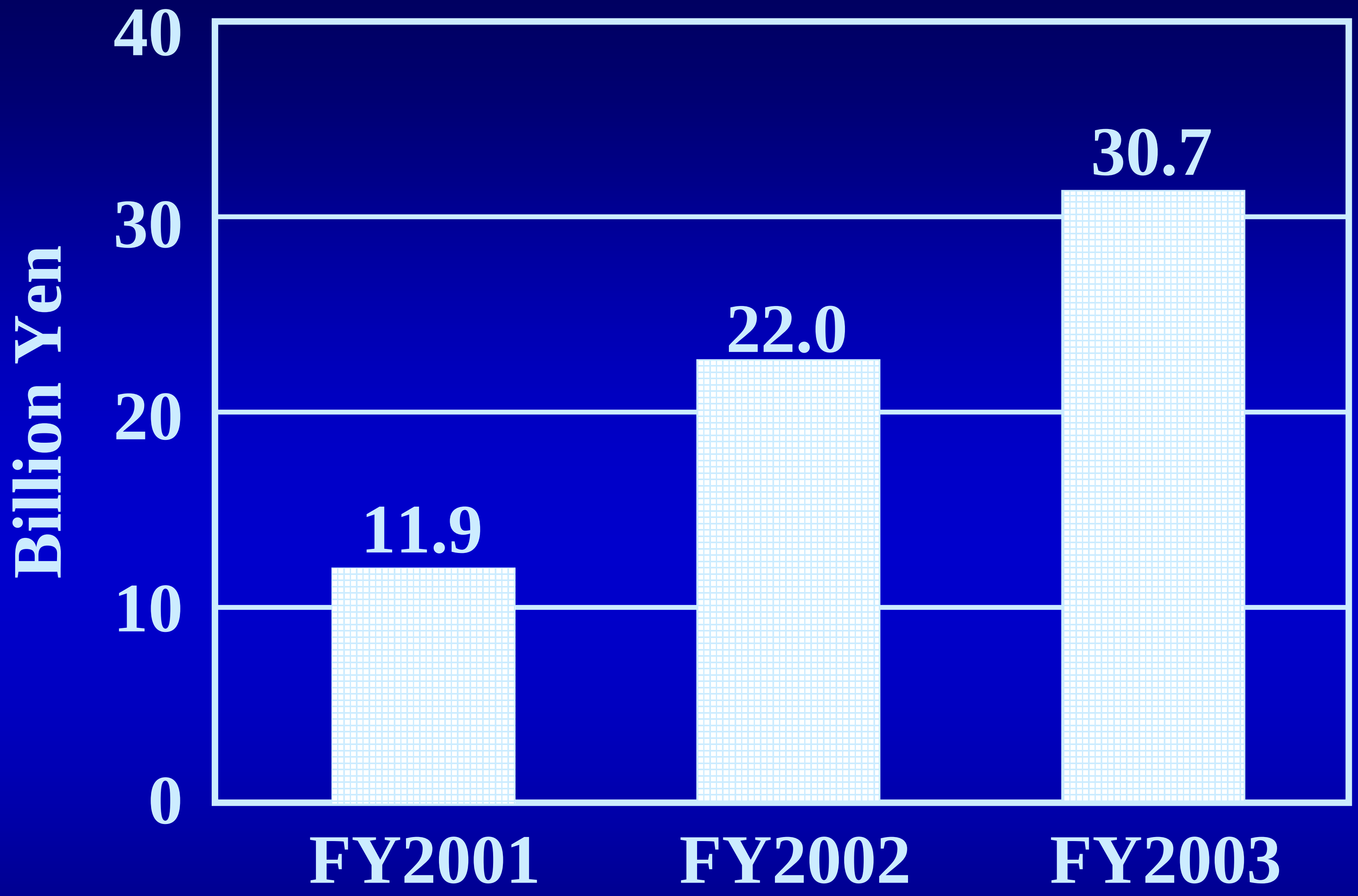
	Advantage and Disadvantage
Compressed (at 25-70 MPa)	○ Lower cost ○ More practical △ Lower safety △ Lower energy density
Liquefied (at -250℃)	○ Highest energy density △ High heat insulation △ Boil-off Loss △ High energy loss
Adsorbed (at 1.0-5.0 MPa)	○ Lower pressure and safer △ Lower energy density (by wt.) △ Longer refueling time △ Adsorbents to be explored

FreedomCAR 2002-2010

- Announced by Bush in January, 2002
- CAR: Cooperative Automotive Research by Big 3 and DOE in place of “PNGV”
- Vehicles: LD trucks and passenger cars
- Freedom:
  - from foreign oil dependence,
  - from pollutant emissions,
  - of vehicle choice, of mobility, and
  - of fuel affordability and convenience
- Development of Fuel Cell Systems and Fuel Stations

Technical Targets of "FreedomCAR"

- Peak overall system efficiency: 45%
- Cost: $45/kW by 2010 and $30/kW in 2015
- Hydrogen storage systems:
  - 6 wt%, specific energy of 2000 Wh/kg,
  - energy density of 1100 Wh/liter at $5/kWh
- High volume vehicle production:
  - 50% weight reduction, affordability, and
  - increased use of recyclable/renewable materials



Annual Governmental Budget for Fuel Cell-Related R&D in Japan (METI)

Major Projects and the Budget for Fuel Cell R&D in Japan (METI)

Budget: FY2002/FY2003 (Billion Yen)

■ R&D of:	
*PEFC Systems	5.3/5.11
*Hydrogen Safety Technologies	0/4.55
*Lithium-ion Batteries	1.0/1.95
*Stationary SOFC and MCFC Systems	3.3/3.59
*Mobile Direct-Methanol FC Systems	0/0.22
■ Testing On-road FCVs and Stationary FC Systems	2.5/3.86
■ Dissemination of PEFC Systems	3.1/3.87

A Scenario for Disseminating FCVs and Hydrogen Infrastructure

	2005	2010	2020
FCV Numbers		50,000	5,000,000
FCV Types	Public PCs & Buses	Light Trucks & Commercial PCs	Private PCs
H_2 Station Capacity	100	300 (80%-20%) 500 (20%-80%)	500 Nm^3/h
H_2 Supply		200 Million	6.2 Billion Nm^3
Station Numbers		Hundreds	3,300
H_2 Price			60 Yen/Nm^3

Japan Hydrogen & Fuel Cell Demonstration Project, "JHFC"

- Fiscal 2002-2004 by METI
- On-Road Tests of Fuel Cell Vehicles
- Automakers: Toyota, Honda, Nissan, GM and DC
- Five Different Hydrogen Refueling Stations for:
  Compressing and Liquefying Hydrogen and Reforming LPG, Desulfurized Gasoline and Methanol
- Purpose: to acquire and analyze data on vehicle performance, reliability, environmental characteristics and fuel economy as well as on the refueling stations

Max. Speed: 150 km/h

Occupancy: 4

Motor Power: 60 kW

FC Power: 78 kW

CH_2: 35 MPa (156.6 L)

Range: 355 km

(Source: http://www.jhfc.jp/fcv001_en.html)

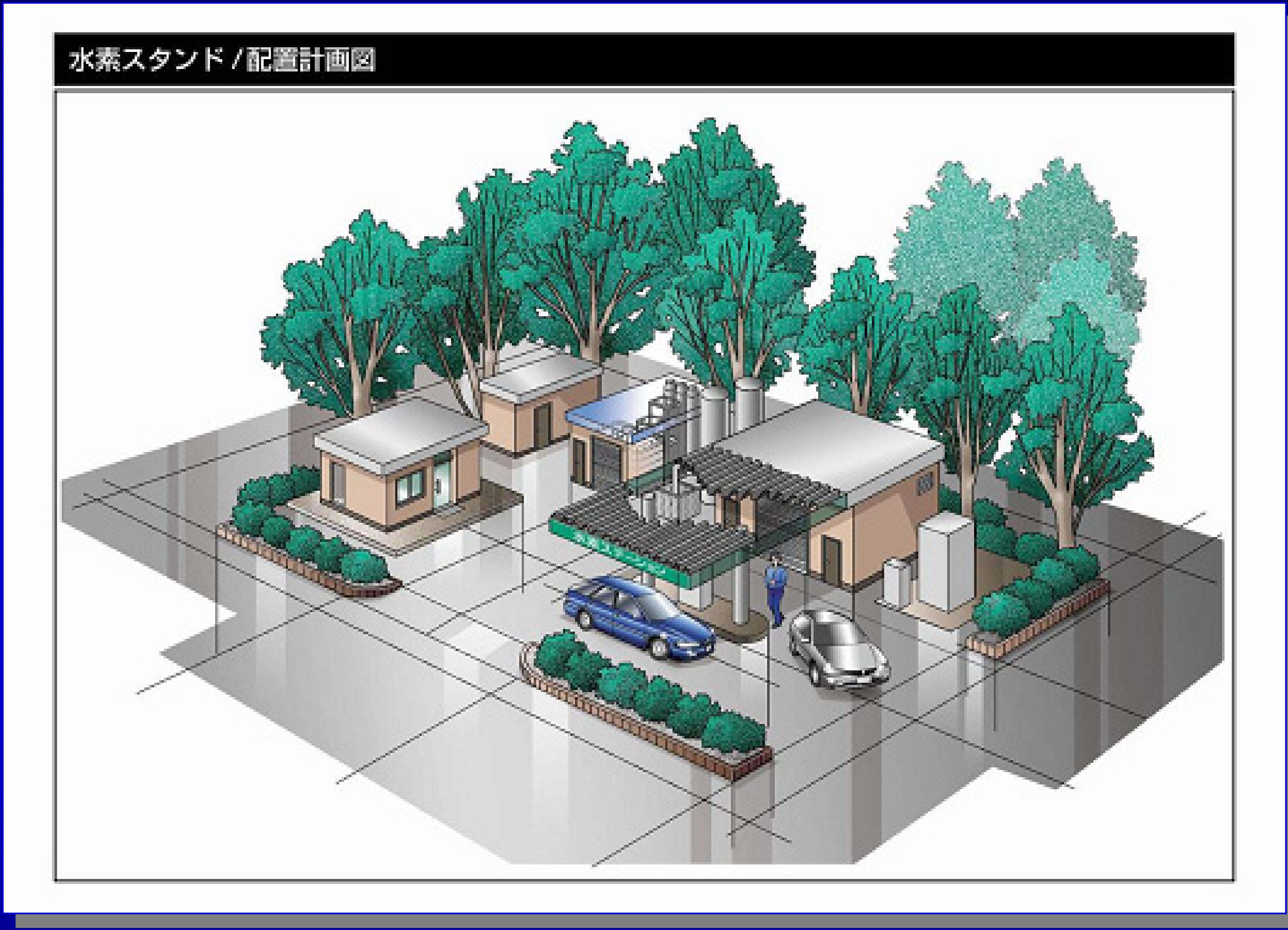
FCVs Participating in "JHFC"

(Source: http://www.jhfc.jp/fcv001_en.html)

Max. Speed: 80 km/h, Max.
Motor Power: 80 kW×2, FC Power: 90 kW×2
Fuel: Compressed H_2 at 35 MPa, MHNi batteries
Occupancy: 60 Passengers, Low Floor Deck

Hydrogen Refueling Stations for "JHFC"

Hydrogen Production	Location	Company
Liquefied H_2 Storage	Ariake, Tokyo	Iwatani Int. and Showa Shell
LPG Reforming	Minami-senju, Tokyo	Tokyo Gas and Nippon Sanso
Desulfurized Gasoline Reforming	Daikoku-cho, Yokohama	Cosmo Oil
Naphtha Reforming	Kami-shirane-cho, Yokohama	Nippon Oil
Methanol Reforming	Kojima-cho, Kawasaki	Air Liquid Japan
Liquefied H_2 Production	Kimitsu, Chiba	Nippon Steel

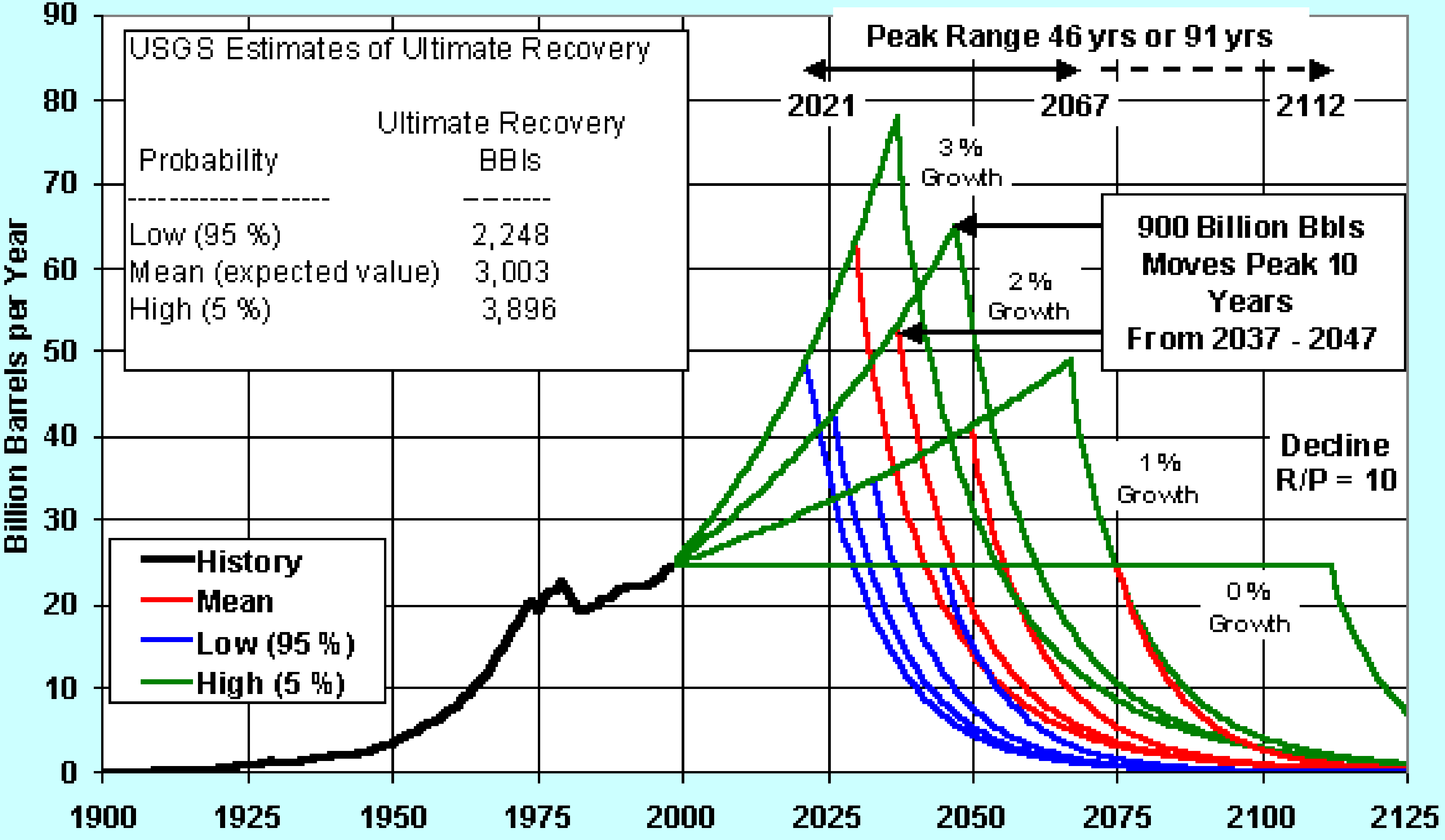


A Hydrogen Station Constructed for “JHFC”

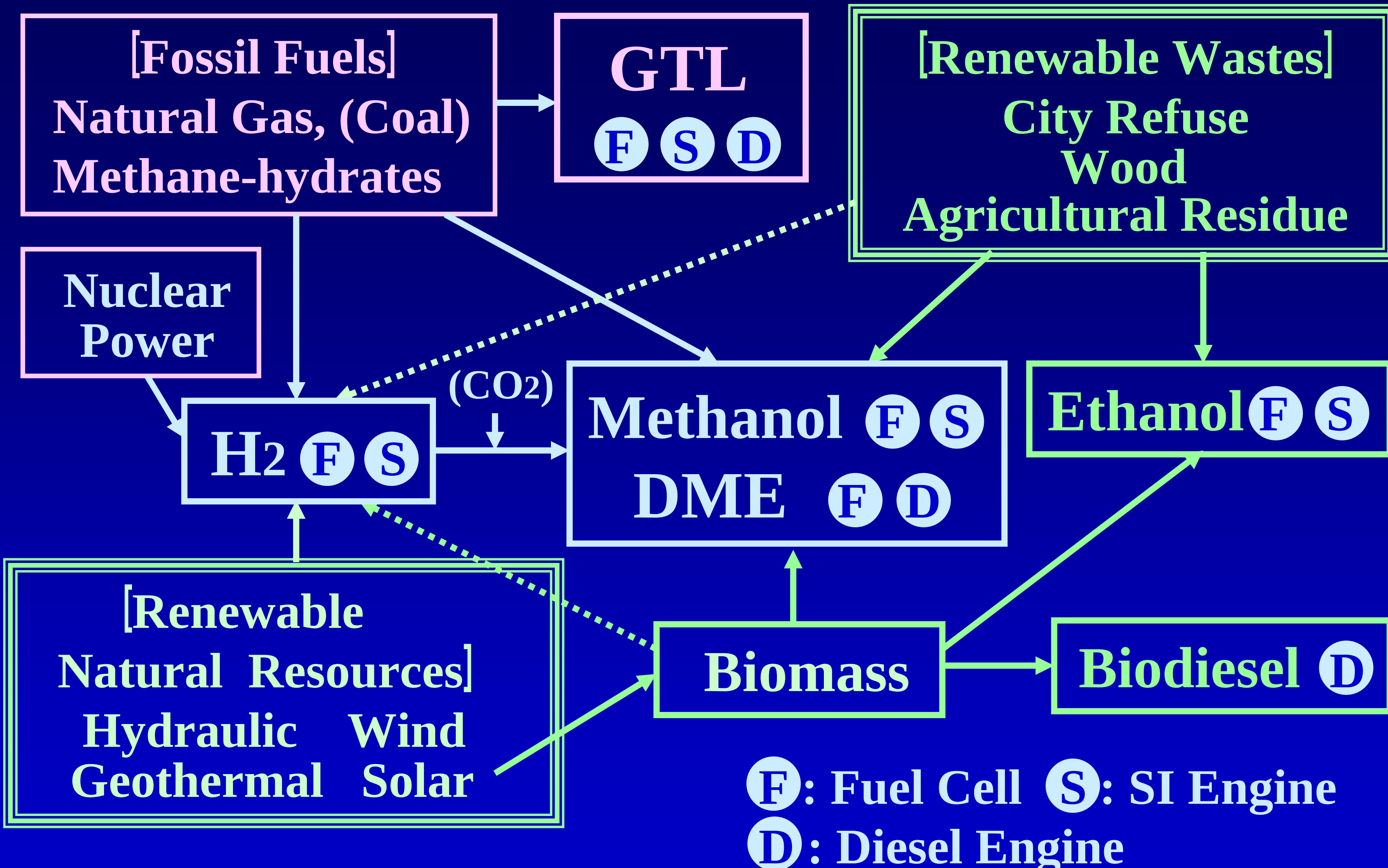
Problems with FCVs to be resolved

- What is the best fuel from the viewpoints of "well-to-wheel" energy and environmental impact? ' ' ' Hydrogen, Clean Gasoline, Natural gas, Methanol or Renewables?
- Improving cold start and war-up performance
- Developing and improving key components
- Developing fuel, air, water and thermal management systems
- Overcoming reliability, safety and cost issues
- Enhancing public awareness

12 EIA World Conventional Oil Production Scenarios



Note: U.S. volumes were added to the USGS foreign volumes to obtain world totals.

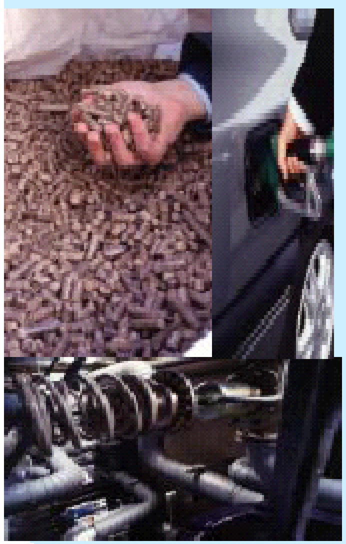


Processes for Producing Alternative Fuels

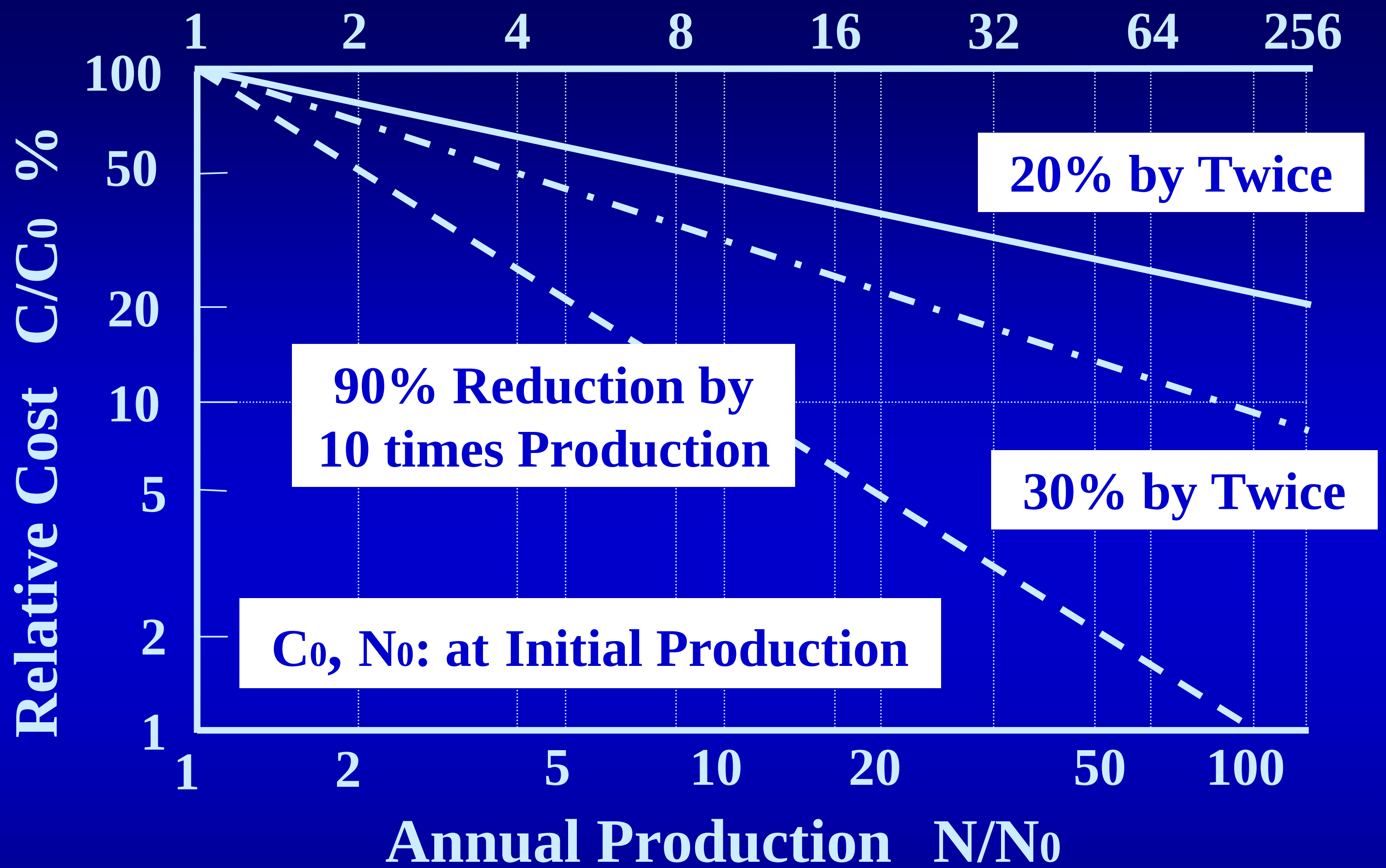
Assessment

Options with potential over the next 20 years

Only three options appear to have a volume potential of more than 5% fuel consumption. If **active policy** is decided to promote them, their **optimistic** development scenario is (% fuel consumption):



	Biofuel	Natural gas	Hydrogen	Total
2005	2			2
2010	6	2		8
2015	(7)	5	2	14
2020	(8)	10	5	(23)



Possibility of FCV's Cost Reduction by Mass Production

Reserves of Platinum-Group Metals

Country	Reserves, tons
United States	800
Canada	310
Russia	6,200
South Africa	63,000
Other Countries	700
World total (rounded)	71,000

100 g/vehicle are available.

(Source: U.S. Geological Survey, 2001)

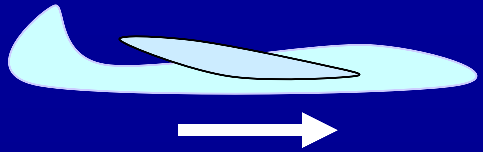
- Public Acceptance -

* Performance * Fuel economy
* Affordability * Reliability
* Safety * Zero-emission

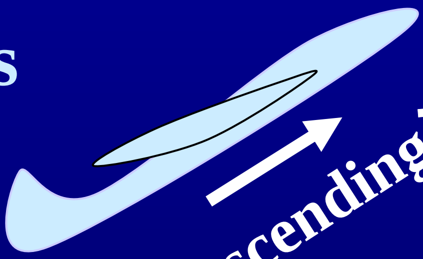
- Policies -

* Incentives * Subsidies
* Deregulations
* Public awareness
* Standardizations

(5,000,000 FCVs in 2020?)

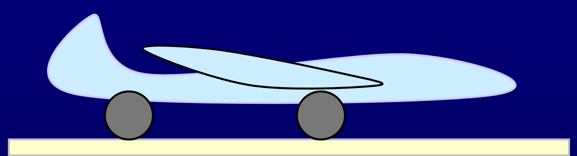


<Cruising>
~Commercialized~
20X0



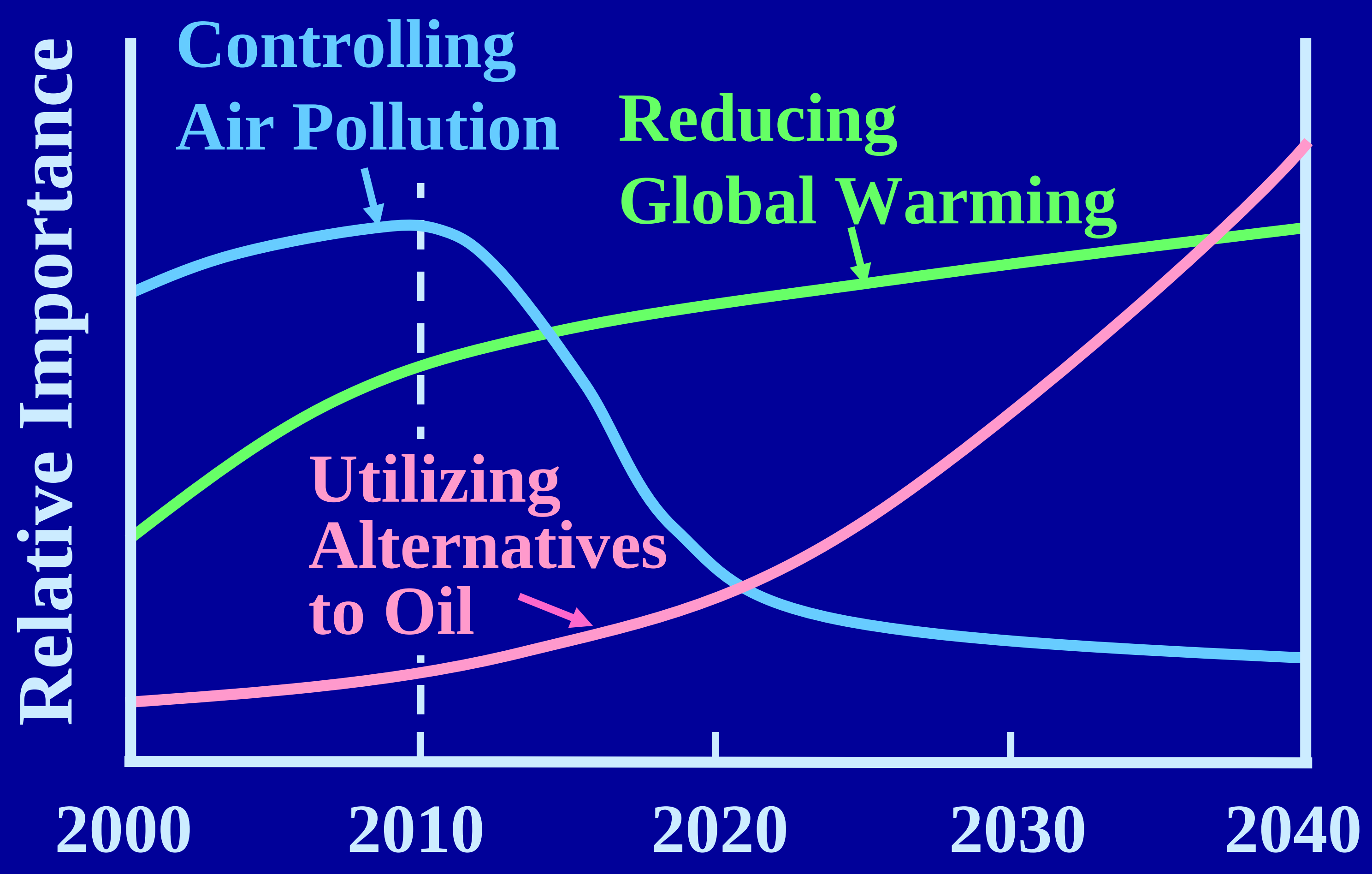
<Ascending>

Coexisting, competing and comparing with conventional vehicles and fuels for decades

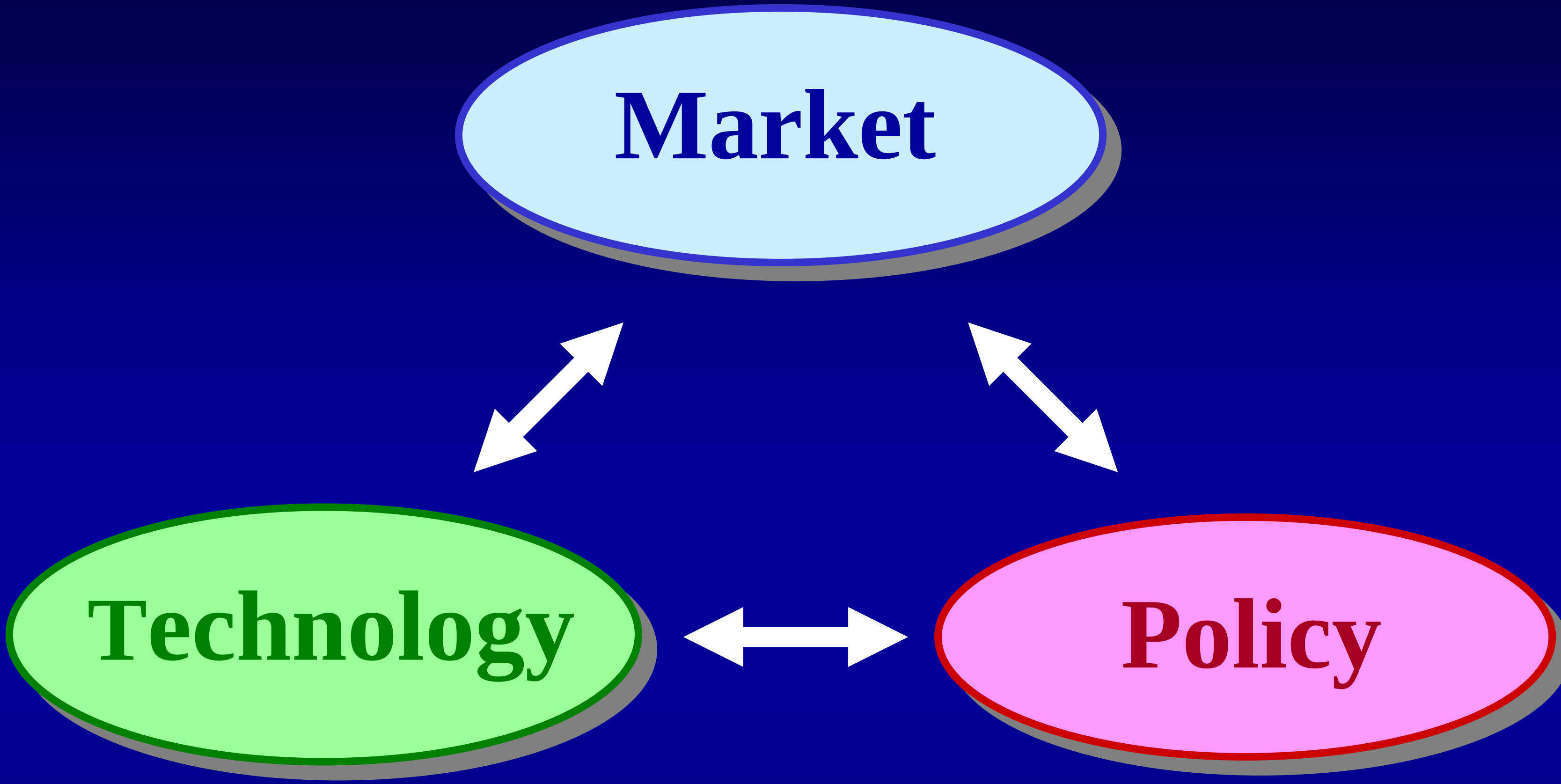


<Taxing on the runway>
~Demonstration~
2002 – 2010
(50,000 FCVs?)

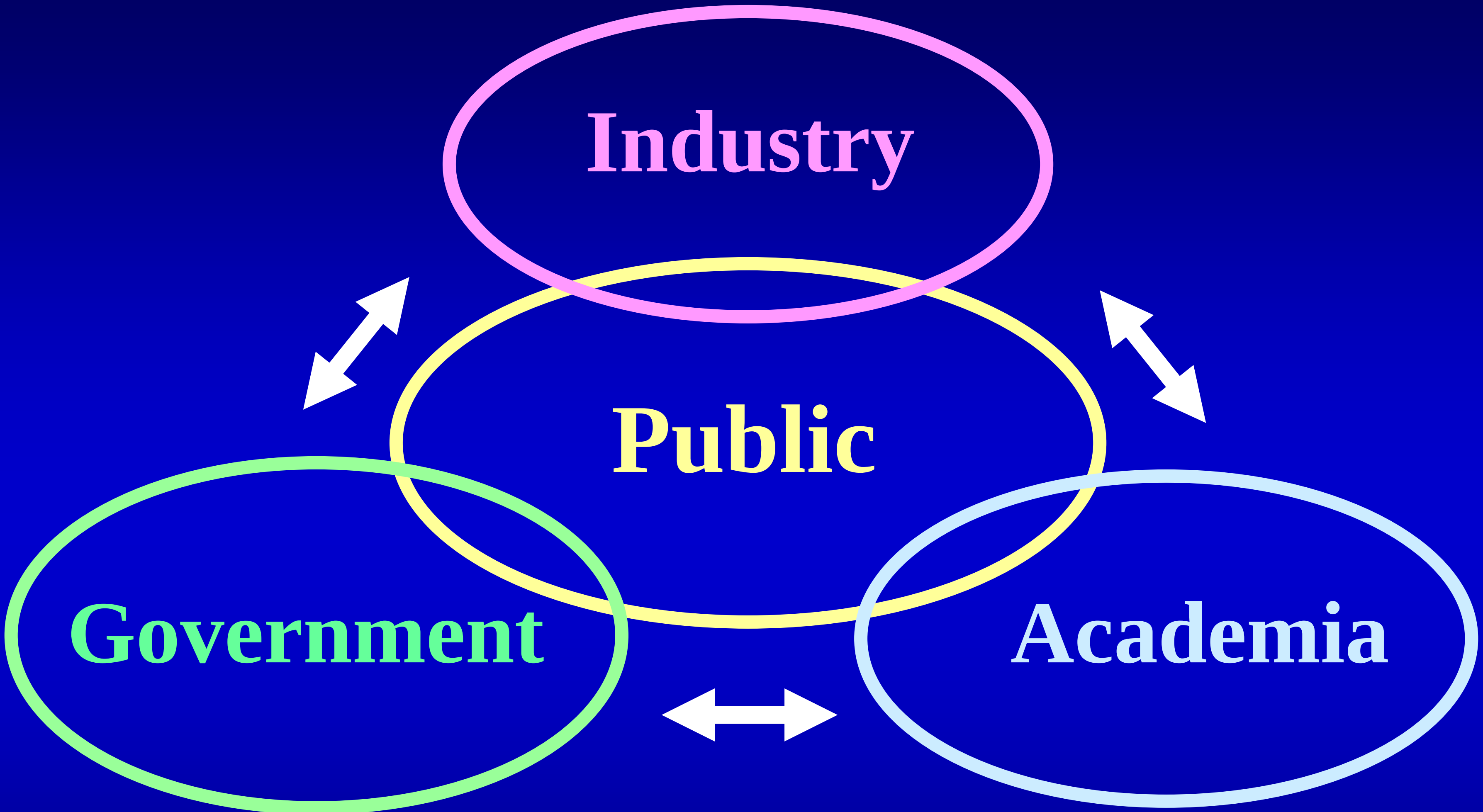
How to Create Transitional Processes for Introducing Fuel Cell Vehicles



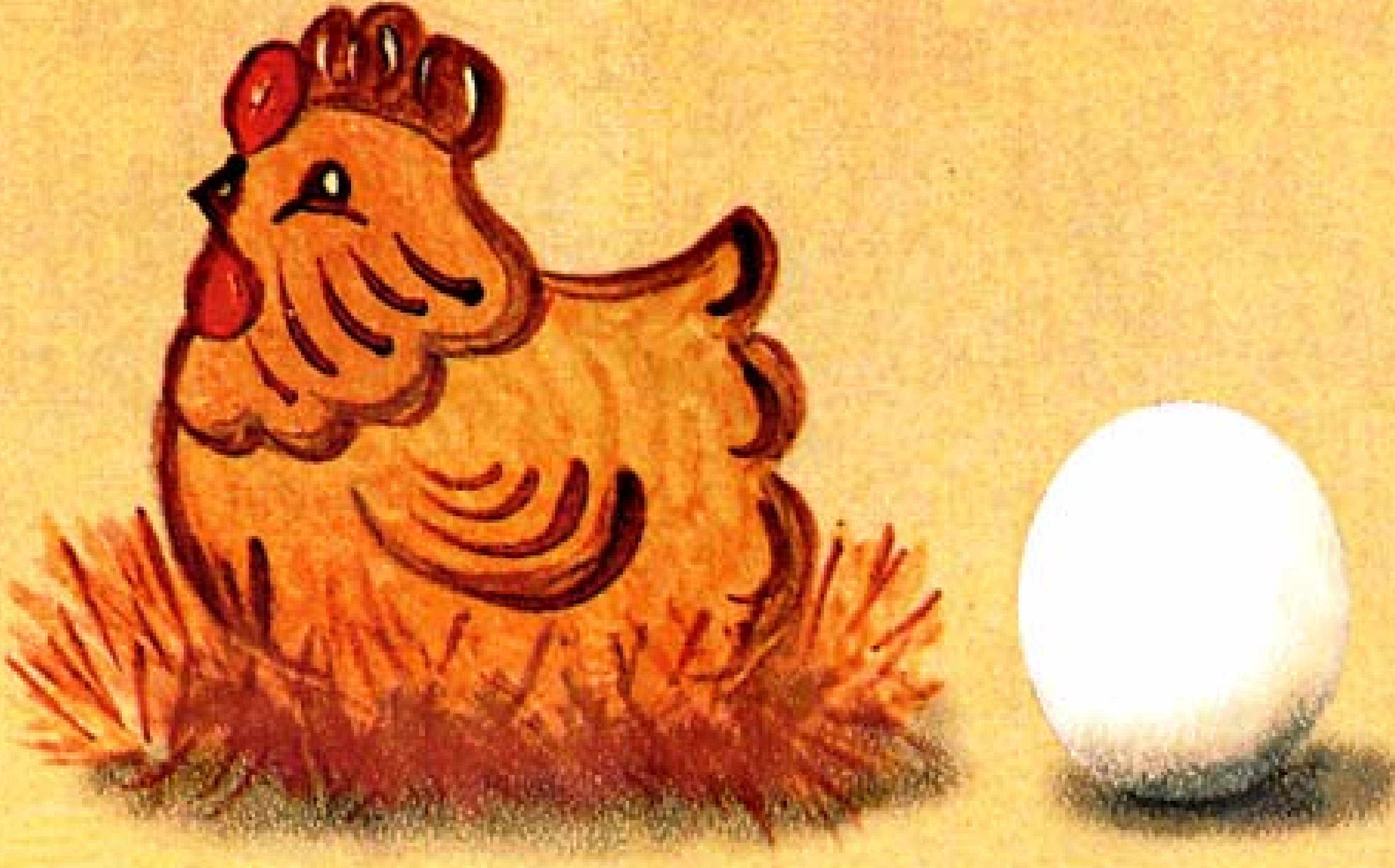
Future Relative Importance of Policy and R&D for EVFs



Three Key Issues for Introducing Low Emission and Energy Efficient Vehicles



Collaboration is important!



"Chicken and the Egg" Dilemma