Future Technology and Fuels What are the Challenges?

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Societal Interests

- National Security
- Environment
- Quality of life

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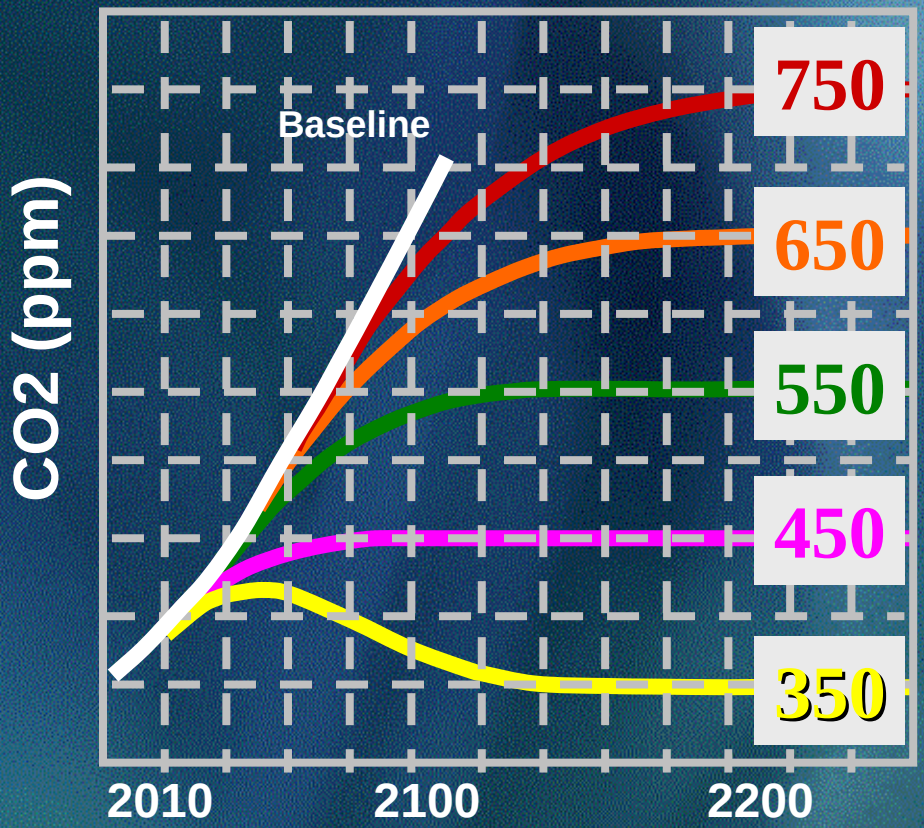
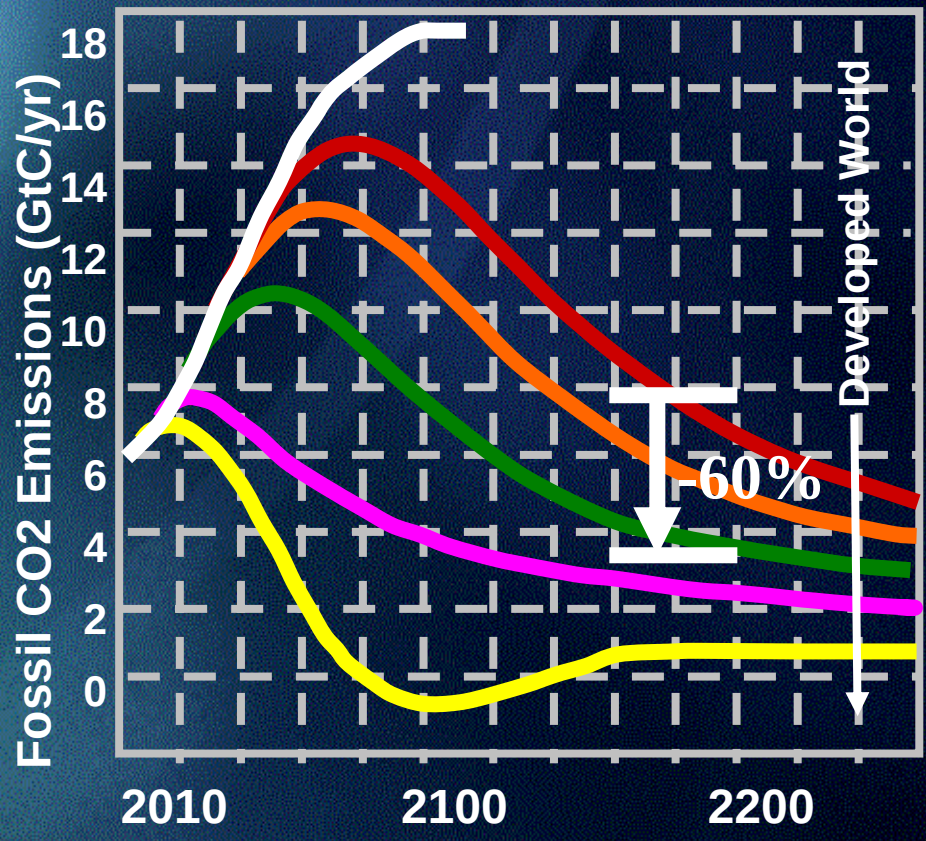
- Quality of life
  - Accessible mobility
  - Technology
  - Economic Competitiveness

The Carbon Challenge:

To reach the stable carbon levels on the left, world emissions need to decline as shown on the right.



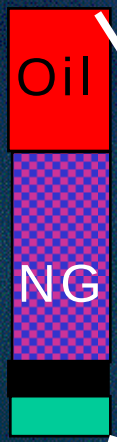
Profiles for
Stabilized CO_2 Concentrations

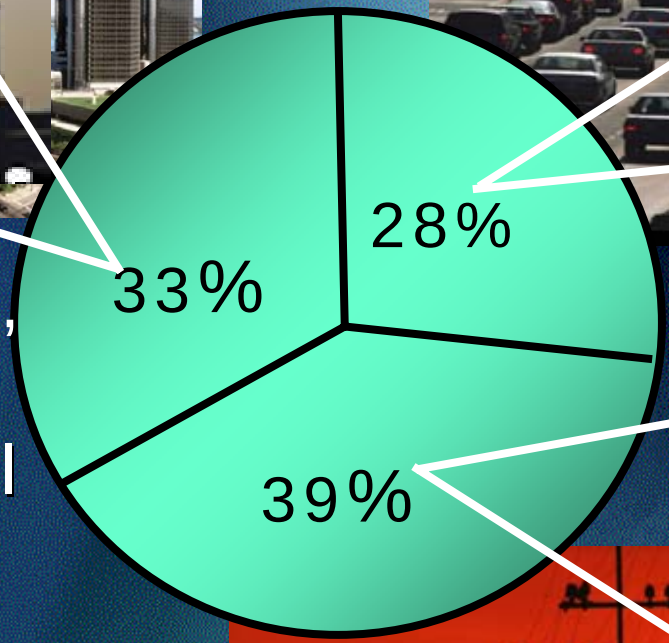


Emission Profiles for
Stabilized CO_2 Concentrations

REVISED WRE STABILIZATION PROFILES

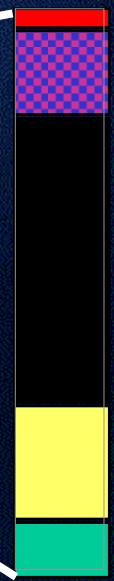
US Energy Use





Commerce, Industry & Residential

Electrical Utilities



Source: DOE Energy Information Administration "Energy Outlook 2005"

Options for Reducing Transportation Fossil CO_2 Emissions

- **use petroleum, but less of it**
  - **vehicle fuel economy gains**
  - **curtail personal mobility and choice in transportation**
- **switch to fuel free of fossil carbon**

Technologies for Improved fuel economy

	urban energy efficiency	highway energy efficiency	challenge
Hybrid (gasoline/electric)			
• regenerative braking	√		battery power density, durability & cost
• engine off at idle & coast	√		$/gallon benefit
• engine down-sized	√		utility
• electric drive at low speed	√		
• electric variable transmission	√	√	
• electric plug-in	√		• battery energy & power density, durability & cost
Engines			
• displacement on demand	√	√	• cost
• stratified charge compression ignition (diesel)	√	√	• emissions, cost
• homogeneous charge compression ignition (hcci)	√	√	• readiness, cost

Long-term consumer acceptance usually requires clear new personal benefit

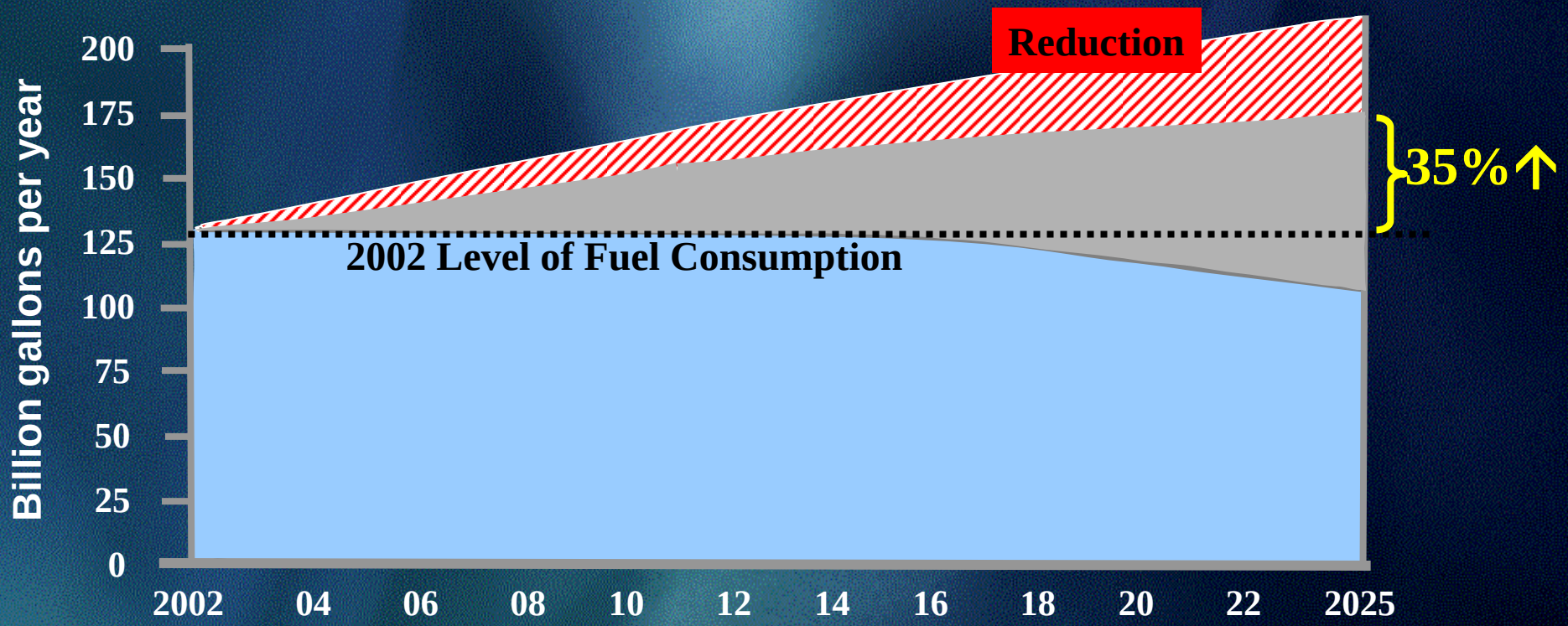
Vehicle Technology Options for Reducing CO_2

- The more optimistic of some analyses suggest the possibility of technology advancements yielding 30-70% improvement in vehicle fuel economy
- The average fuel economy of the on-road fleet lags behind recent technology advances:
  - fleet turn-over is ~20 years
  - the consumer must prioritize fuel economy (accept cost & trade-off against other attributes)

Fuel Consumption by light-duty vehicles

50 % Penetration of Vehicles with 50% Fuel Economy Improvement by 2025

Result: 35% more fuel is consumed in 2025



Energy Information Administration 2002 – 2025 Projection

Growth

(population, access to vehicles, miles driven)

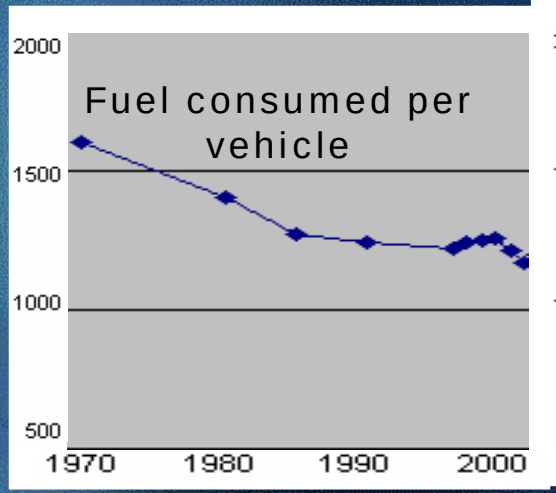
is expected to outpace fuel economy gains

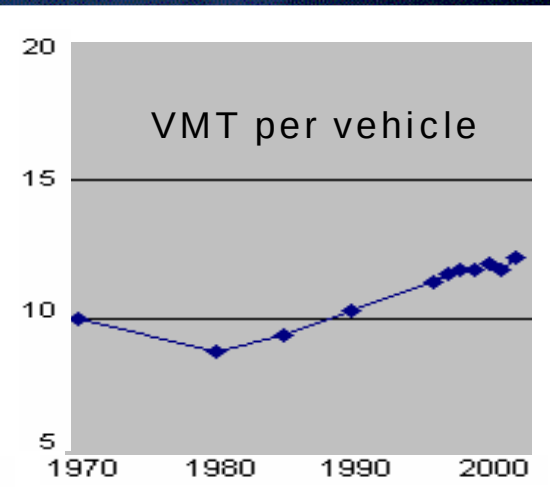
Is this consistent with recent history?

- Developed economies
- Developing economies

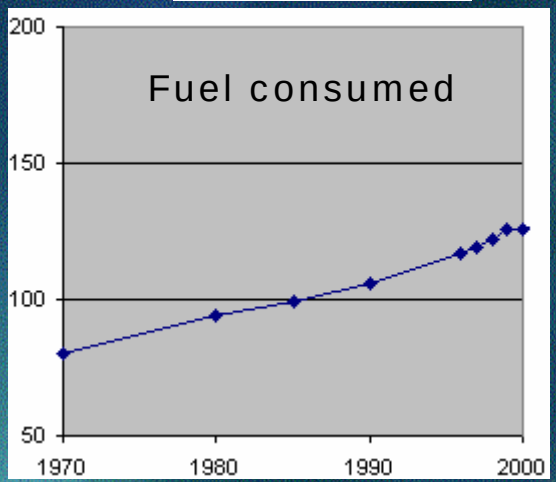
USA

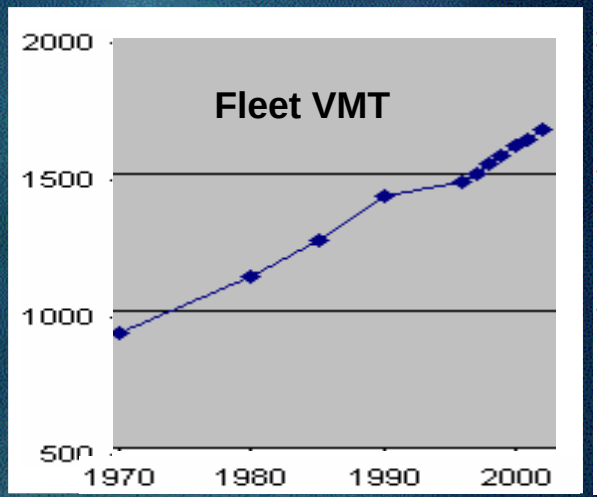
39% improvement in fuel economy of on-road fleet 1970-2002

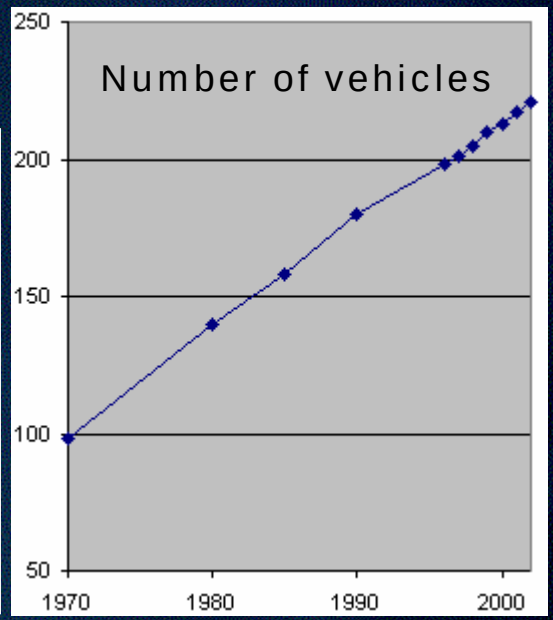




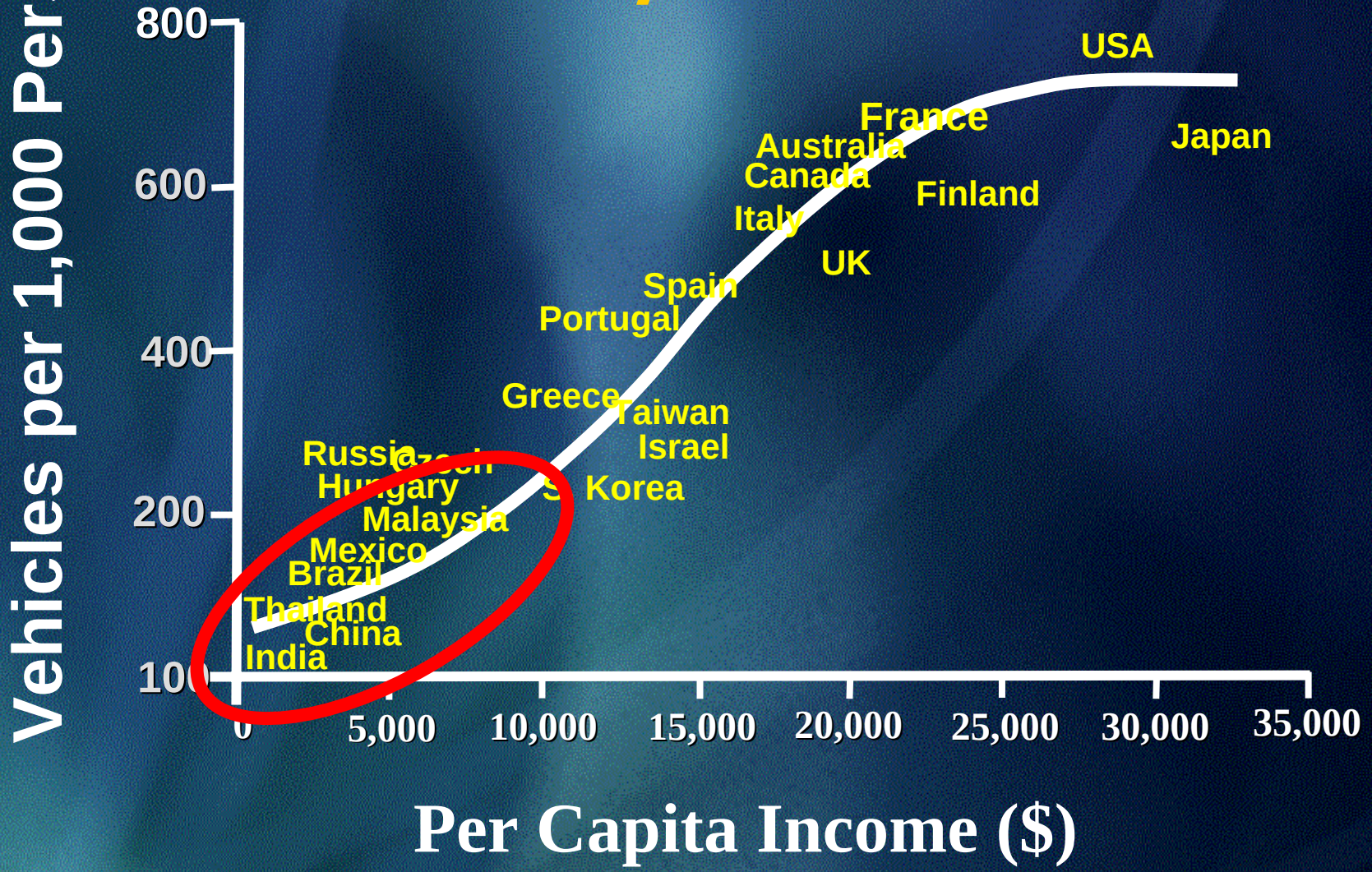
but on-road fuel consumption for the total fleet of vehicles <u>increased</u> 64%







Relationship of Vehicles Sales to Per Capita Income



Technology Options for Reducing Transportation Fossil CO_2 Emissions

- **vehicle fuel economy gains**
  - **growth in number of vehicles and VMT is reasonably expected to overwhelm improved fuel economy of individual vehicles**
  - **Increases in CO_2 emissions are slowed but not reversed**

- **fuels free of fossil carbon**

Critical Need for Transportation Energy Sources Other than Petroleum

Energy Security through Source Diversity

Stationary applications use a variety of energy sources because each facility can make independent, long-term fuel arrangements.

Vehicle energy use is > 99% oil dependent because nearly all vehicles use the same fuel infrastructure nation-wide.

Vehicles could use a variety of energy sources if they fed into a common energy carrier -- such as electricity or hydrogen.

Trade-Off Between Electricity and Hydrogen

Electricity		Hydrogen
• linked to coal & natural gas	**CO_2 Emissions** • zero vehicle emissions • infrastructure emissions	• linked to natural gas
• production exists – capacity • distribution exists -- capacity	**Infrastructure** • pathway to renewables • undeveloped dispensing	• localized production exists – capacity • distribution not developed
• vulnerability – adds transportation sector to reliance on grid	**Energy security**	• widespread backup for grid

Society

Trade-Off Between Electricity and Hydrogen

Electricity

- limited duration of high power driving
- recharging time
- limited driving range
- limited access to charging at market entry

- in-life replacement of expensive battery
- elimination of off-peak electricity rates

Hydrogen

- limited access to fuel at market entry

Vehicle Performance

- electric drive –
  - launch torque
  - stability & traction
  - turning radius
  - stopping distance
  - quiet
- possibility of home refueling
- design opportunities

Cost

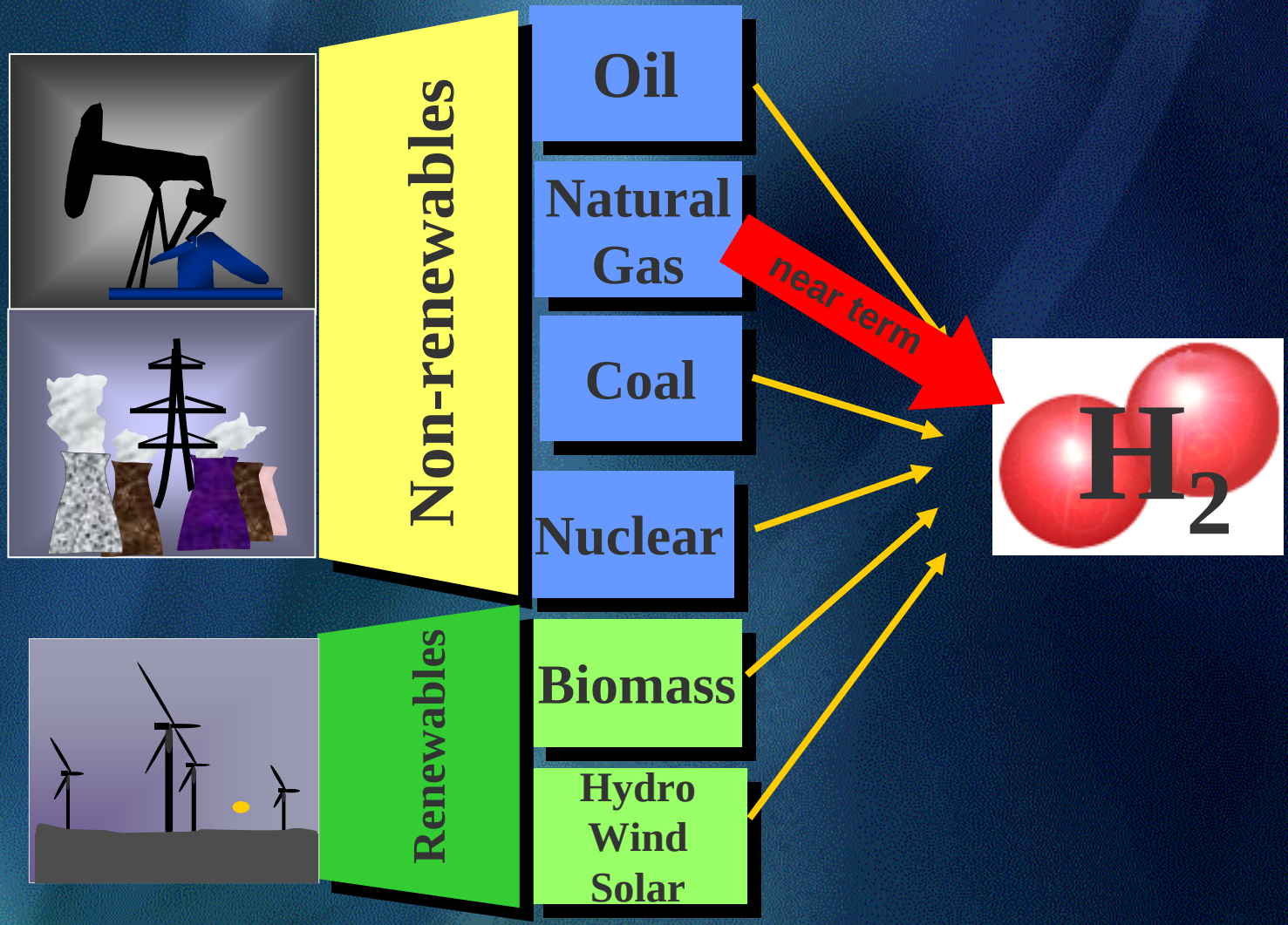
- added cost of new technology

Are hydrogen-fueled fuel-cell vehicles realistic possibility well before 2020?

- Investment by major OEMs is consistent with market entry in 2010s
- Fuel cell technology on track to meet automotive targets: Ten-fold reduction in cost of fuel cell power stack in 3 years; 3-fold increase in power density; cold stop/start achieved
- Demonstration vehicles achieving gains in driving range; durability on track with projections

Is a hydrogen fuel infrastructure a realistic possibility before 2020?

Hydrogen: An Energy Carrier That Offers Tremendous Feedstock Diversity

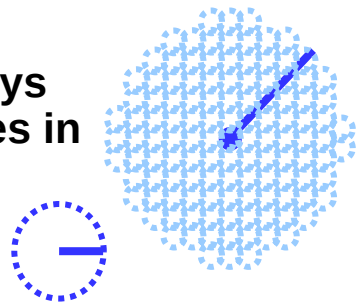


Perspectives on U.S. Infrastructure Development

- **Hydrogen initially produced from natural gas in current infrastructure**
  - **cost close to gasoline/mile cost given fuel cell efficiency**
  - **early demand for natural gas not significant (< 1% of current usage)**

- **Capital risk is constraint in launching H2 fueling infrastructure**
  - **$10-15B establishes a network of 12,000 fueling stations**
  - **covers urban areas (100 areas = 70% of US population**
  - **covers 130,000 miles for interstate connection of urban areas**
  - **Govt can make capital risk manageable**

Station always within 2 miles in urban areas



Top 100 U.S. metro areas

1 highway station every 25 miles

Hydrogen infrastructure is significant challenge, but not "show stopper"

California Hydrogen Highway

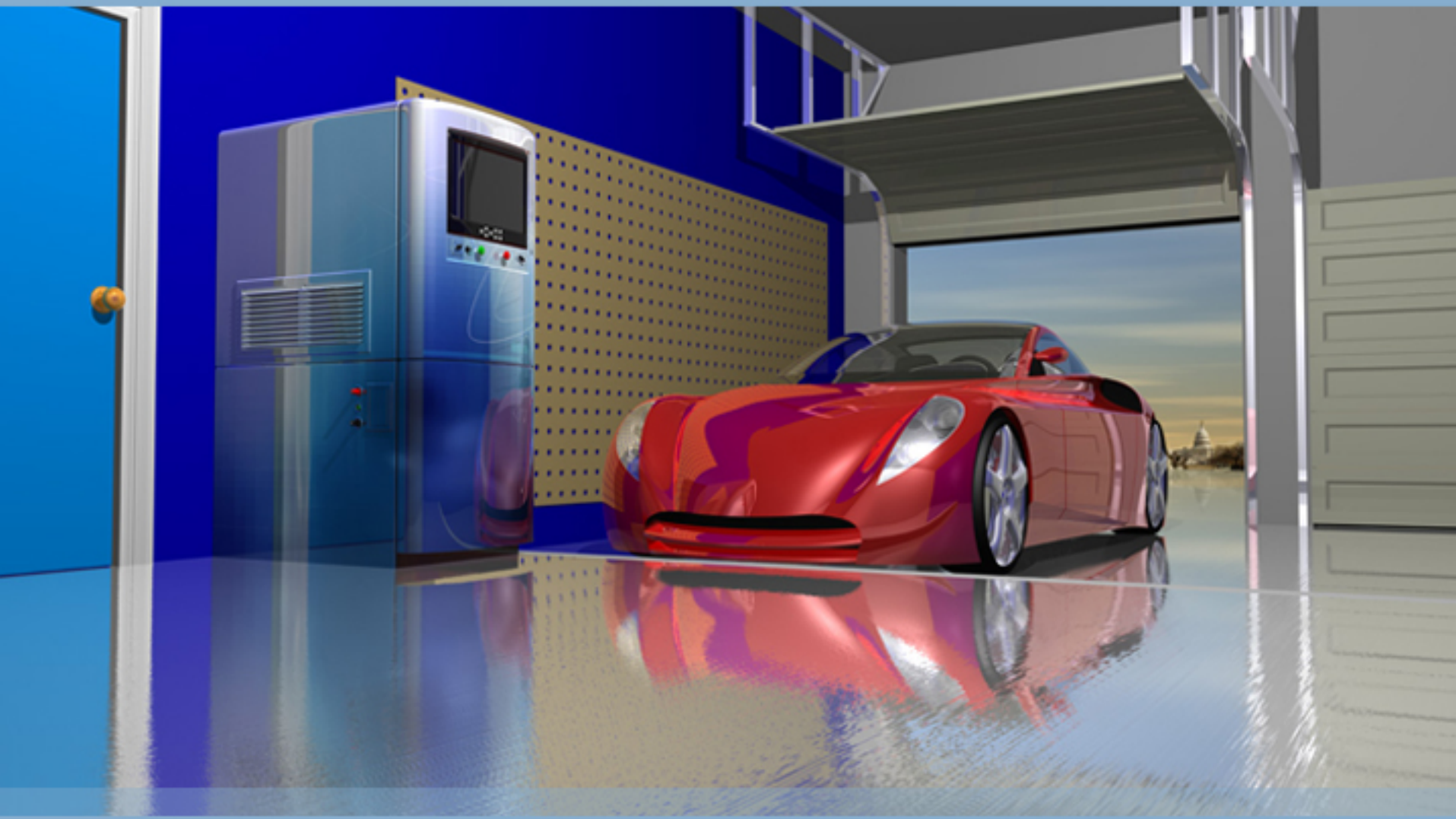
Roadmap to a Hydrogen Economy for Transportation in California

- Initiates deployment of refueling infrastructure consistent with growing availability of hydrogen-fueled vehicles
- Provides for experience building, demonstration & evaluation of advancements in infrastructure technologies
- Provides roadmap to inclusion of renewables as transportation energy sources
- Provides for development of regulatory framework for efficient deployment of a safe refueling infrastructure
- Provides clear leadership – Governor Schwarzenegger and Cal-EPA --that now is the time to move toward a long-term solution for transportation – the hydrogen economy -- rapidly and efficiently

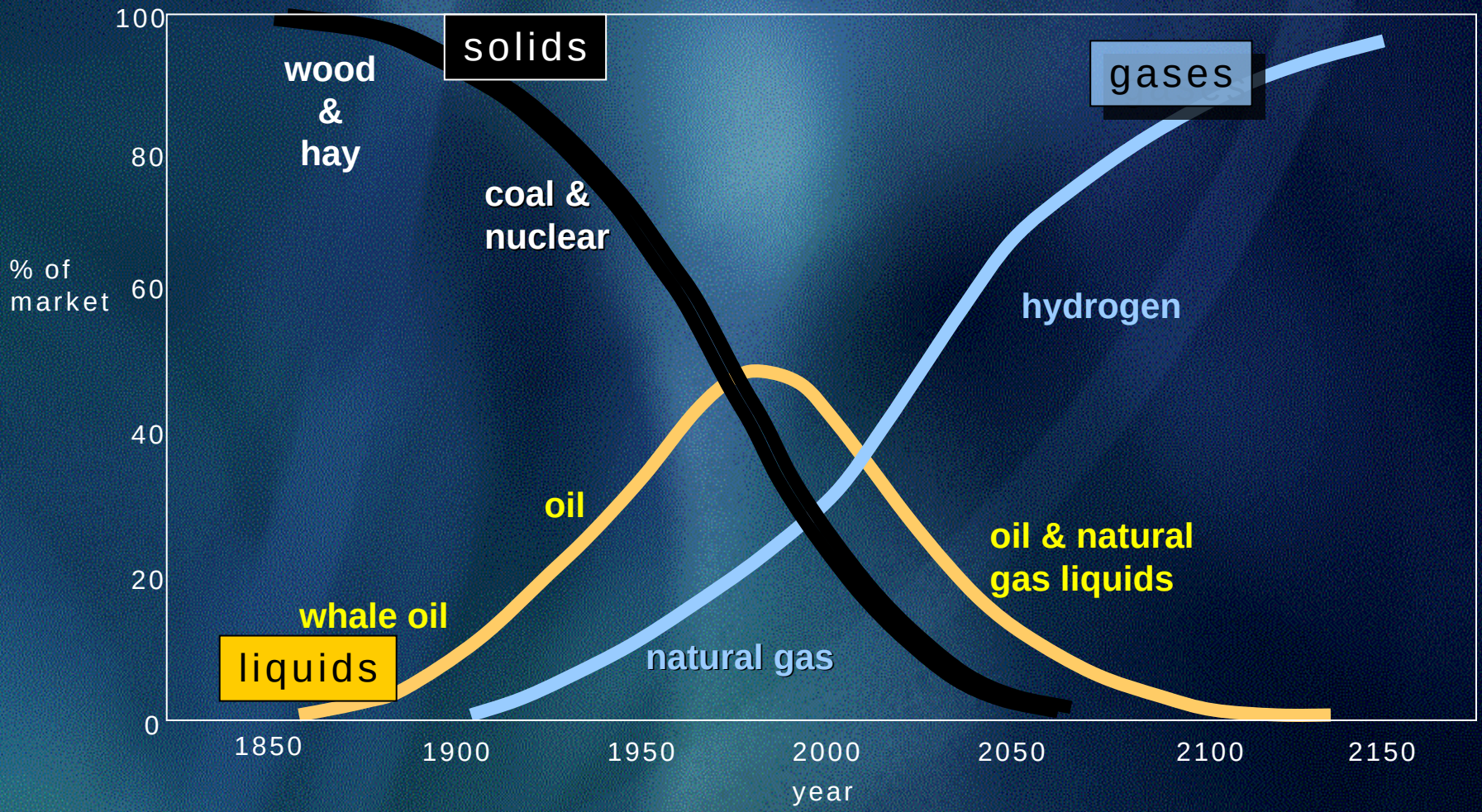
In the case of the Hydrogen Economy, perhaps infrastructure is

but instead

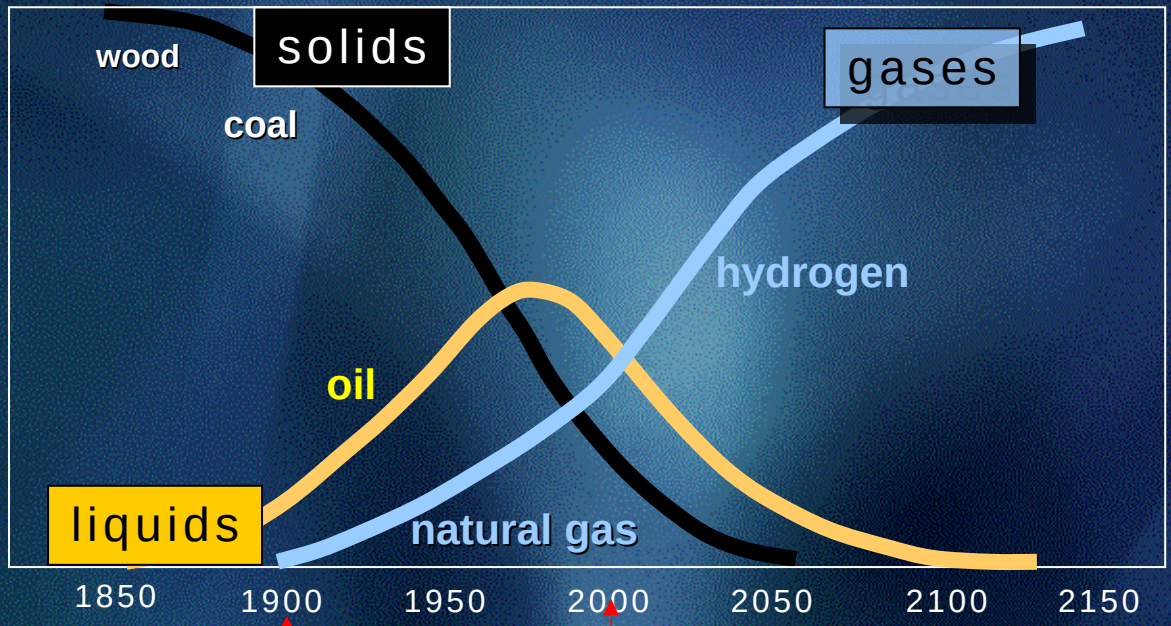
Home Refueling

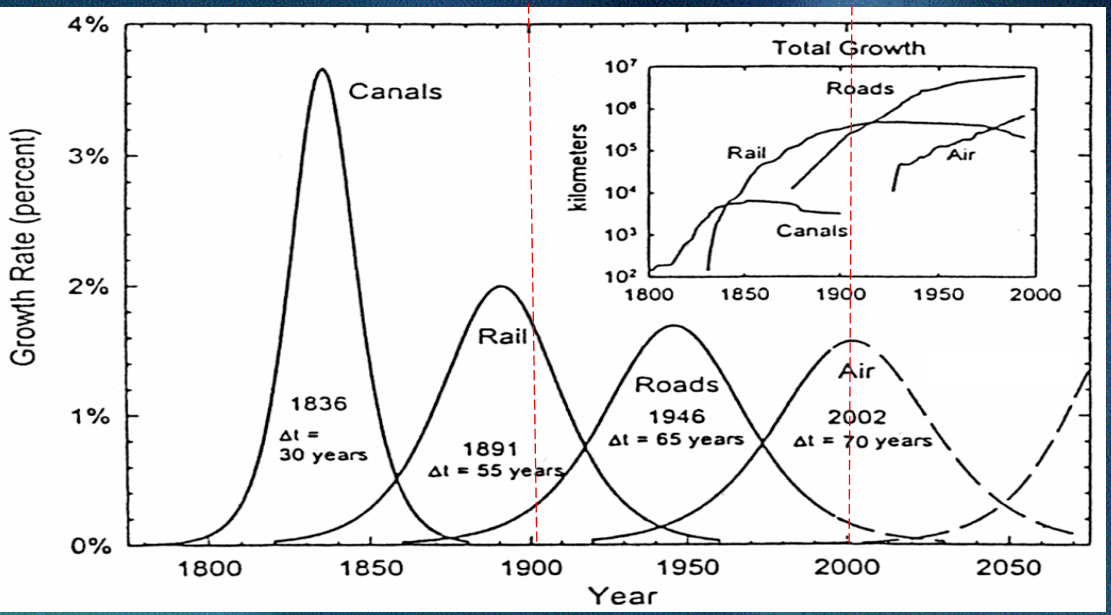


The Progression toward Hydrogen



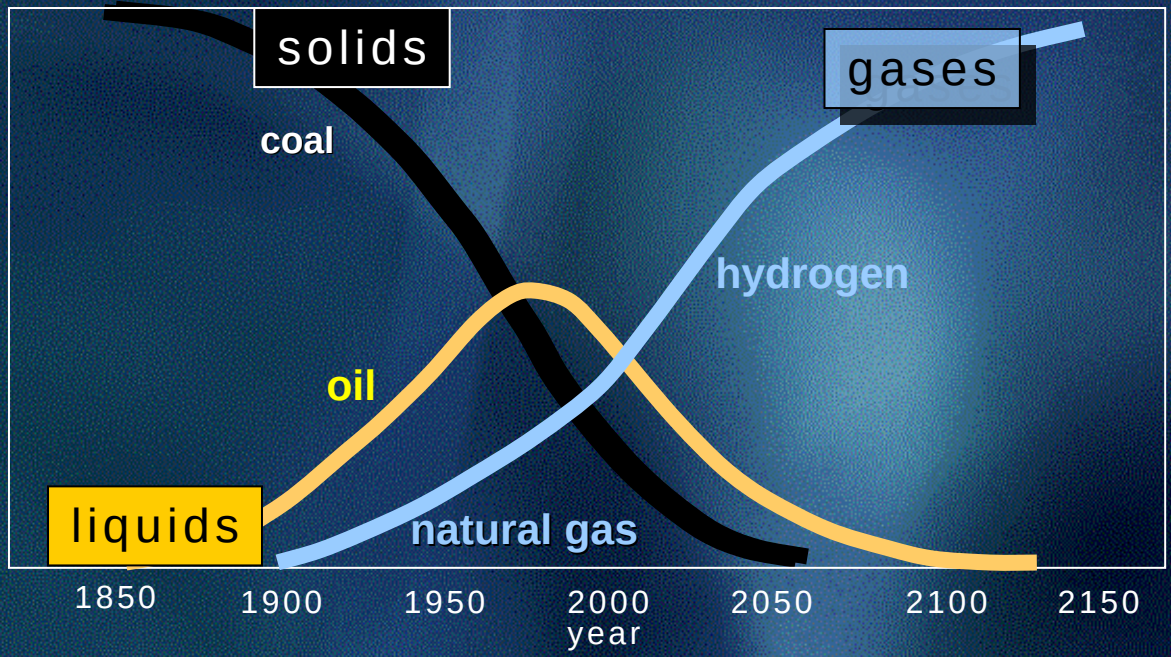
Modified from “The Economist” February 10, 2001 edition -- GTI.



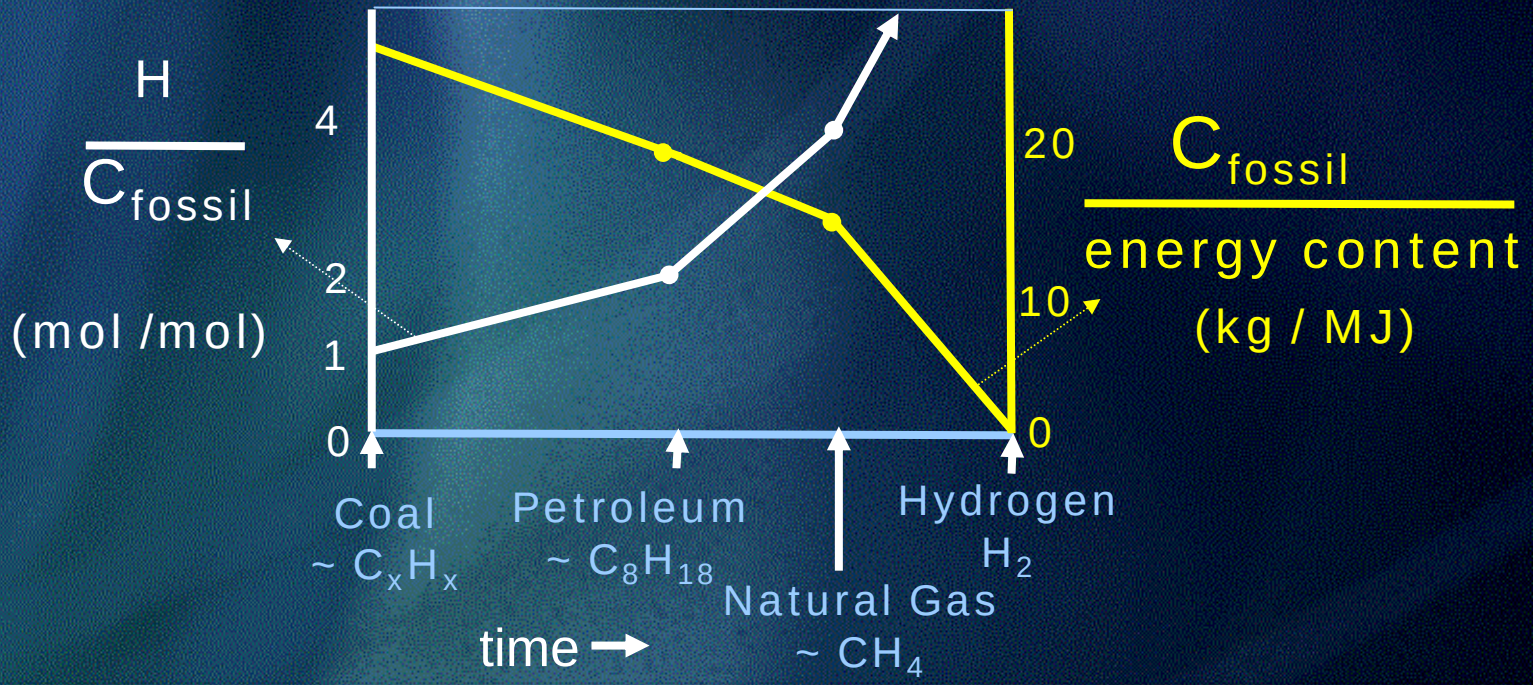


The progression in fuels with H/C ratios characteristic of wood to coal to oil to methane corresponded to periods requiring about 50 years.

The essential driver in these transitions was new technology with exceptional performance.



Hydrogen has been displacing fossil carbon as the fuel energy carrier



Measures of Progression

$$\text{CAFE} = \left\langle \frac{\text{miles}}{\text{gallon}} \right\rangle_{\text{sales}}$$

$$\text{CAFI} = \left\langle \frac{\text{H}}{\text{C}_{\text{fossil}}} \right\rangle_{\text{sales}}$$

Corp Average Fuel Economy

Corp Average Fuel Index

- today ~ 2
- raise CAFI by
  - reducing fossil C content of fuel
  - biofuel blends
  - hydrogen production
  - fossil carbon capture in production
- 2020 ~ ??

Concluding Observations

Why do anything now? If light duty vehicles are the most costly segment to approach ($/tonne CO2), why not just work on buildings & power generation?

- **Several other factors are converging – energy security, petroleum dependence, balance of payments, mega-city air quality – their solution should address GHG**
- **GHG stabilization does not appear possible without a transition away from fossil fuels, which will require a long lead time**

When will it be the time to initiate a hydrogen transition ?

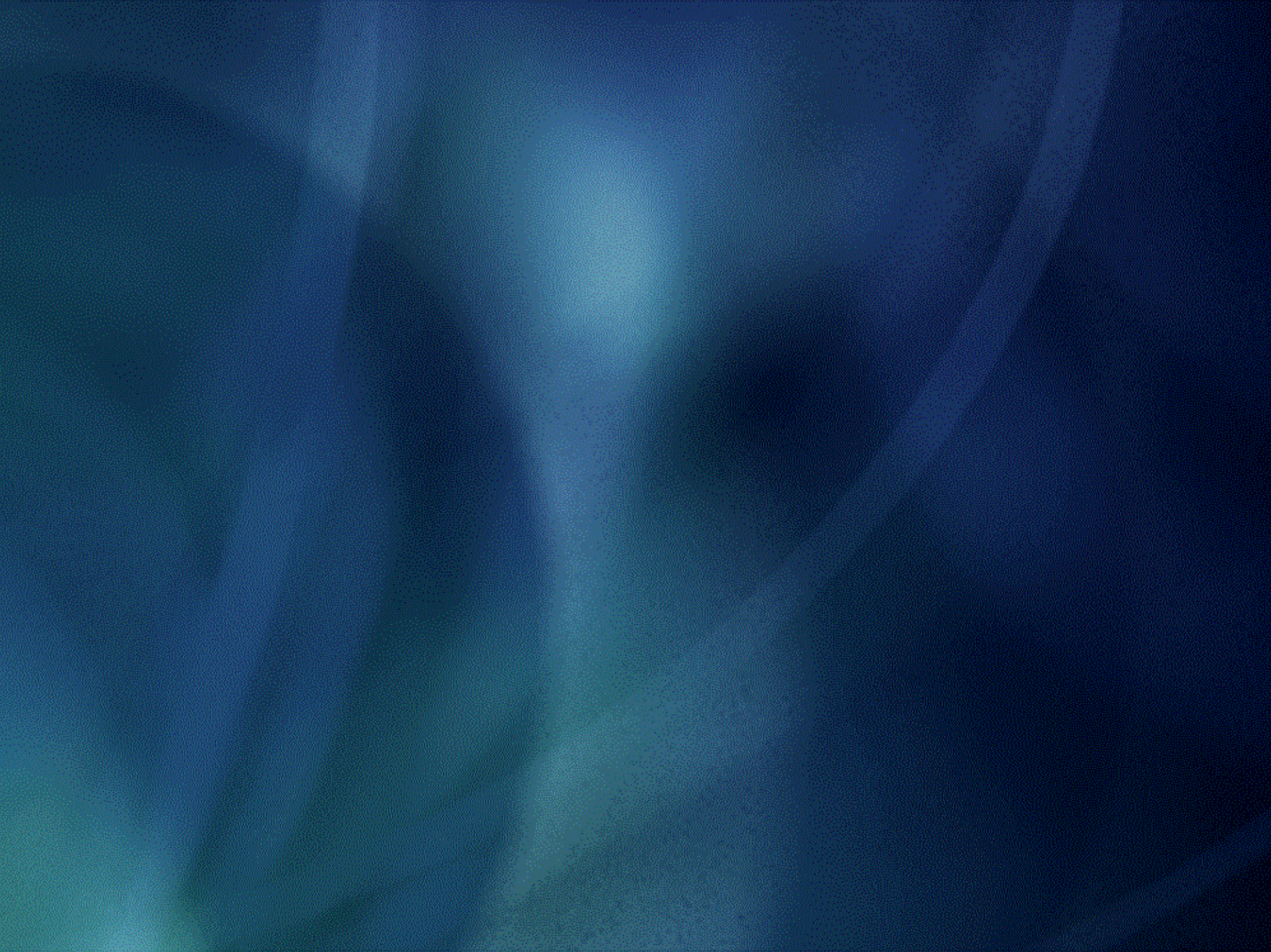
- **As soon as fuel cell/hydrogen storage technologies meet customer needs : 2010-15**
  - **transitions in the fuel infrastructure take decades to fully deploy**
  - **turn over of the on-road vehicle fleet takes decades**

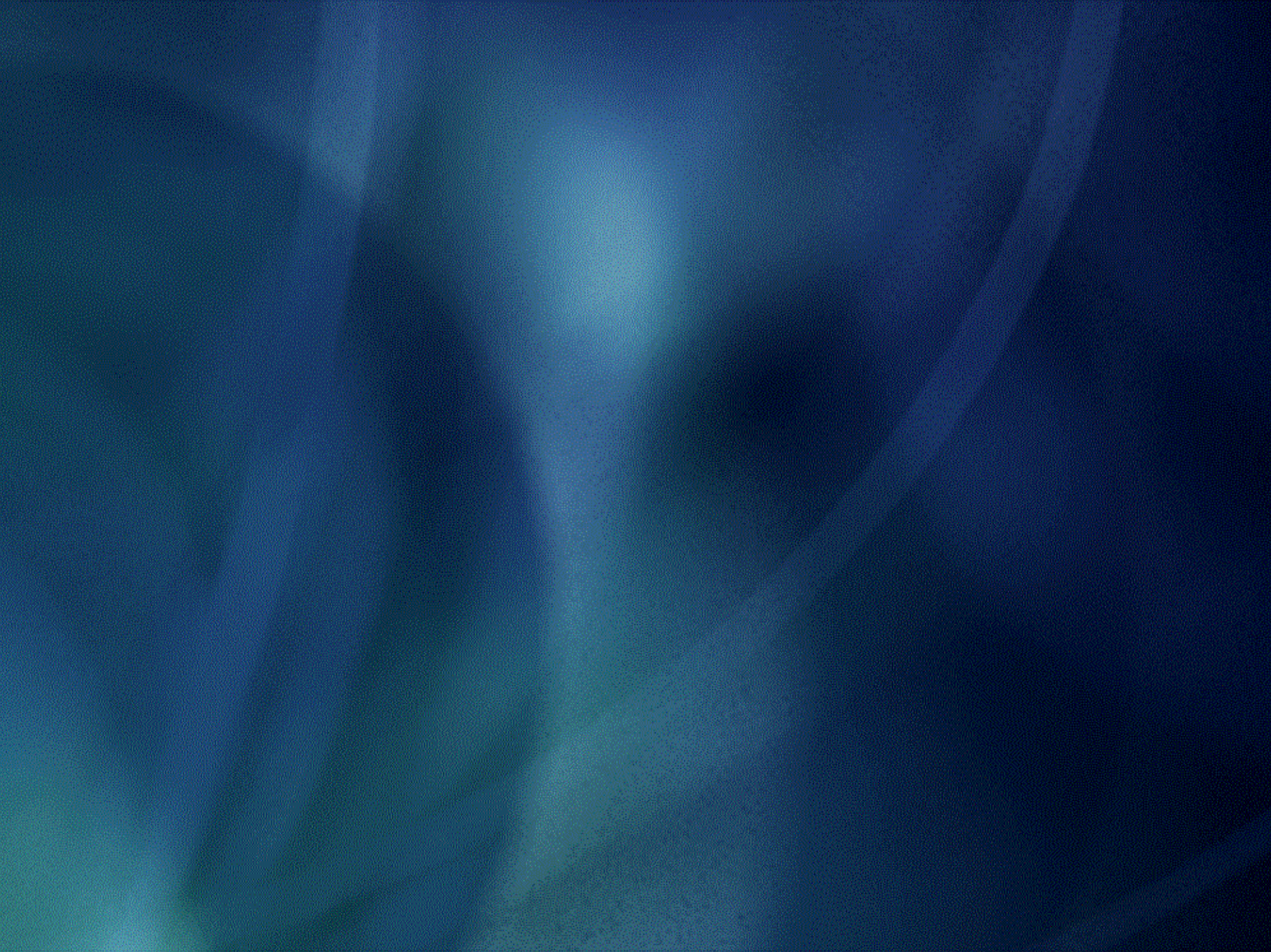
What do we do in the meantime?

Commit to Vision; Call to Action

- develop next generation of hydrogen infrastructure technology (seeded pipelines, local reformer appliances)
- solve carbon capture & improve efficiency of electrolysis & renewables
- biofuel/petroleum blended fuel & powertrains advances for ICE vehicles


General Motors





Feedstock Diversity & Opportunity for No Fossil Carbon Emissions