California and U.S. Initiatives to Mitigate Greenhouse Gas Emissions in the Transportation Sector

National Fuel Cell Research Center

UCIrvine | University of California

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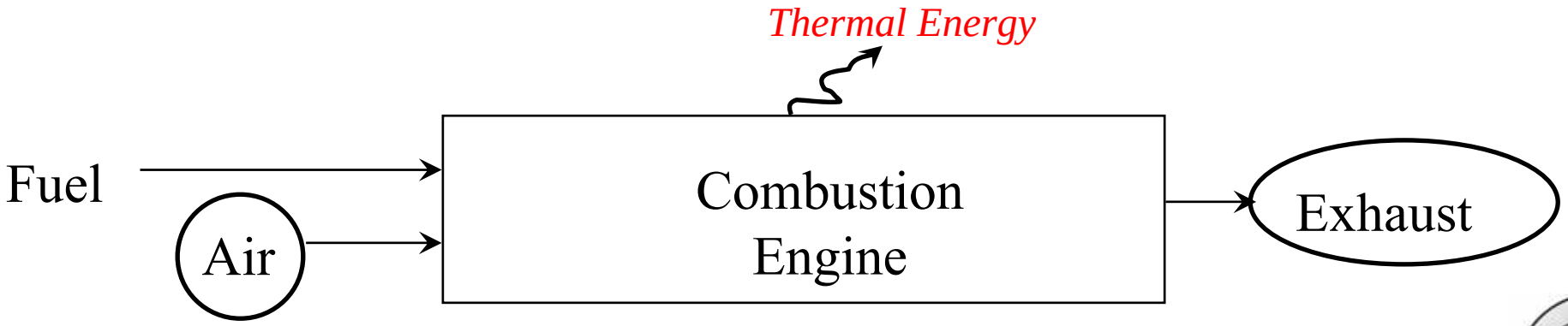
Associate Director

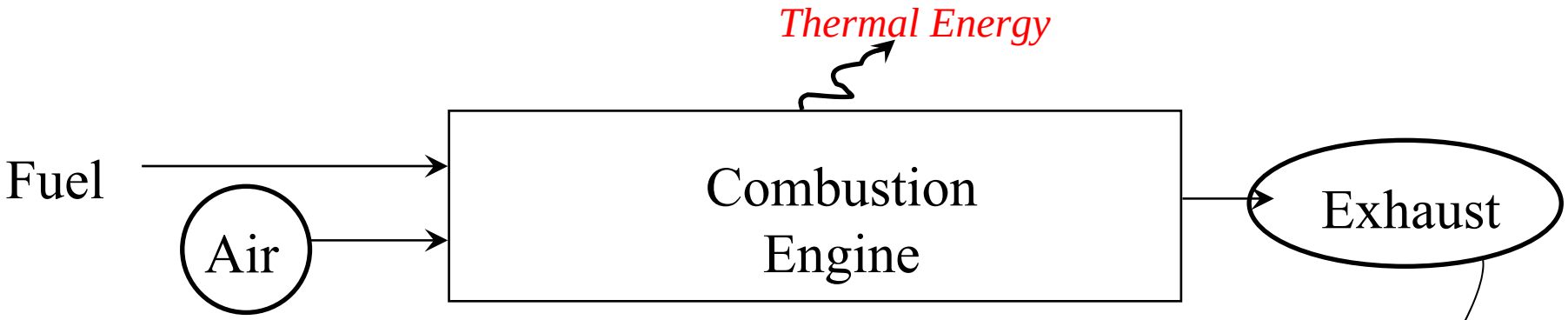
July, 2008

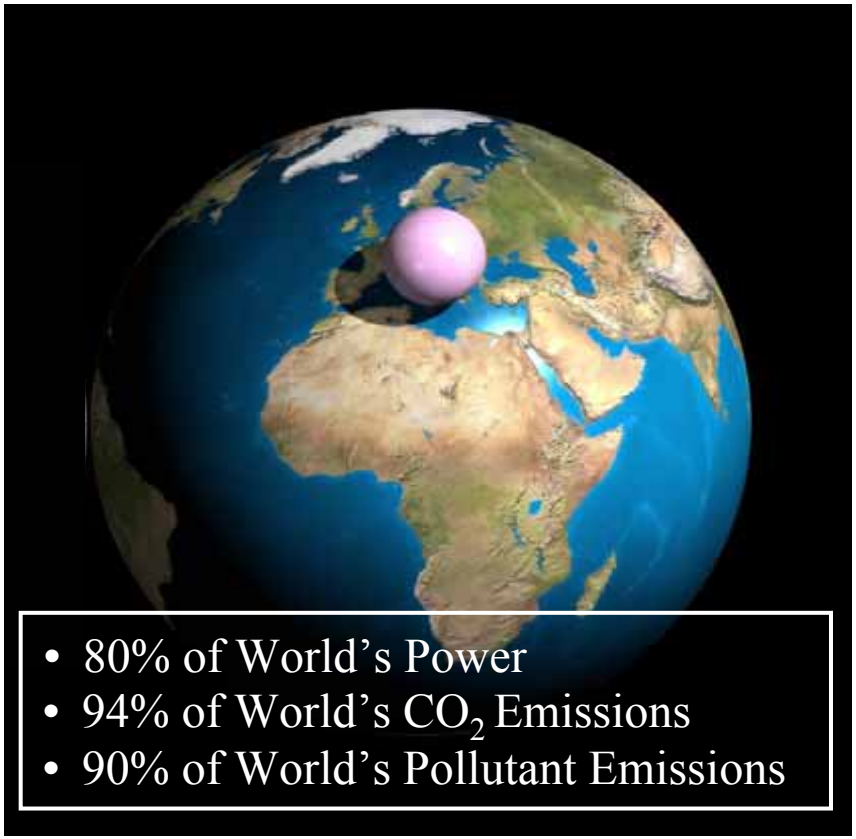
Setting the Stage

Primary Energy → Engine → Societal Use



Combustion





Source: Science Photo Library

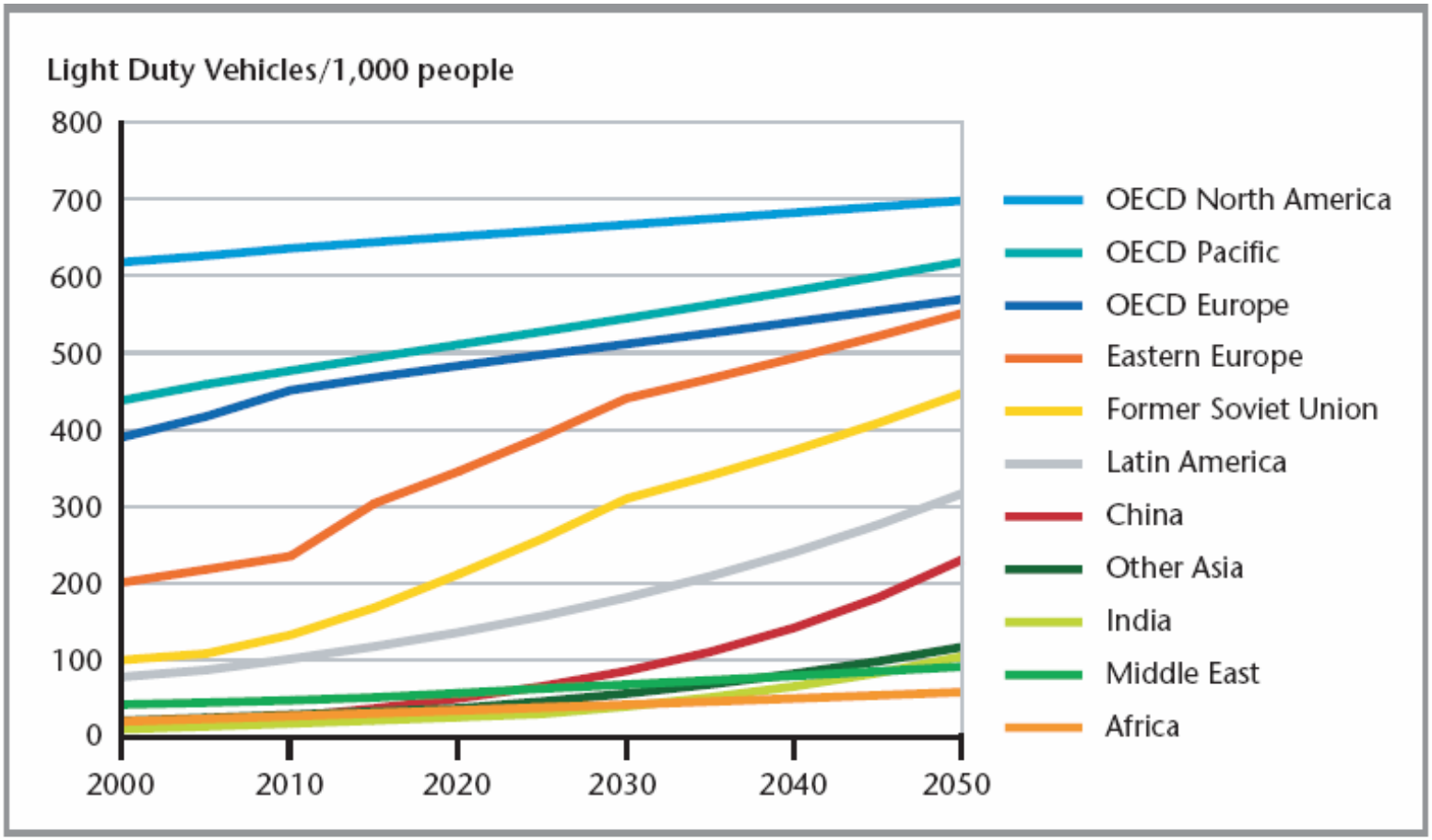
CO_2 + H_2O + N_2 + Pollutants

GHG

Smog

Vehicle Demand Forecast

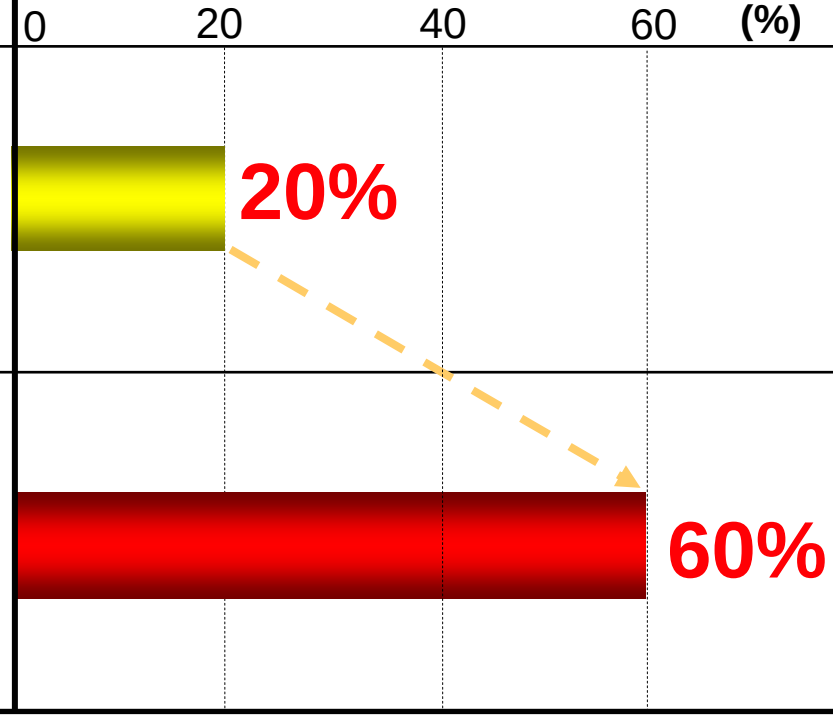
- OECD vehicle populations are huge and still growing
- Demand increase is tremendous in Eastern Europe, Former Soviet Union, China, Latin America, Other Asia, …



Source: Sustainable Mobility Project calculations.

Vehicle Demand Forecast

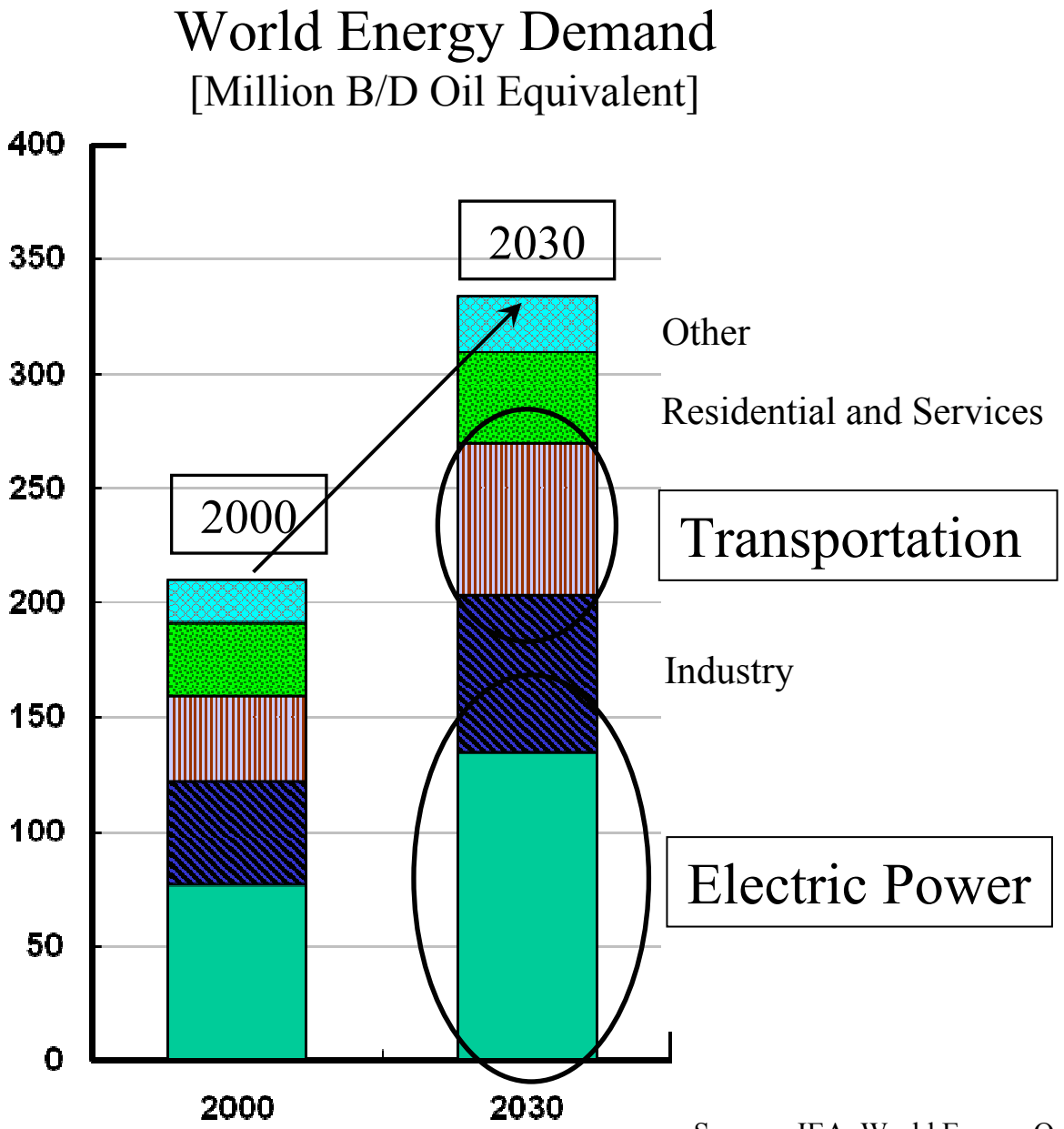
Year	World Population (Billions)	Availability of Automobile	World Vehicle Ownership (Billions)	Environmental Impact
2000	6.1	20%	0.74	1.0
2050	8.9	60%	3.24	4.4



Toyota estimates, 2006

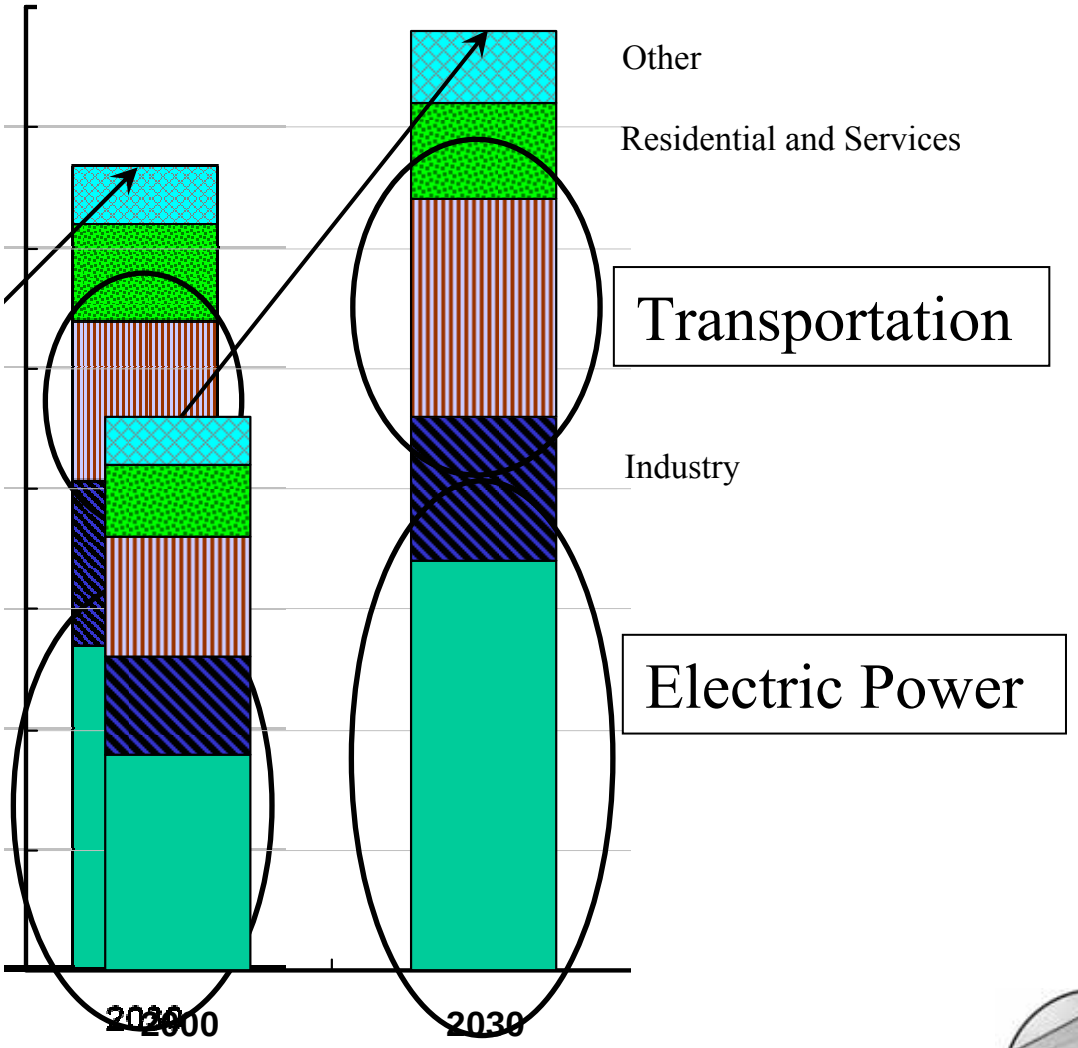
→ Factor of ~4 – 5

Energy Demand Forecast



Source: IEA World Energy Outlook, 2006

Greenhouse Gas (GHG) Intensity Forecast



SOURCE: IEA WORLD ENERGY OUTLOOK

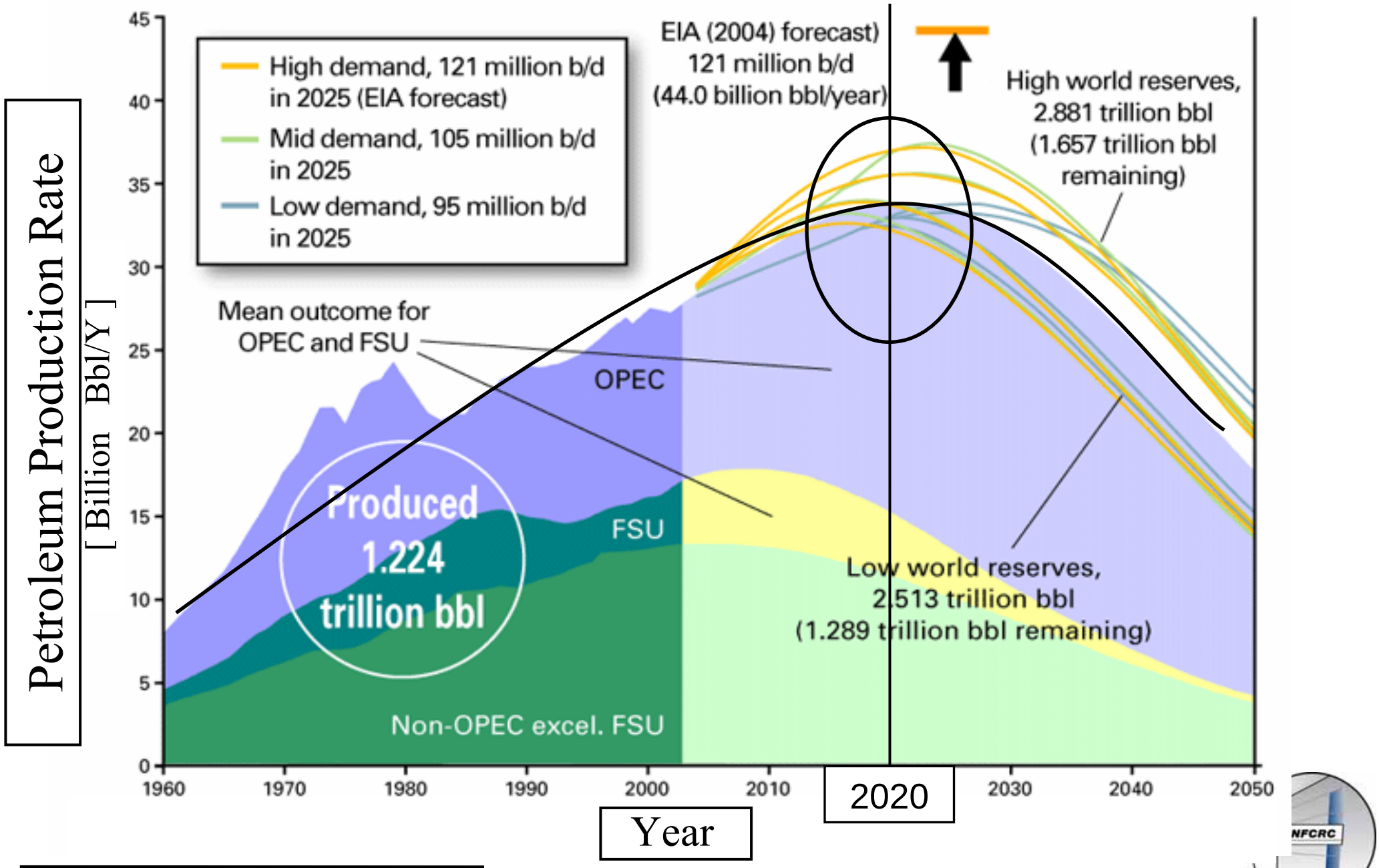
Forces for Change

#1 Green House Gas Intensity (1990)

#2 Pollutant Impacts (1940)

#3 Hubbert's Curve (1980)

Hubbert's Curve



Forces for Change

#1 Greenhouse Gas Intensity (1990)

#2 Pollutant Impacts (1940)

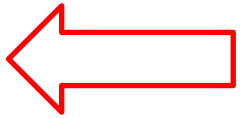
#3 Hubb

#4 Fuel

#5 Natic

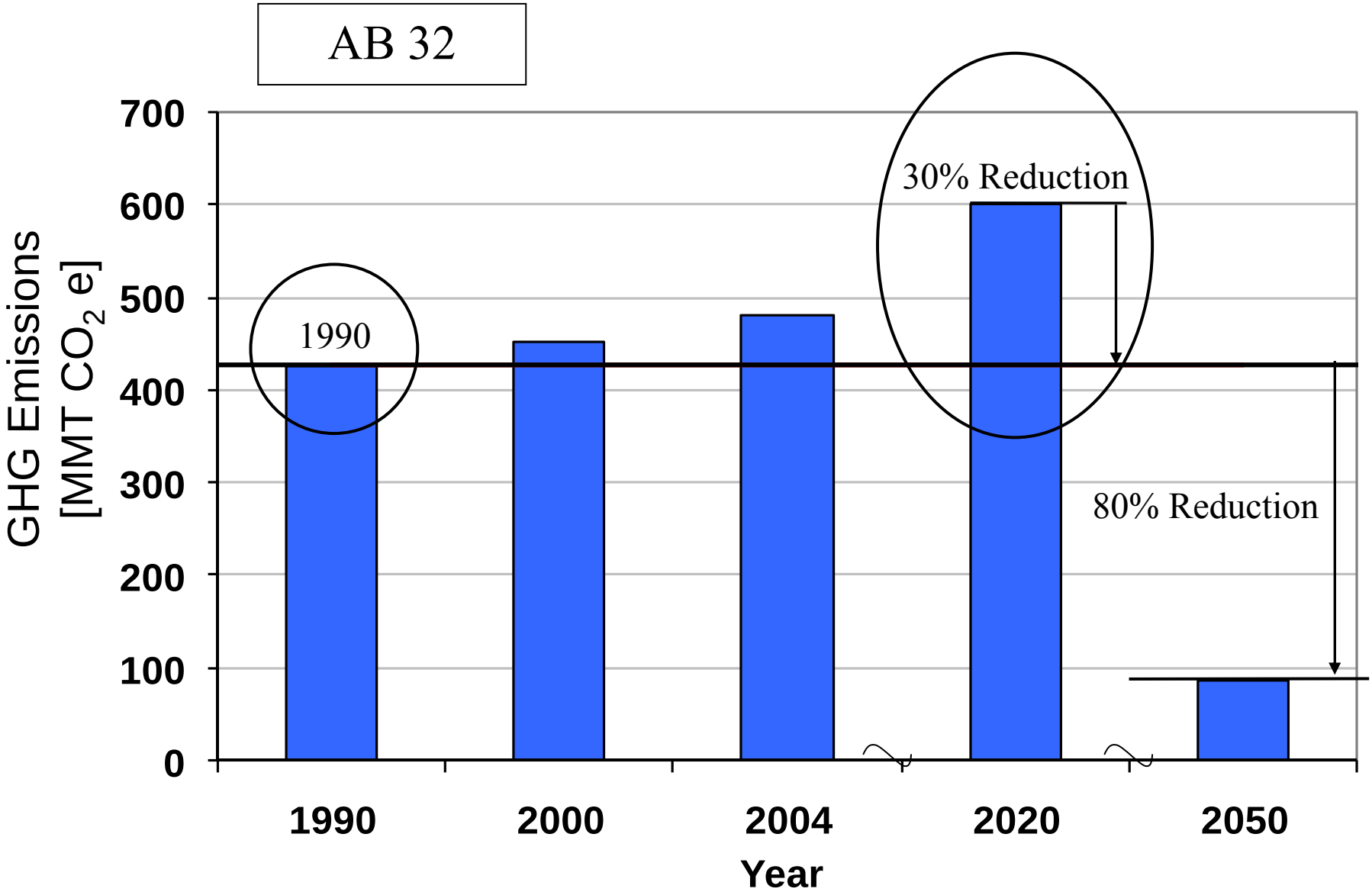
Paradigm Shifts

- Electric Power
- Transportation
  - Fuel
  - Engine



- Conservation
  - Electrical Power
  - Personal Vehicle
- Building Design
- Urban Design

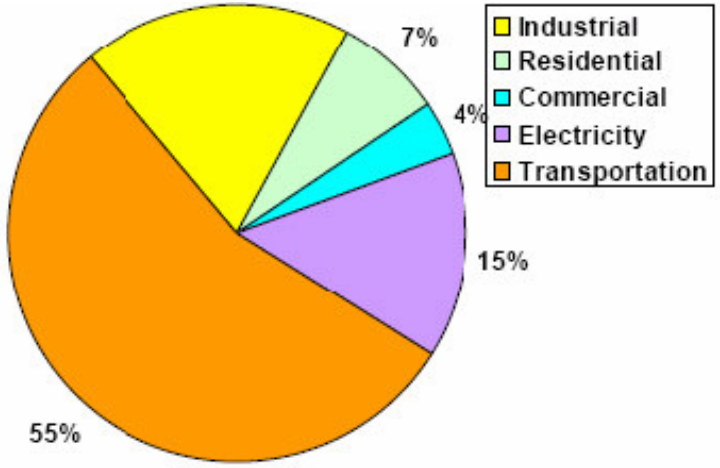
California Leadership



California Leadership

Recent (2003-2008) California Global Climate Initiatives

- AB 1493 (2003): (Pavley) mandates 30% reduction in GHG emissions for new light duty vehicles by 2016
- AB 1007 (2005): requires plan to replace gasoline use with low carbon alternatives
- AB 32 (2006): "Global Warming Solutions Act" aggressive goals for GHG reduction by 2020-50
- SB 1368 (2006): GHG emissions standards for IOUs and POUs
- AB 2021 (2006): Energy efficiency for POUs

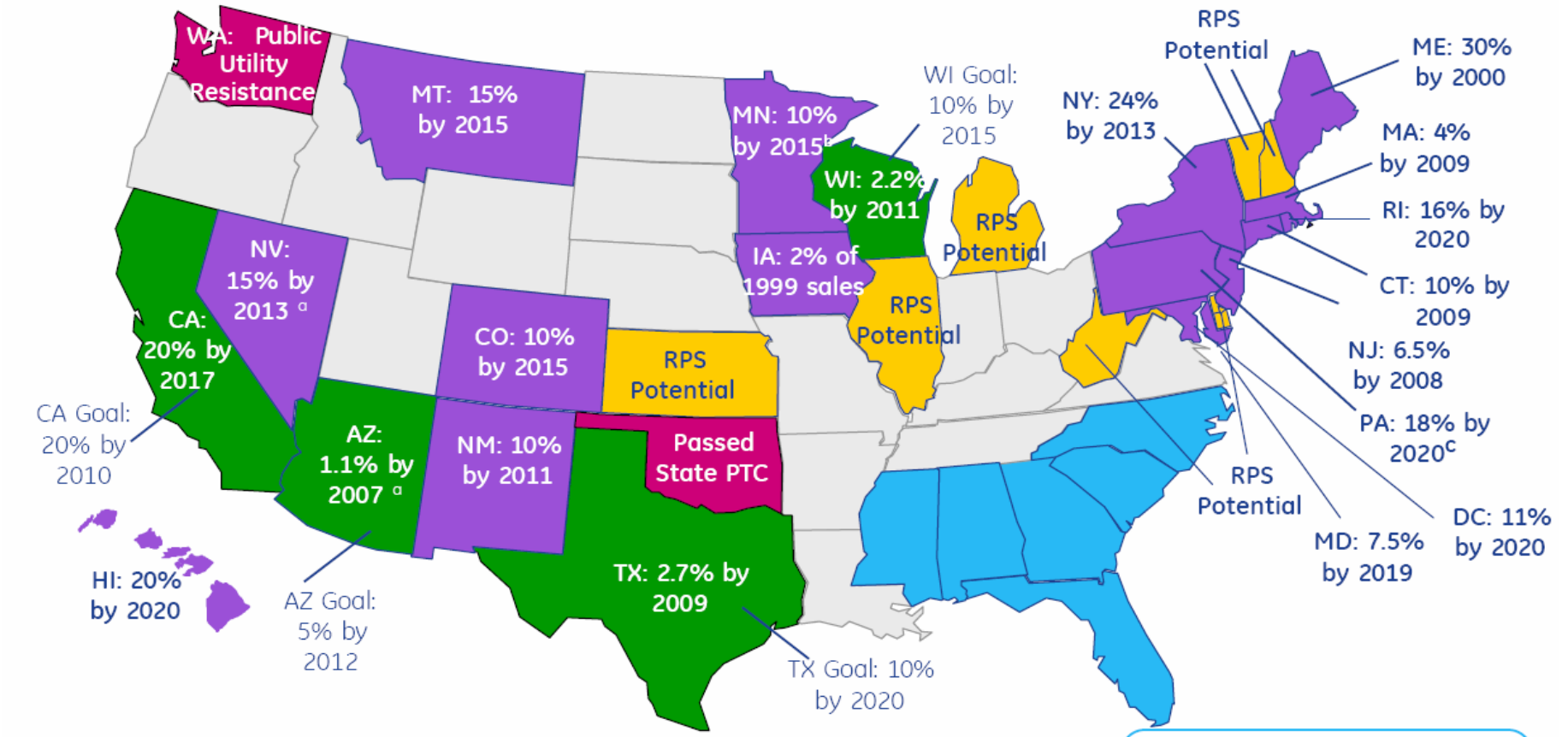


California Carbon Dioxide Emissions by Energy Sectors, 2001
383.1 million metric tons carbon dioxide

- AB 2160 (2006): Green Building acquisition financing for state facilities
- SB 107 (2006): Accelerated RPS Goals (20% by 2010)
- SB 1 (2006): Renewable goals for residential and commercial structures
- AB 2778 (2006): Self generation incentive program for fuel cells and wind
- SB 1250 (2006): PIER renewables incentive program
- EO (2007) – Governor implements Low Carbon Fuel Standard
- ARB (2008) – AB 32 Plan released (June 26)

United States Initiatives

Renewable Portfolio Standards (RPS)



Many states following California lead

- RPS standards
- GHG reduction mandates for all sectors

What Alternatives Are Available?

- 80% of World's Power
- 94% of World's CO_2 Emissions
- 90% of World's Pollutant Emissions

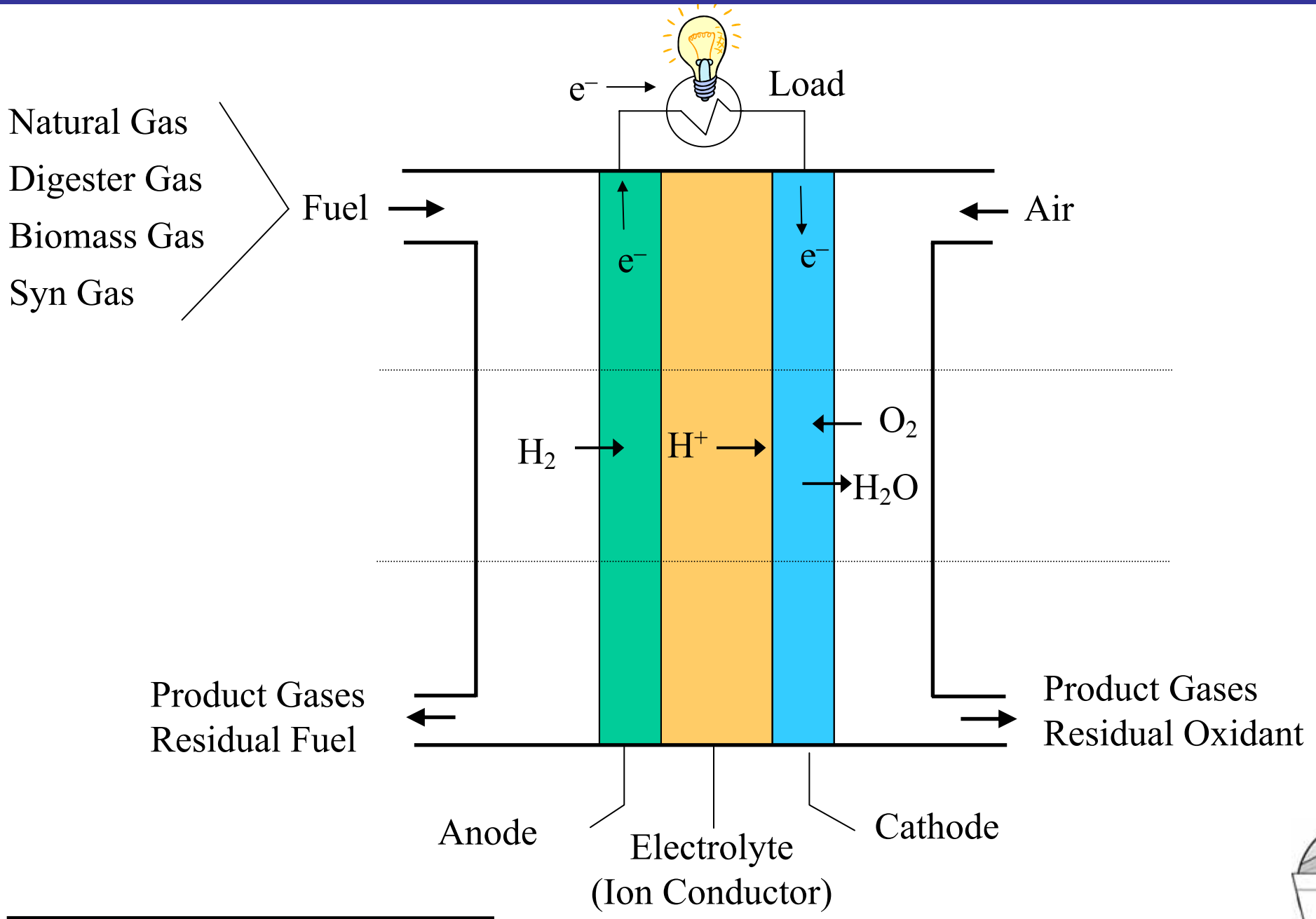
- Combustion

Fossil Fuel → Combustion → Heat → Hot Gases → Turbine → Generator → Electricity

- Fuel Cell

Fossil Fuel → Electrochemistry → Electricity

Fuel Cell Alternative



Transportation Fuel Cells

~60 %

~~~20 %~~~

~~H_2~~

~~gasoline~~

air

~~2,000 lbs~~

600 lbs

H_2O

N_2

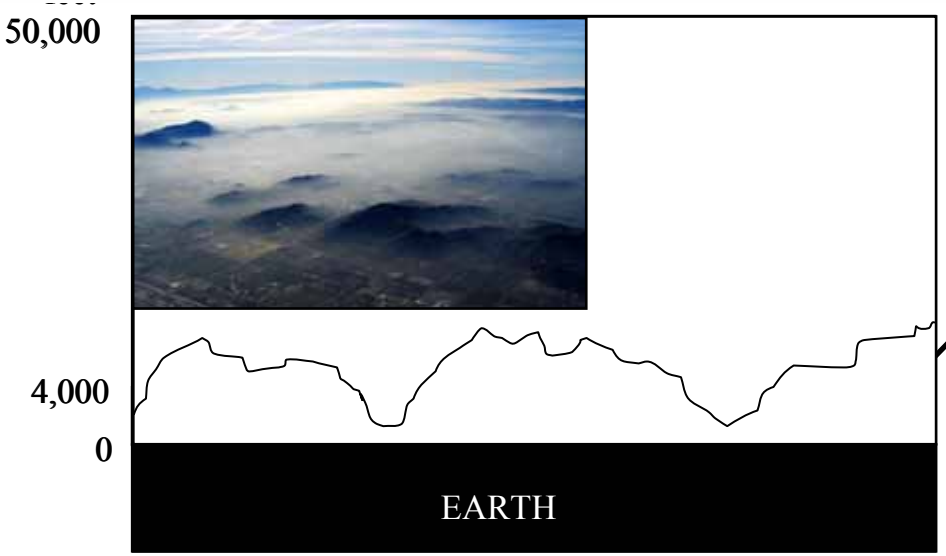
~~CO_2~~

exhaust

~~HC~~

~~CO~~

~~NO_x~~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Fuel Cell Vehicles

Fuel Cells – All major auto manufacturers pursuing

GM_Opel Hydrogen 1

Honda FCX V3

GM Sequel

GM Equinox

Mazda Premacy

Nissan FCV

Daimler FCell

Ford P2000 H2

Hyundai FCEV

Toyota Fine

Toyota FCHV

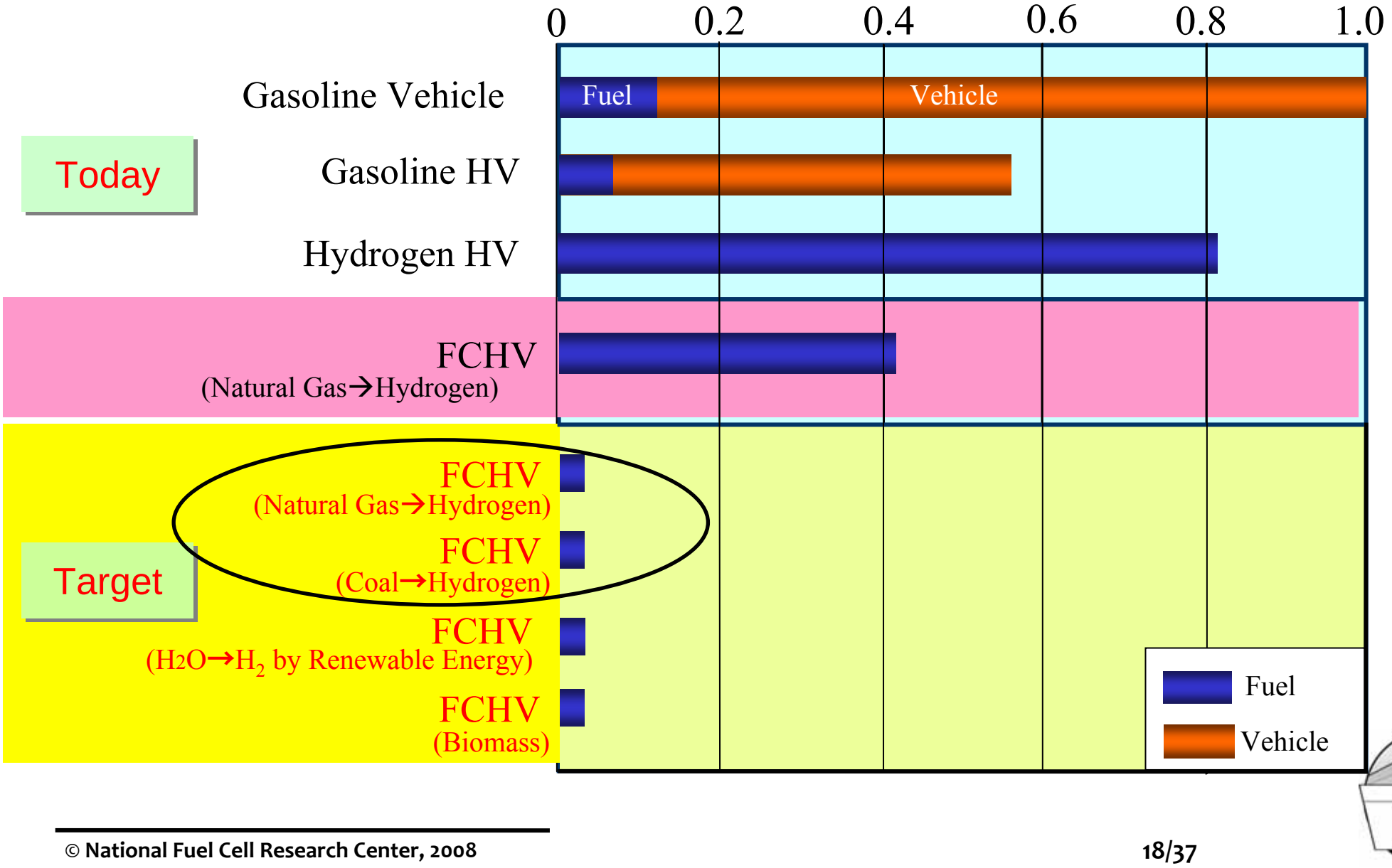
Honda FCX Clarity

GM HyWire

Hyundai iBlue

Transportation Fuels

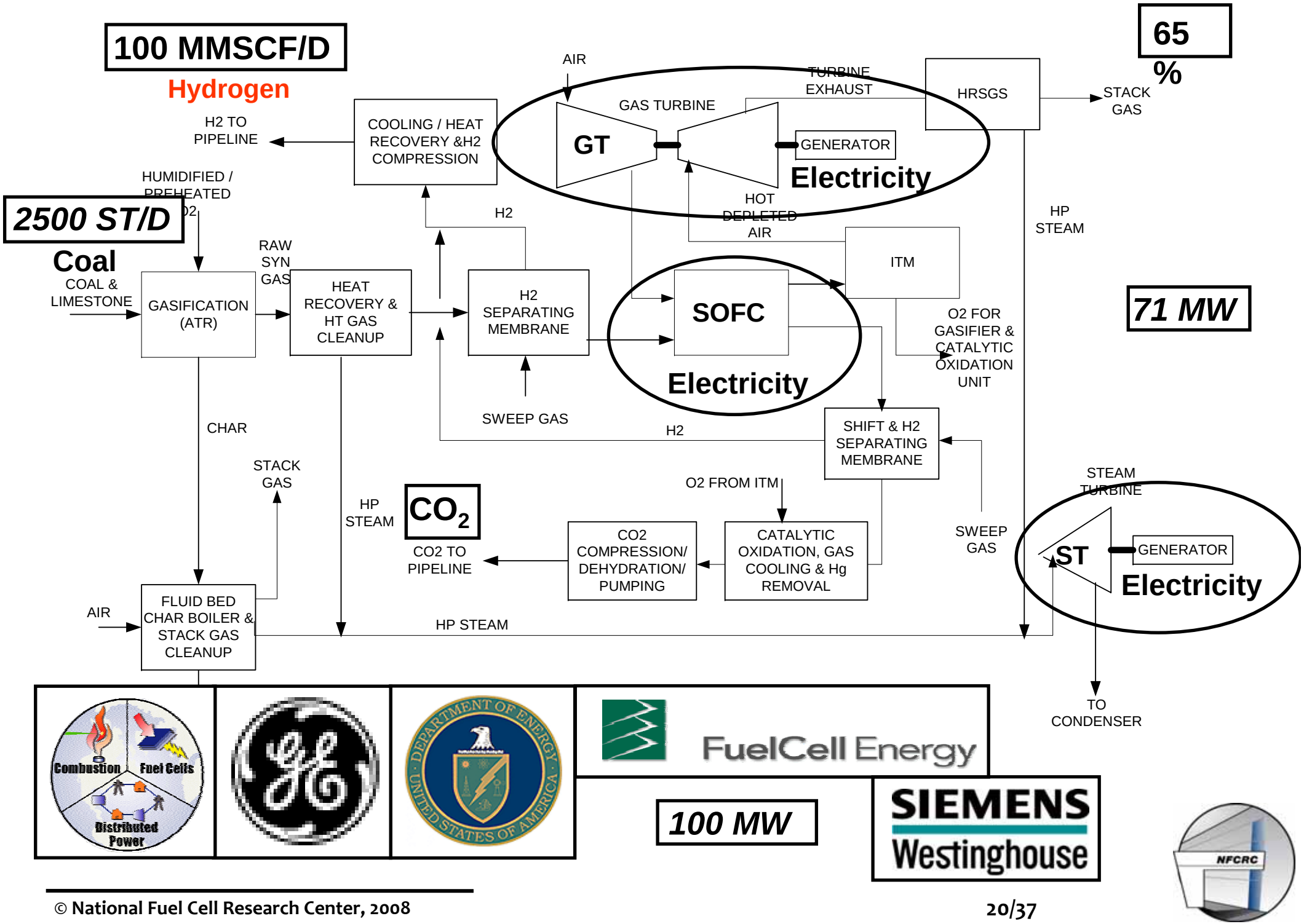
- **CO_2 Emission: Fuel & Vehicle**



Transportation Fuels

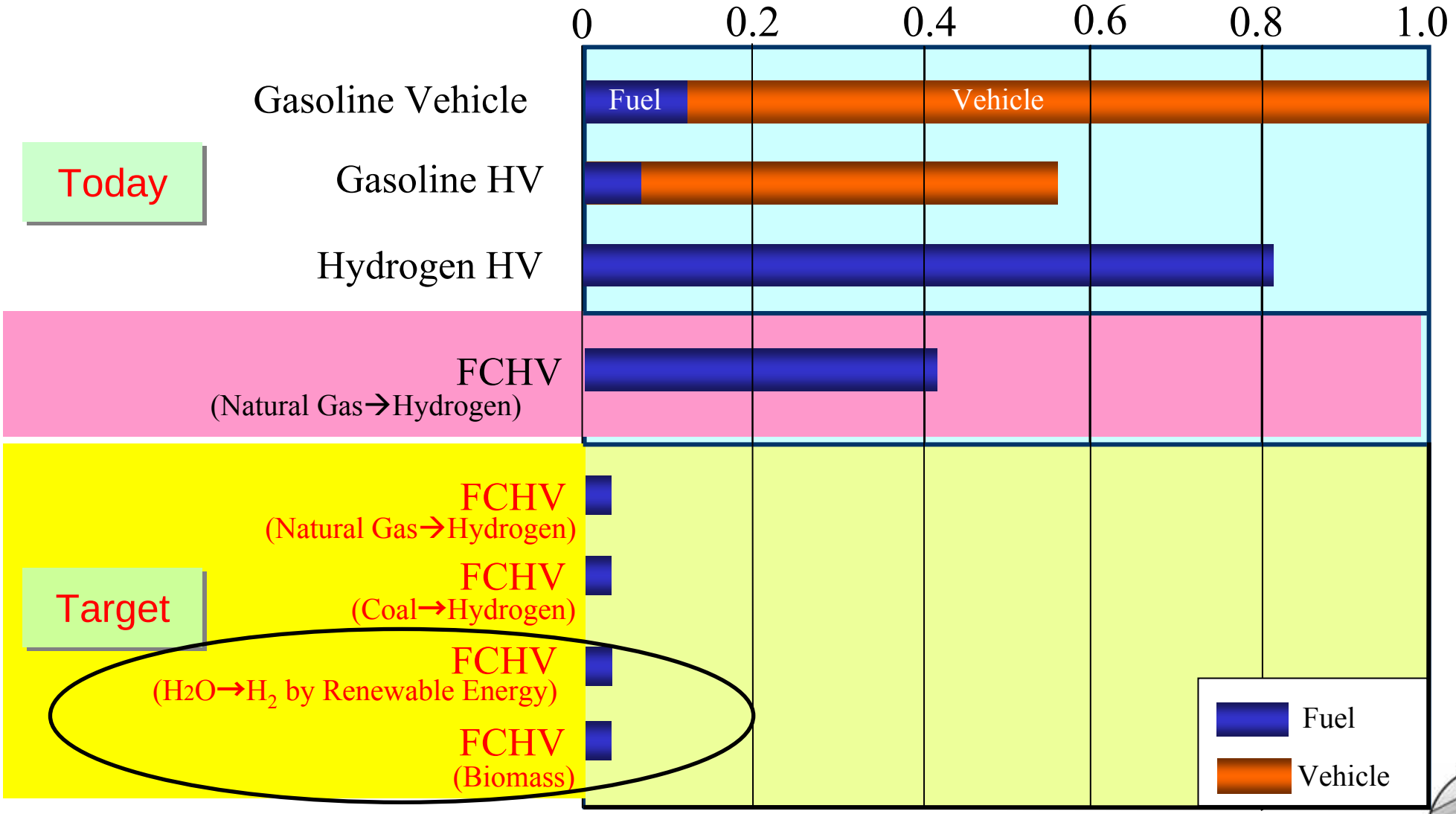
- **U.S. Department of Energy Initiative for Advanced Power Plants**
  - **100-1000 MW**
  - **Natural Gas**
  - **Coal**

- High-Efficiency Electrical Generation
  - Natural Gas: 75%
  - Coal: 60%
- Zero Emission of Criteria Pollutants
- CO_2 Capture for Sequestration
- Co-Production of Hydrogen & Other Fuels



Transportation Fuels

- **CO_2 Emission: Fuel & Vehicle**

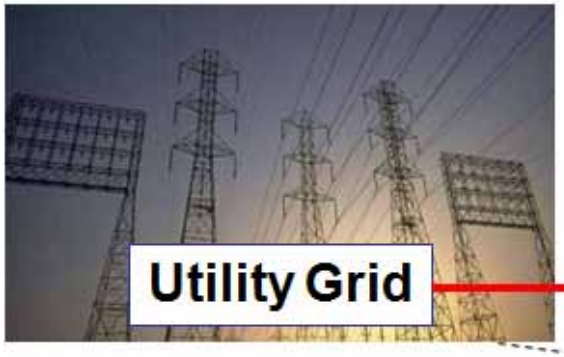


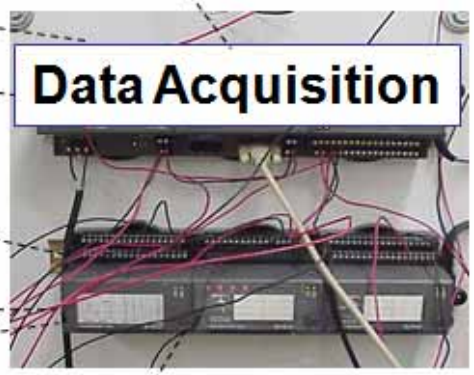
Transportation Fuels

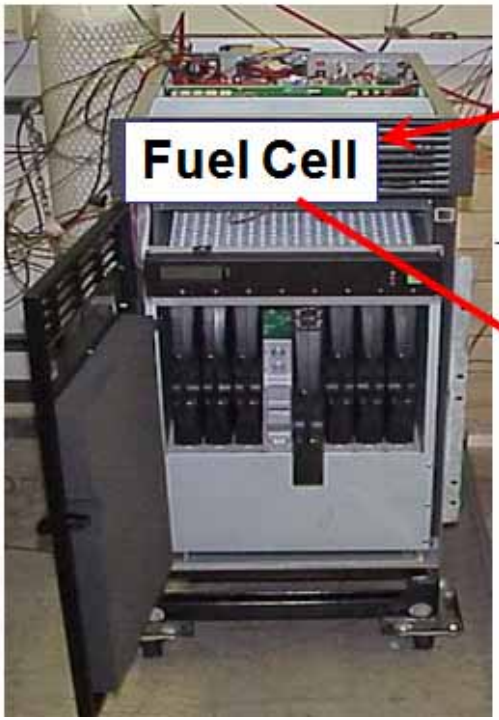
- **Energy Station Concept**

Transportation Fuels

- **Renewable Residential Fuel Cell System**

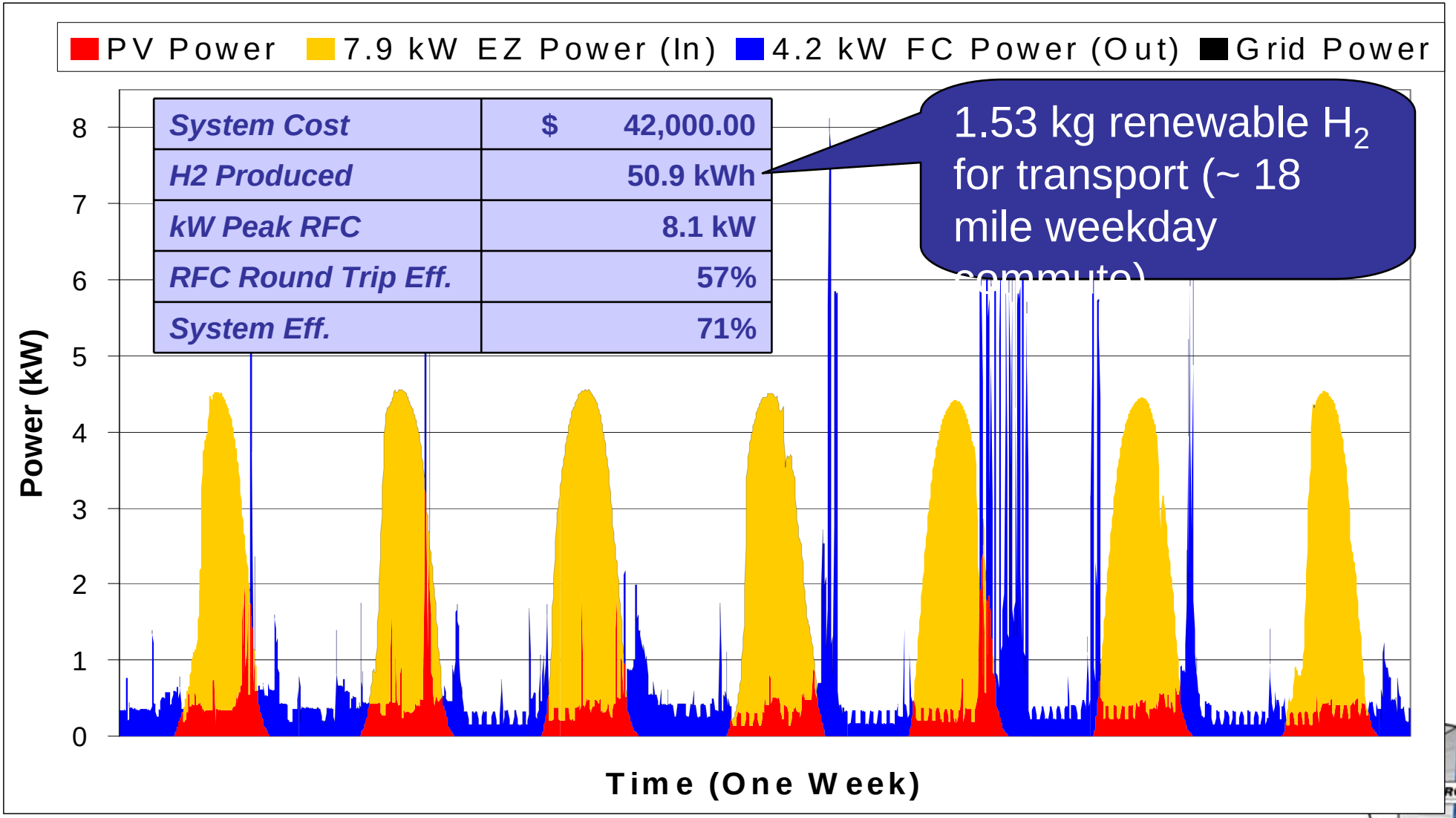






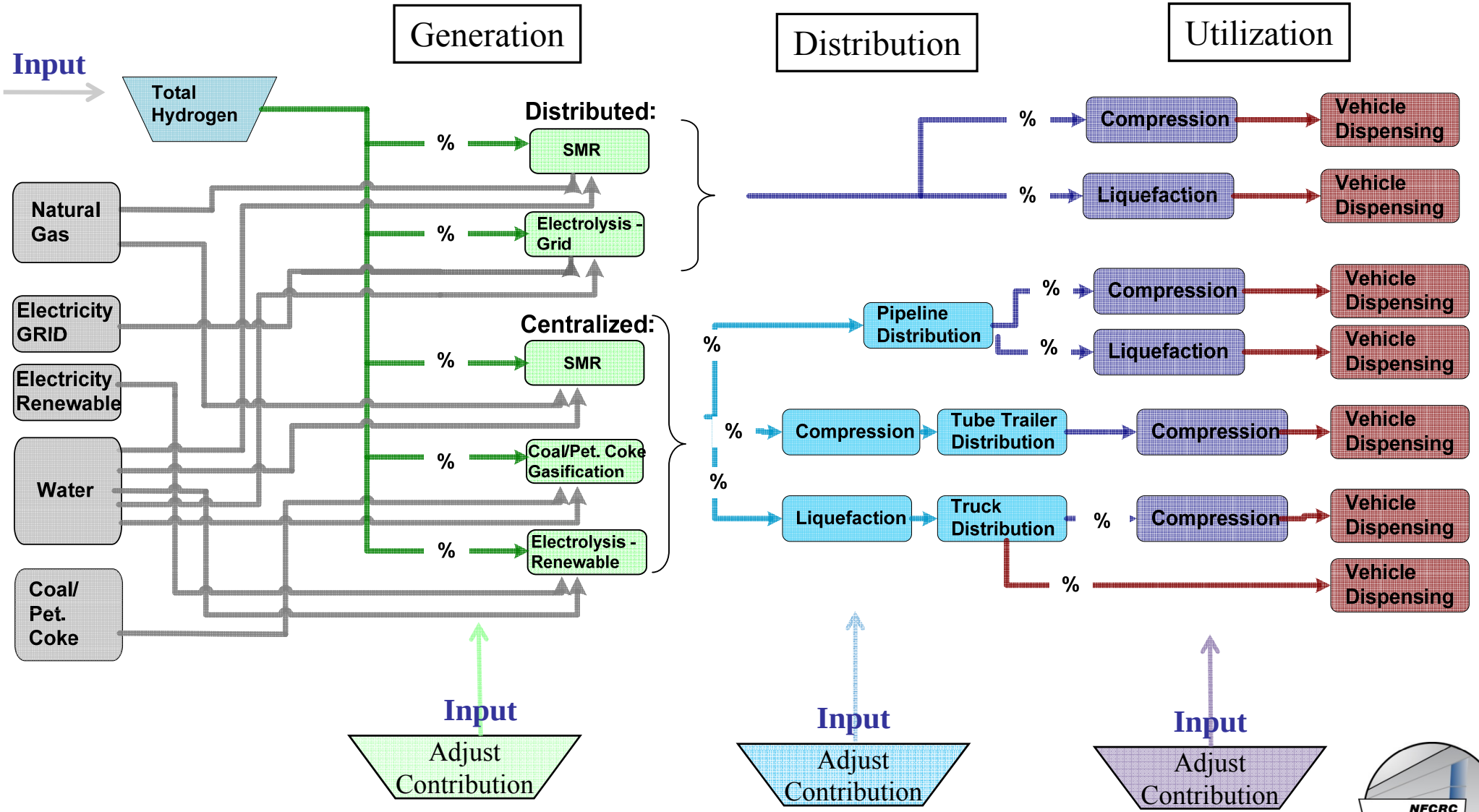
Transportation Fuels

- **Renewable Residential Fuel Cell System – 4.2 kW RFC Supply & Demand Power Flow:**



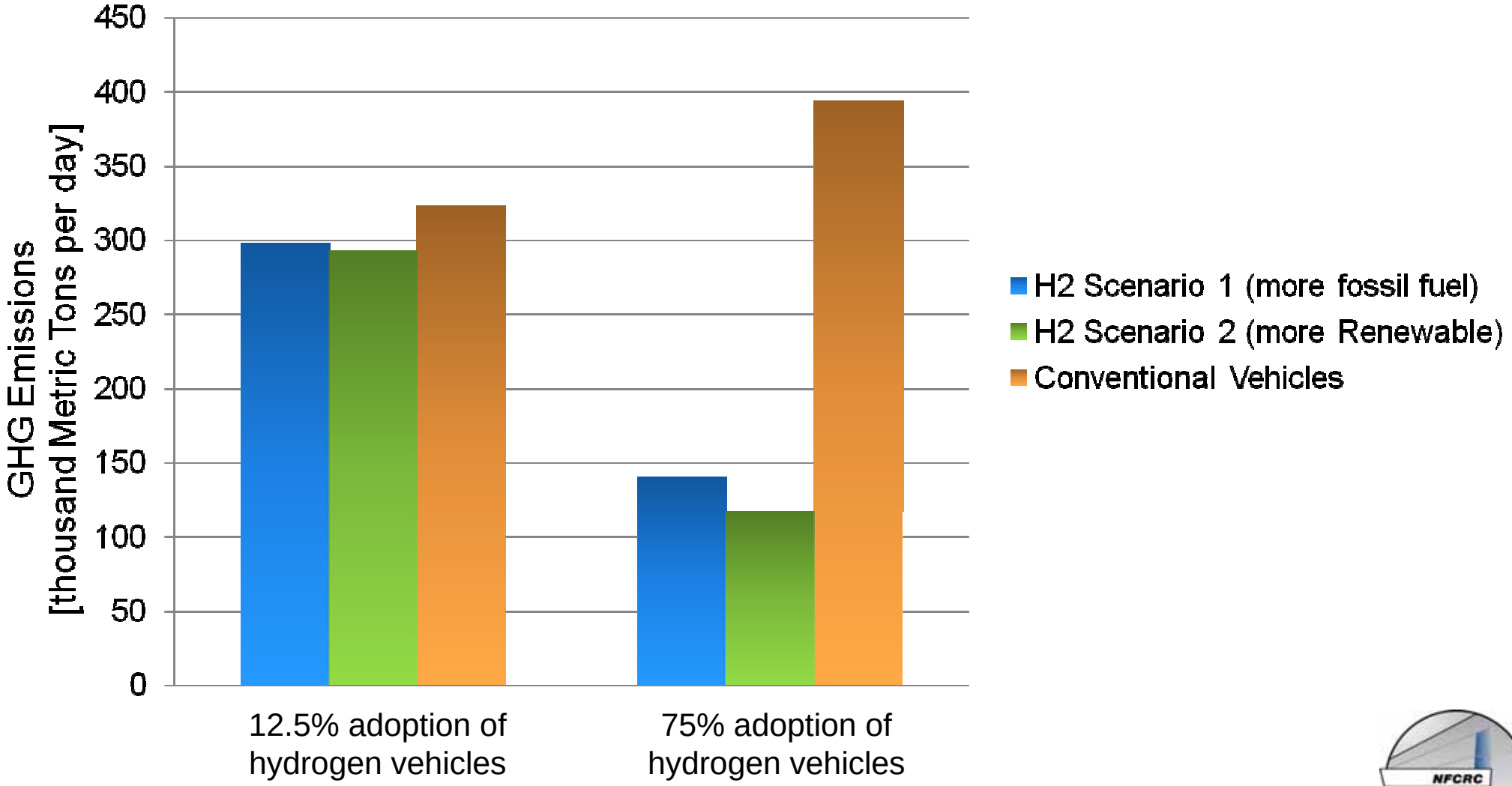
Fuel Cycle Analytical Tool

- **Simplified scheme, adaptable to include other technologies**



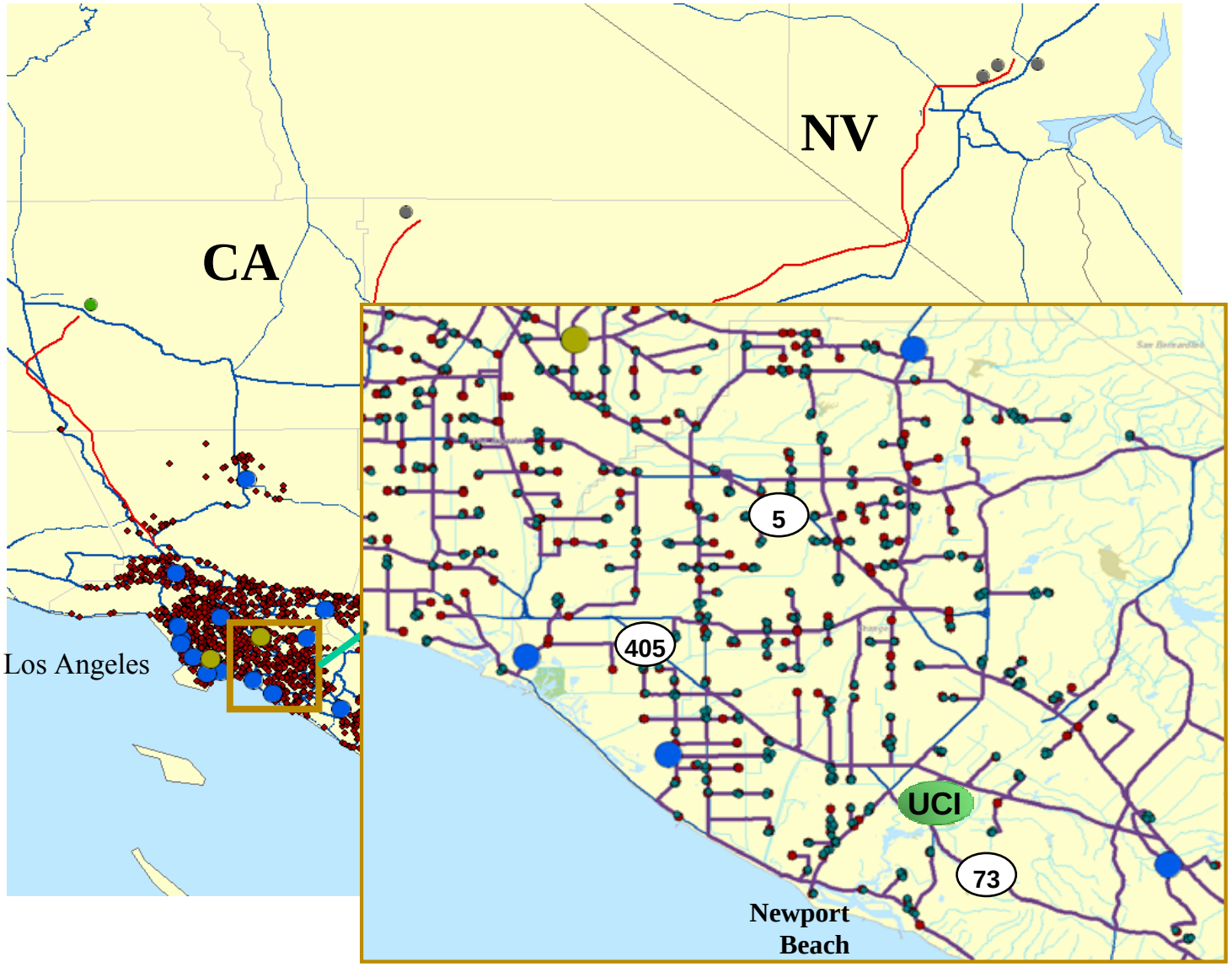
Fuel Cycle Analytical Tool

- **GHG emissions with the adoption of hydrogen infrastructure for passenger vehicles in Southern California**



Fuel Cycle Analytical Tool

- **Spatial & Temporal Analyses**



- Interstates & Freeways
- H2 Fueling Stations
- Central SMR Facilities
- Petroleum Coke
- Coal
- Renewable (Solar, Wind, Geo) & Nuclear
- High Temperature Fuel Cells
- H2 Pipelines
- H2 Truck Deliver Routes

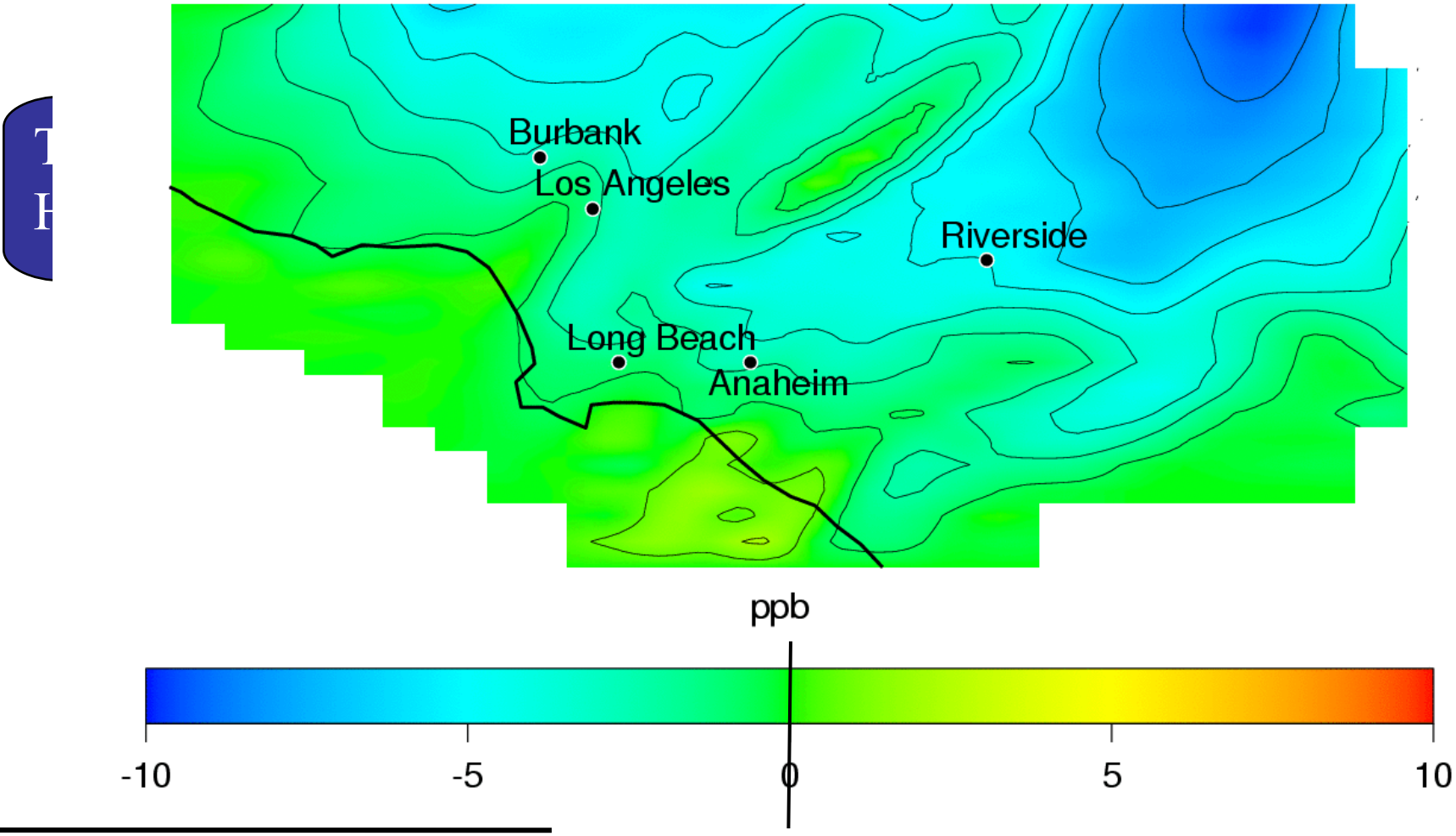
Fuel Cycle Analytical Tool

$$\frac{\partial Q_m^k}{\partial t} + \nabla \cdot \left(u Q_m^k \right) = \nabla \cdot \left(K \nabla Q_m^k \right) + \left(\frac{\partial Q_m^k}{\partial t} \right)_{\substack{sources / \\ sinks}} + \left(\frac{\partial Q_m^k}{\partial t} \right)_{aerosol} + \left(\frac{\partial Q_m^k}{\partial t} \right)_{chemistry}$$

Fuel Cycle Analytical Tool

- **Accounting for spatial & temporal variations of emissions of all hydrogen infrastructure (generation, distribution, end-use)**

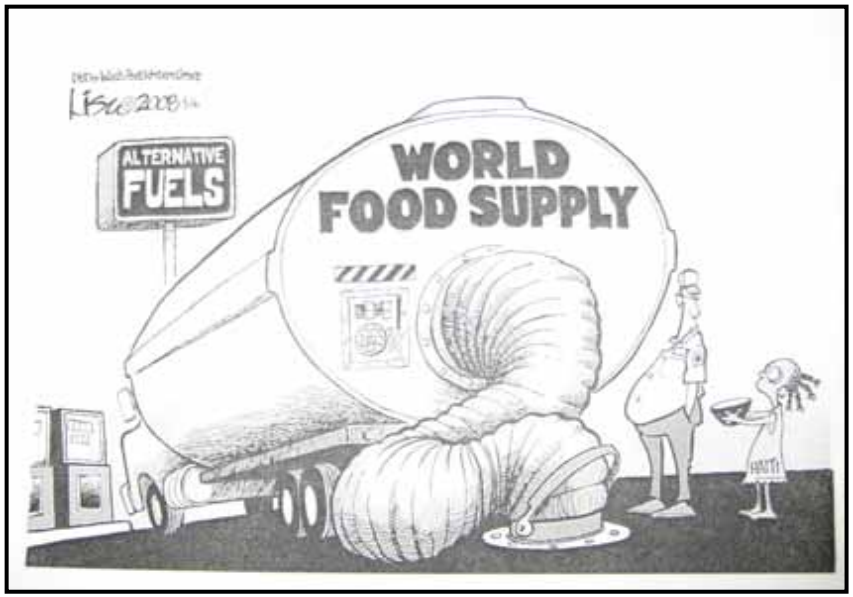
Δ peak 8-hr O_3 for H_2 vs. Conventional Scenario



Transportation Fuels

Many Alternative Fuel Options

- Hydrogen
  - Renewable hydrogen
  - Sustainable hydrogen
  - Less sustainable hydrogen
- Bio-fuels
  - Biodiesel
  - Ethanol, Methanol
  - Hydrogen
- Electricity
  - Renewable electricity
  - Sustainable electricity (e.g., nuclear)
  - Less sustainable, less environmentally sensitive electricity
  - Evolving as the “dual” fuel



Source: Lisa Benson, Los Angeles Times, 16 April 2008

No alternative fuel is the “silver bullet” BUT electricity use in transportation is clearly desirable

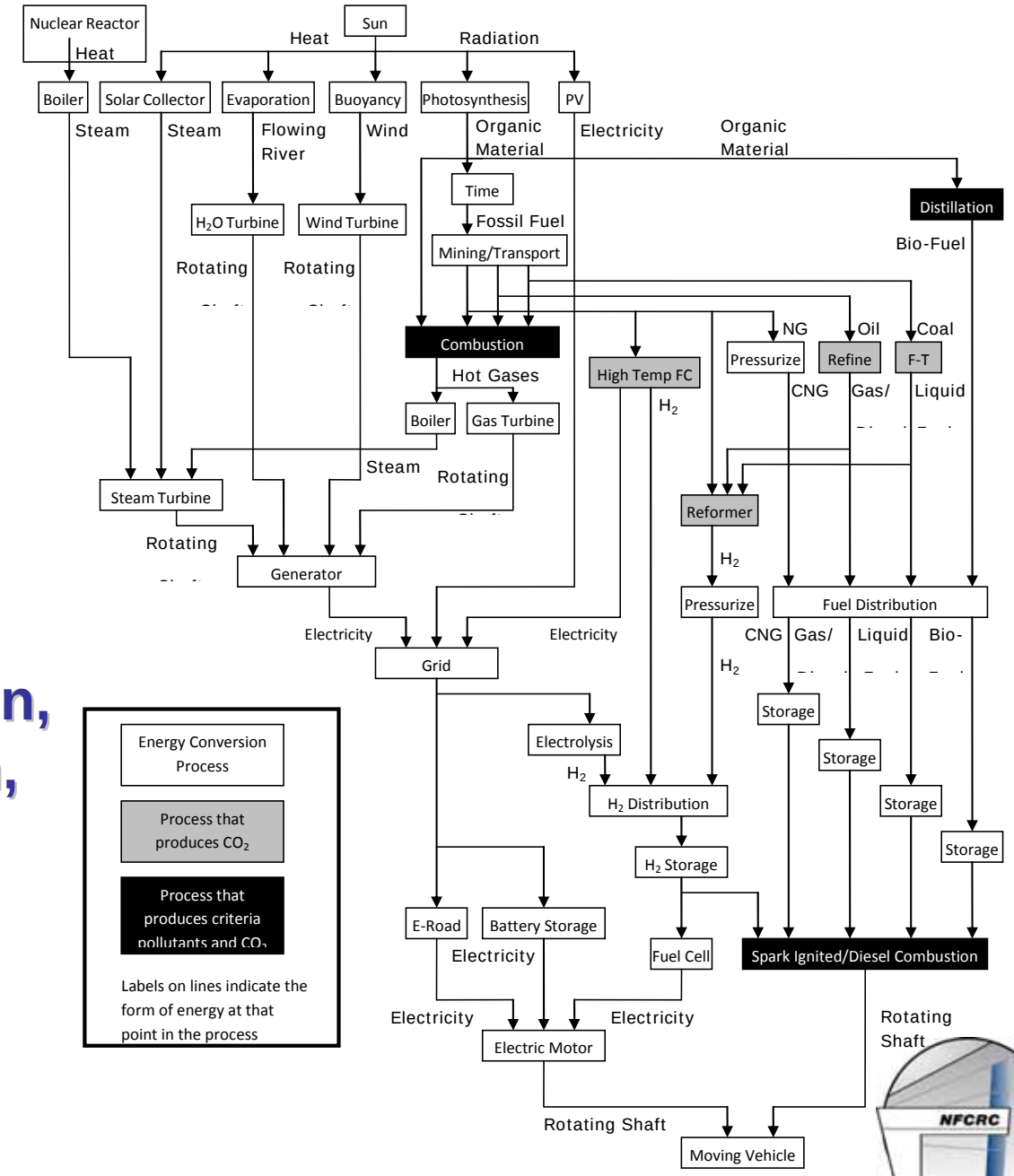
Convergence of Technologies

- **Energy / Consumer / Environmental analyses**

Technology	*Meets User Requirements*	*Fulfills Personal Mobility*	*Eliminates Criteria Pollutants*	*Eliminates GHG Emissions*	*Eliminates Fossil Fuel Use*	*Provides Energy Security*
Traditional gasoline car	Yes	Yes	No	No	No	No
Hybrid	Yes	Yes	No, but better	No, but better	No, but better	No, but better
Hydrogen	Yes (but technology hurdles)	Yes	Yes, if renewable, nuclear	Yes, if renewable, nuclear	Yes, if renewable, nuclear	Yes, if renewable, nuclear
Bio-Fuel	Yes	Yes	No	No	No, not enough feedstock	Yes
Electric	No (range & recharge limits)	Yes	Yes, if renewable, nuclear	Yes, if renewable, nuclear	Yes, if renewable, nuclear	Yes
Mass Transit (bus)	Yes	No	No, but better	No, but better	No, but better	No, but better
Mass Transit (electric rail)	Yes	No	Yes, if renewable, nuclear	Yes, if renewable, nuclear	Yes, if renewable, nuclear	Yes
PRT	Yes (shipping, no)	Yes (if stops convenient)	Yes, if renewable, nuclear	Yes, if renewable, nuclear	Yes, if renewable, nuclear	Yes

Convergence of Technologies

- **Energy / Consumer Environmental analyses identify *electrification* as desirable for transport**
- **Assess all major primary energy sources**
- **Apply to moving vehicle**
- **Analyze criteria pollutant and GHG impacts of primary energy conversion, transmission, distribution, and end-use**



Convergence of Technologies

- **Energy / Consumer / Environmental analyses – identify *electrification* as desirable for transport**

Vehicle (study)	Fuel Energy (MJ/MJ)	Fuel Carbon (g C/MJ)	EPA City (MJ/km)	EPA Highway (MJ/km)	Grams C/km (gC/km)	Total Energy (MJ/km)	Total C (gC/km)
BEV (UCI)	1.25	51.5	0.582	0.443	0	1.17	26.8
BEV (ADVISOR)	1.25	51.5	0.471	0.374	0	0.96	22.0
BEV (MIT)	1.16	54	0.579	0.422	0	1.10	27.5
BEV (GM)	1.45/1.13	49/36					
Current gas (MIT)*	0.211	4.9	3.195	2.152	53.3	3.30	66.7
Current gas (GM)§	0.23	5.5	3.79 †	3.79 †	70.1	4.66	90.9
Diesel Hybrid (MIT)	0.139	3.3	1.029	0.788	19.2	1.05	22.2
Diesel Hybrid (GM)	0.19	4.4	2.65 †	2.65 †	52.9	3.15	64.6
H_2 Fuel Cell (MIT)	0.77	36	0.905	0.684	0	1.43	29.0
H_2 Fuel Cell (GM)	0.81	31.1	1.67 †	1.67 †	0	3.02	51.9
TRV (UCI)	1.25	51.5	0.446	0.362	0	0.92	21.0
TRV (ADVISOR)	1.25	51.5	0.403	0.336	0	0.84	19.2

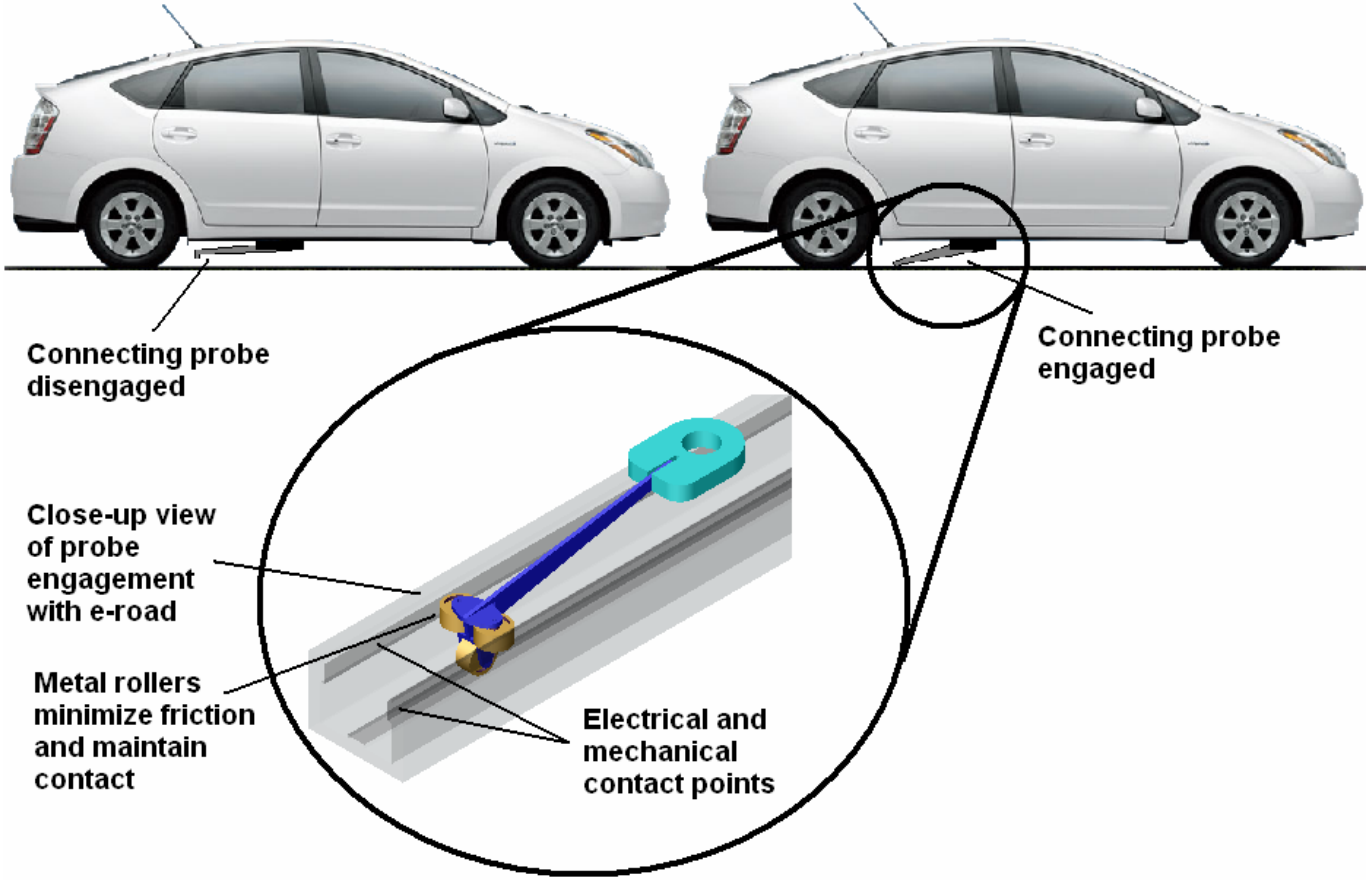
* 1996 Toyota Camry

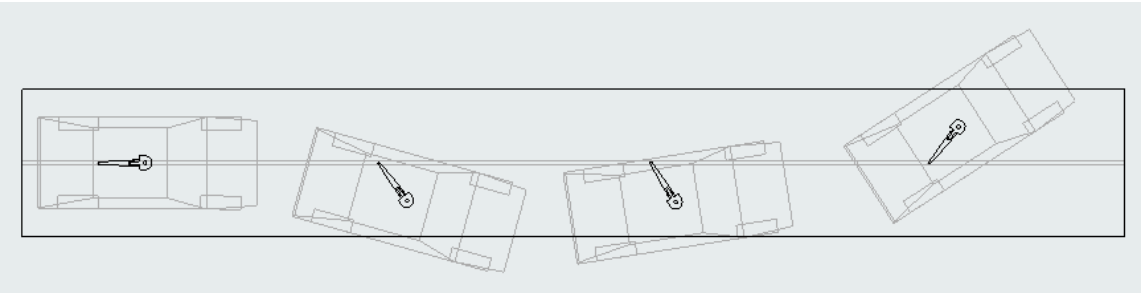
§ GM full-size pick-up truck

† The GM study did not differentiate between city and highway driving

Convergence of Technologies

- Energy / Consumer Environmental analyses – identify *electrification* as desirable for transport
- Third Rail Vehicle (TRV) idea
- All auto features of personal interest
- Charge on major electrified roads ‘e-road’
- BEV of ‘e-road’





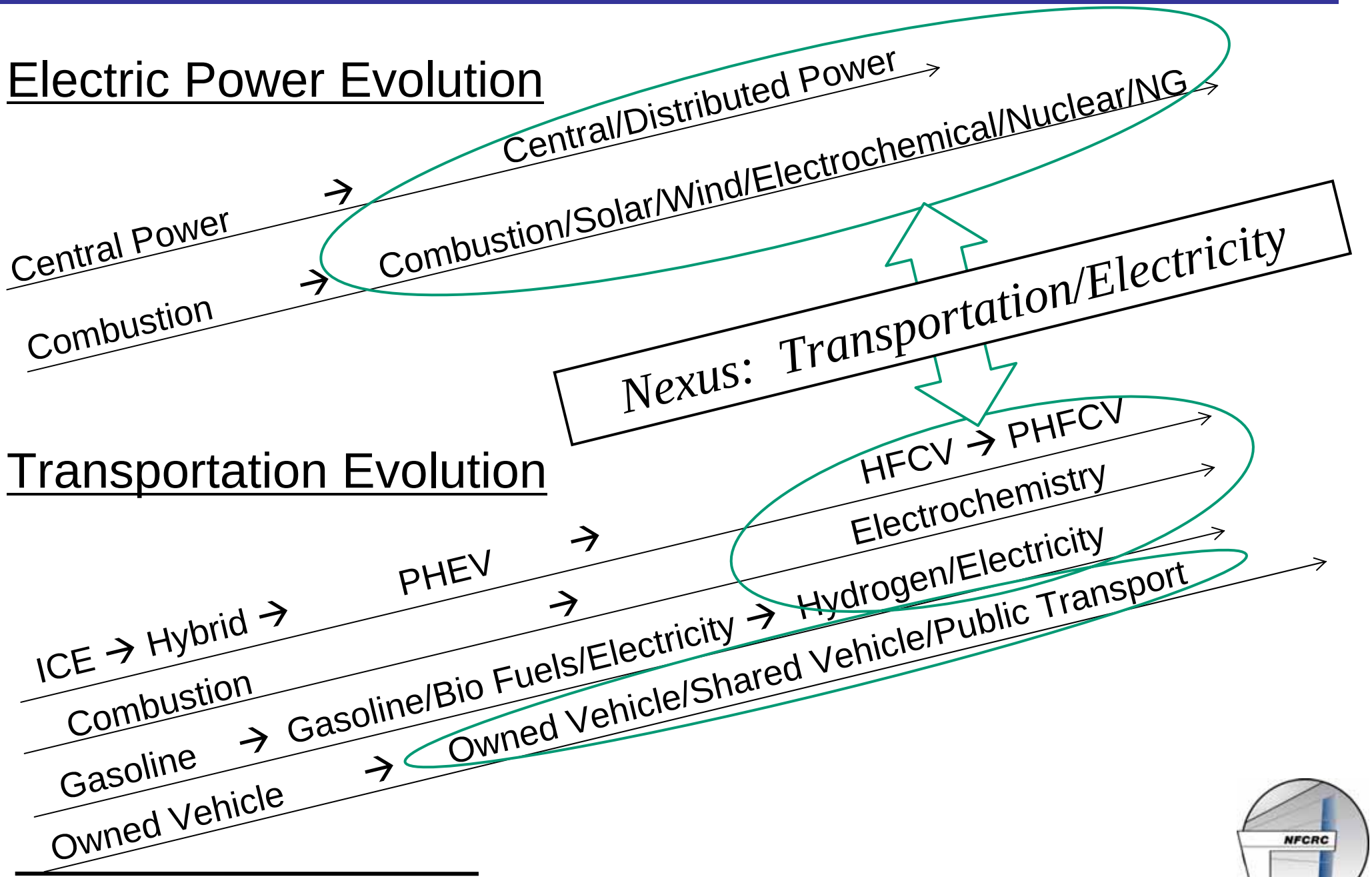
60 %

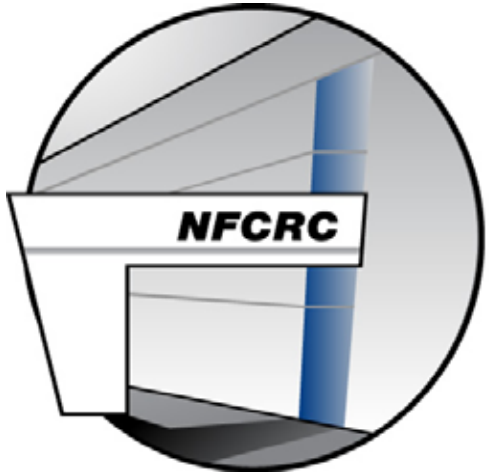
Air

600

EN

Convergence of Technologies





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