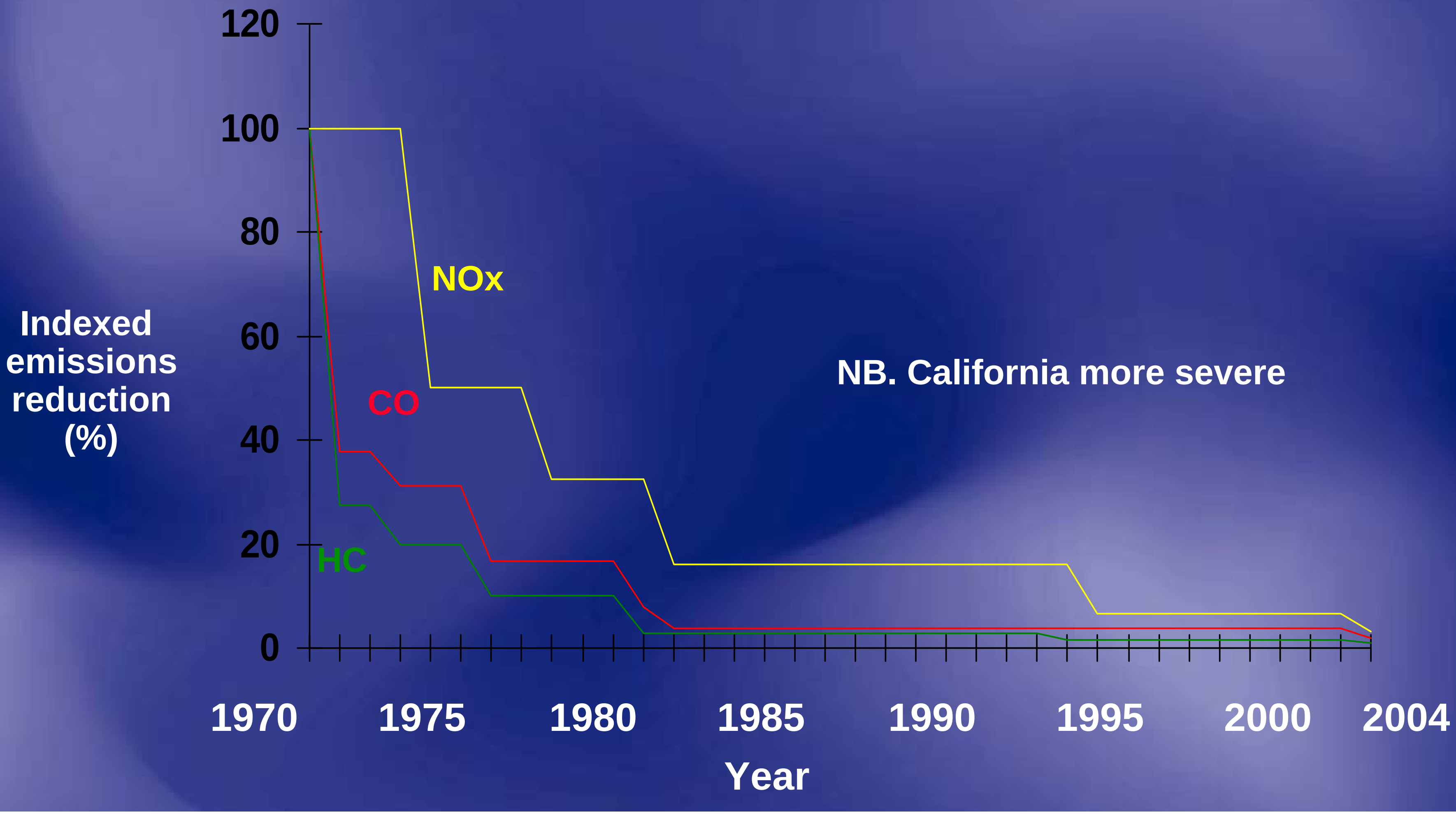
Well-to-Wheels: Vehicle Efficiency Standards and Climate Change

Andrew Armstrong
Global Fuels Technology, Sunbury

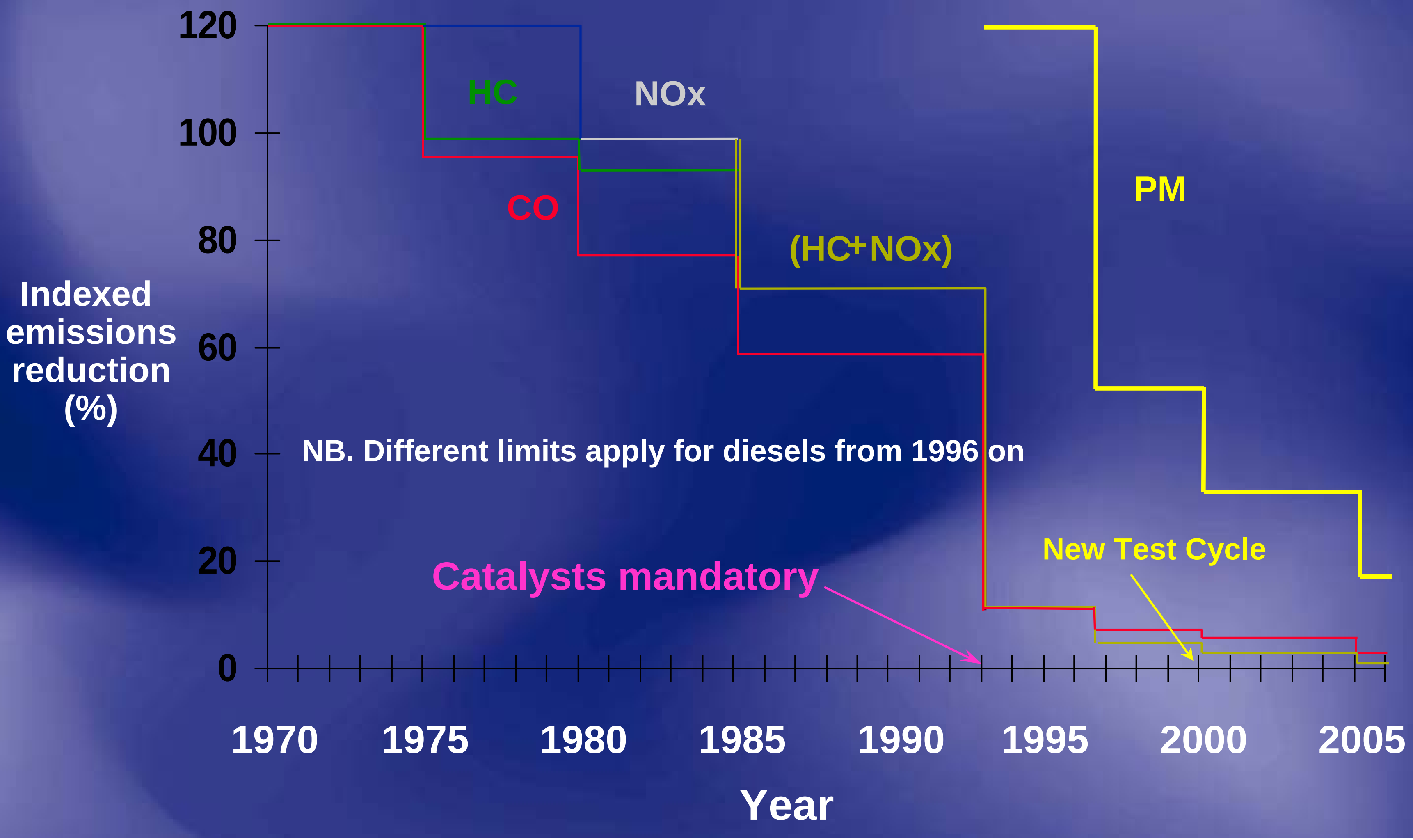
Evolution of US Emissions Legislation

(for light duty vehicles)



Evolution of EU Emissions Legislation

(for light duty vehicles)

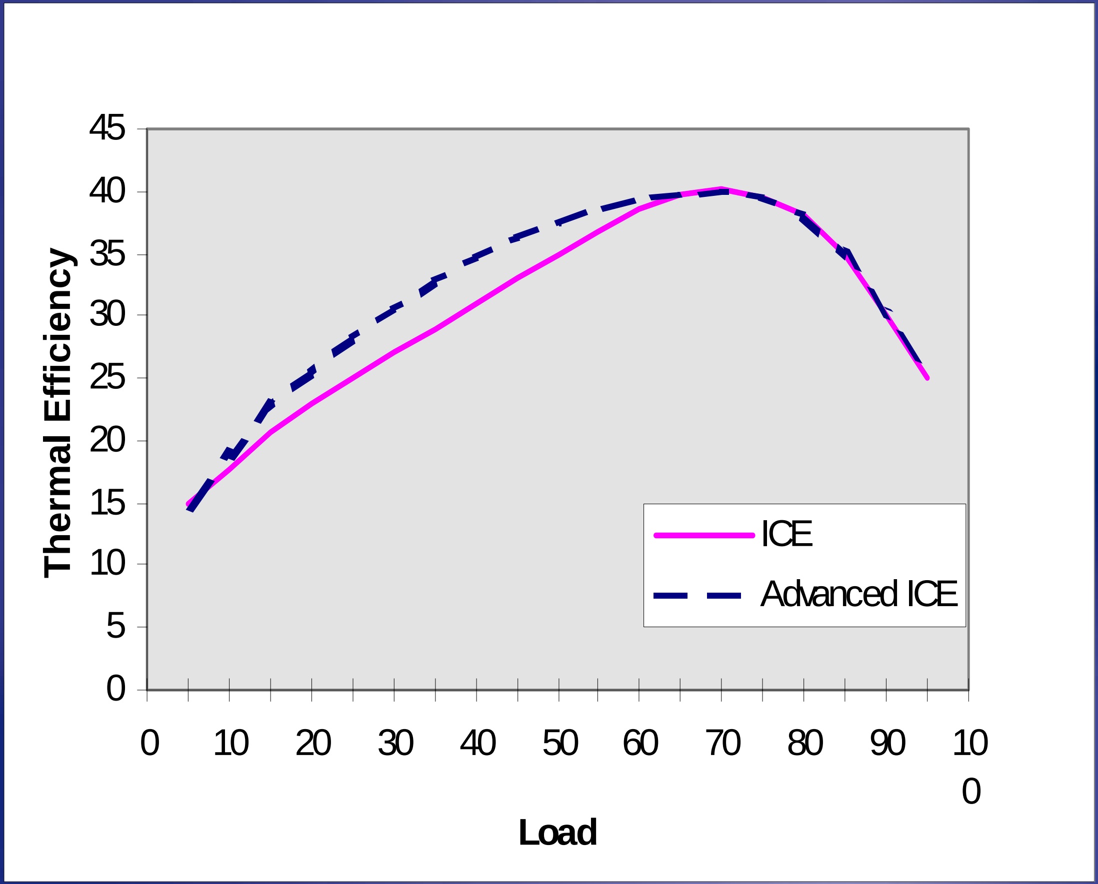


CO_2 Emissions

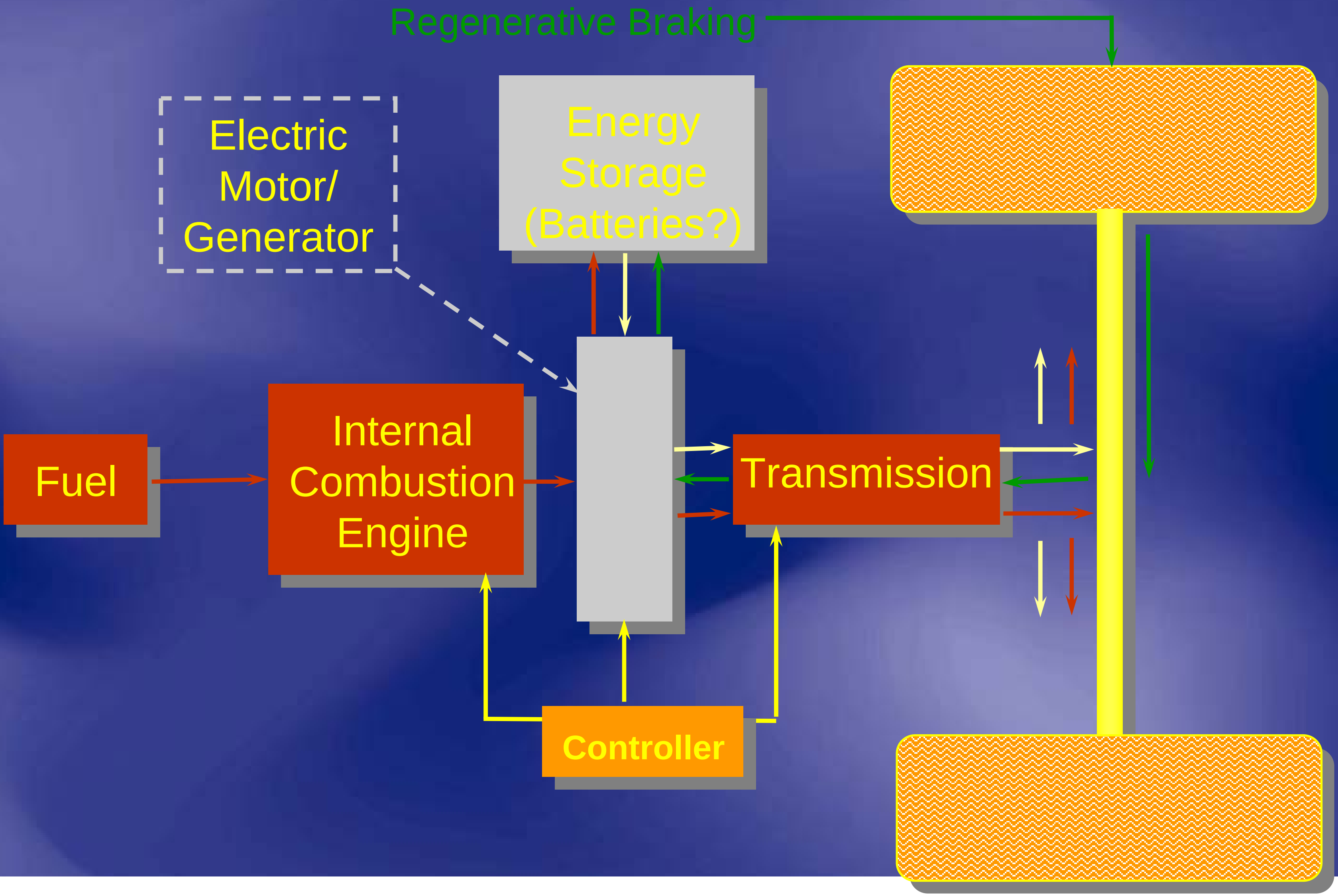
- EU has agreed CO_2 fleet targets with ACEA - 140 g/km by 2008 (= 5.8 l/100km) - 120g/km for small cars from 2000. Japanese and Korean Autos following suit
- US has the PNGV initiative seeking ~80mpg (=3l/100km, gasoline, or ~70g/km CO_2) - for 6-seater passenger cars
- Internal Combustion Engines will get cleaner, but fuel economy/CO_2 improvements are a major challenge
- Significant weight/size reductions and/or improved energy efficiency required, plus perhaps alternative fuels?

ICE Efficiency

- Overall efficiency improving with use of electronic management, VVT, etc, but peak efficiency levelling out at ~41% for HSDI diesel and ~35% for GDI (stratified charge)
- Increasingly complex after-treatment may conflict with FE gains
- Advanced transmissions help ICEs to operate in more efficient range



Hybrid Electric Vehicle: Integrated



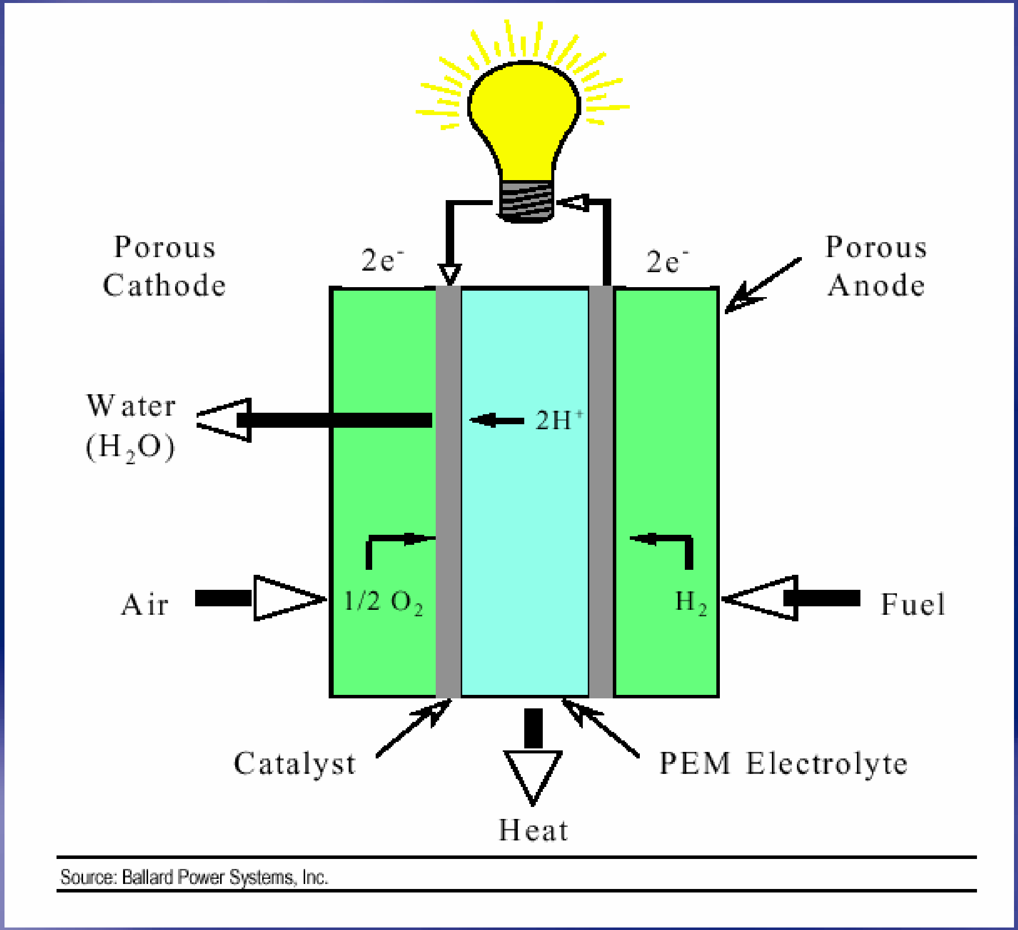
Alternatives (1)

- Mild hybridisation option offers several advantages;
  - compact packaging (flywheel generator)
  - absence of ICE-driven ancillary equipment
  - 42 volt vehicle electrics
  - regenerative braking capability
  - engine-off at idle/instant re-start
  - modest energy storage requirement
  - good driveability
- Claims of potential 30-40% fuel economy improvement over ECE/EUDC cycles
- Manageable weight/cost increase (~10%?)
- Pump fuel

Alternatives (2)

- Gaseous fuels touted as cleaner alternatives, but efficiency generally worse than gasoline/diesel ICEs and limited fuel infrastructure discourages market uptake
- Fuel Cells more efficient than ICEs, but require primary on-board fuel processors until cost-effective hydrogen storage available
- Complexity/weight = extra cost, and still CO_2 emissions, but less moving parts and cost/size coming down ($50/kW target)
- Auto OEMs racing to develop ‘production-ready’ vehicles by 2004/5 (buses by 2002/3) - numerous concepts/prototypes already shown (buses already in service trials)
- Which is the best primary fuel – methanol, ‘gasoline’ or?

Fuel Cells: highly efficient electrochemical process



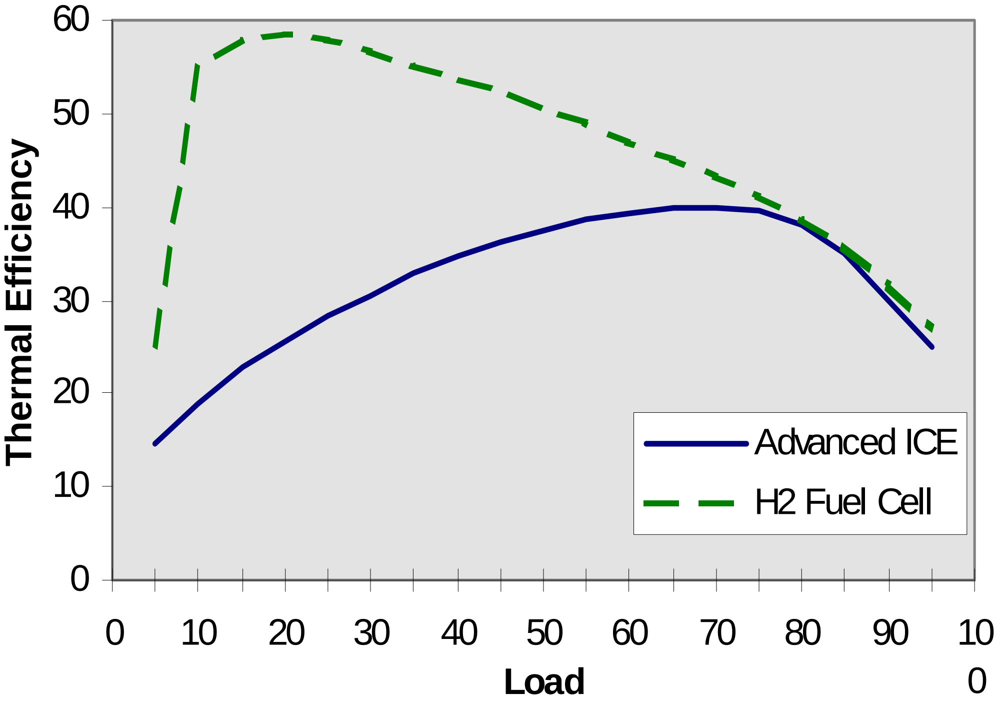
Source: Ballard Power Systems, Inc.

Categorised by electrolyte

- PEM
- Alkaline
- Phosphoric Acid
- Molten Carbonate
- Solid Oxide

Fuel Cell Efficiency

- Direct hydrogen fuel cell capable of peak efficiency approaching 60% at part load, with stretch potential
- Stacks using reformate stream ~5% less efficient



What is a Well-to-Wheel Analysis?

- Systems Approach
- Assessment of energy consumption and greenhouse gas emissions

Well-to-Tank

Tank-to-Wheel

Why Do We Need Well-Tank-Wheel Analysis?

- Evaluate emerging propulsion technologies
  - Advanced Internal Combustion Engine (ICE)
  - Hybrid Electric Vehicles (HEV)
  - Fuel Cell Vehicle (FCV)

- Evaluate new fuels

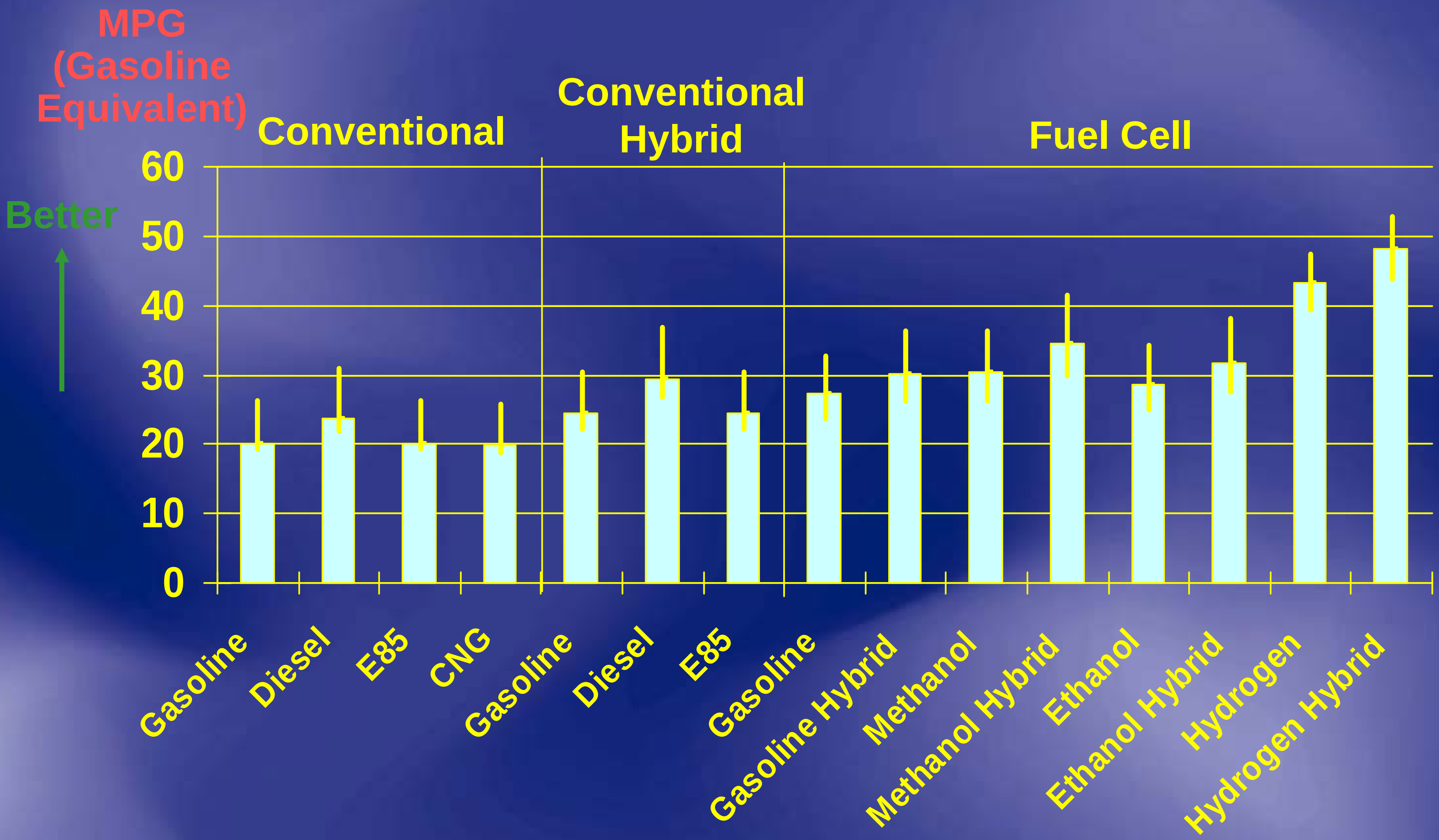
- Aid public policy development and business strategy

Background

Study commissioned by GM

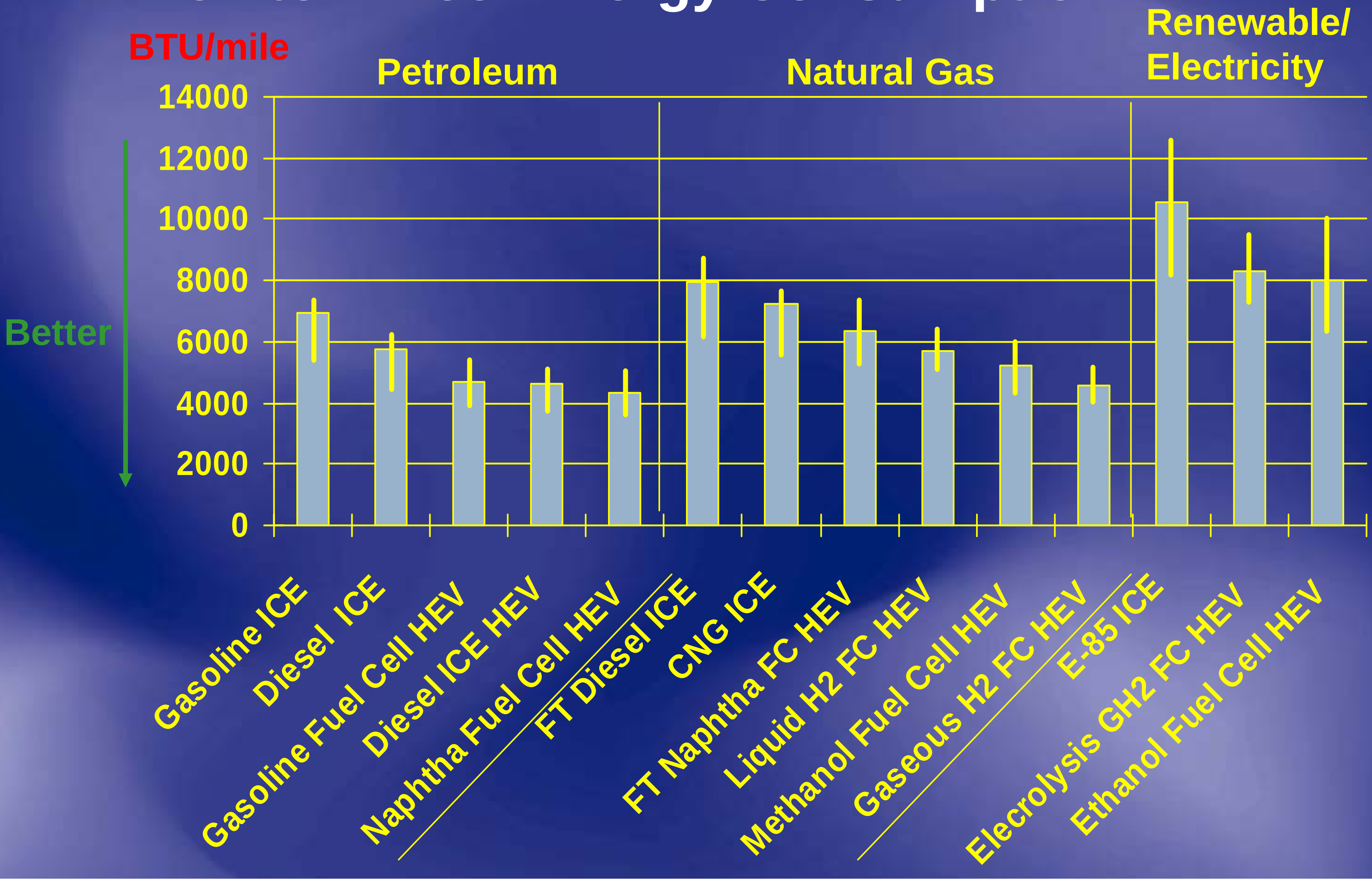
- Well-to-Tank work done by Argonne National Labs with input from BP, ExxonMobil, and Shell
- Tank-to-Wheel work performed by GM (pick-up truck as baseline vehicle)
- Considered 75 fuel “pathways” (from petroleum, natural gas, electricity and bio-ethanol) plus 15 advanced and conventional powertrain systems
- US-focused, but European study to follow

Tank-to-Wheel Vehicle MPG



bp ExxonMobil ARGONNE Argonne National Laboratory is operated by The University of Chic GM

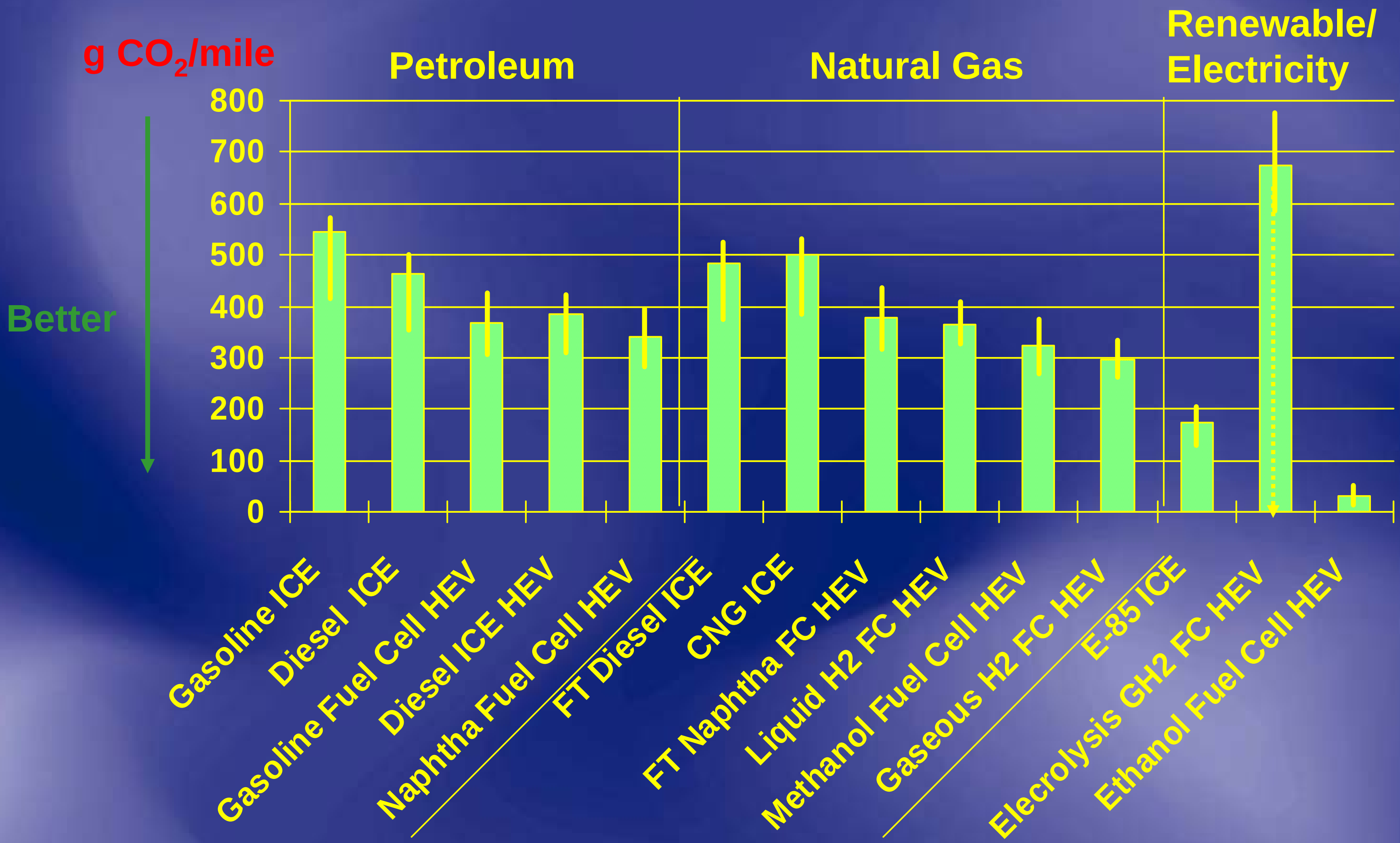
Well-to-Wheel Energy Consumption



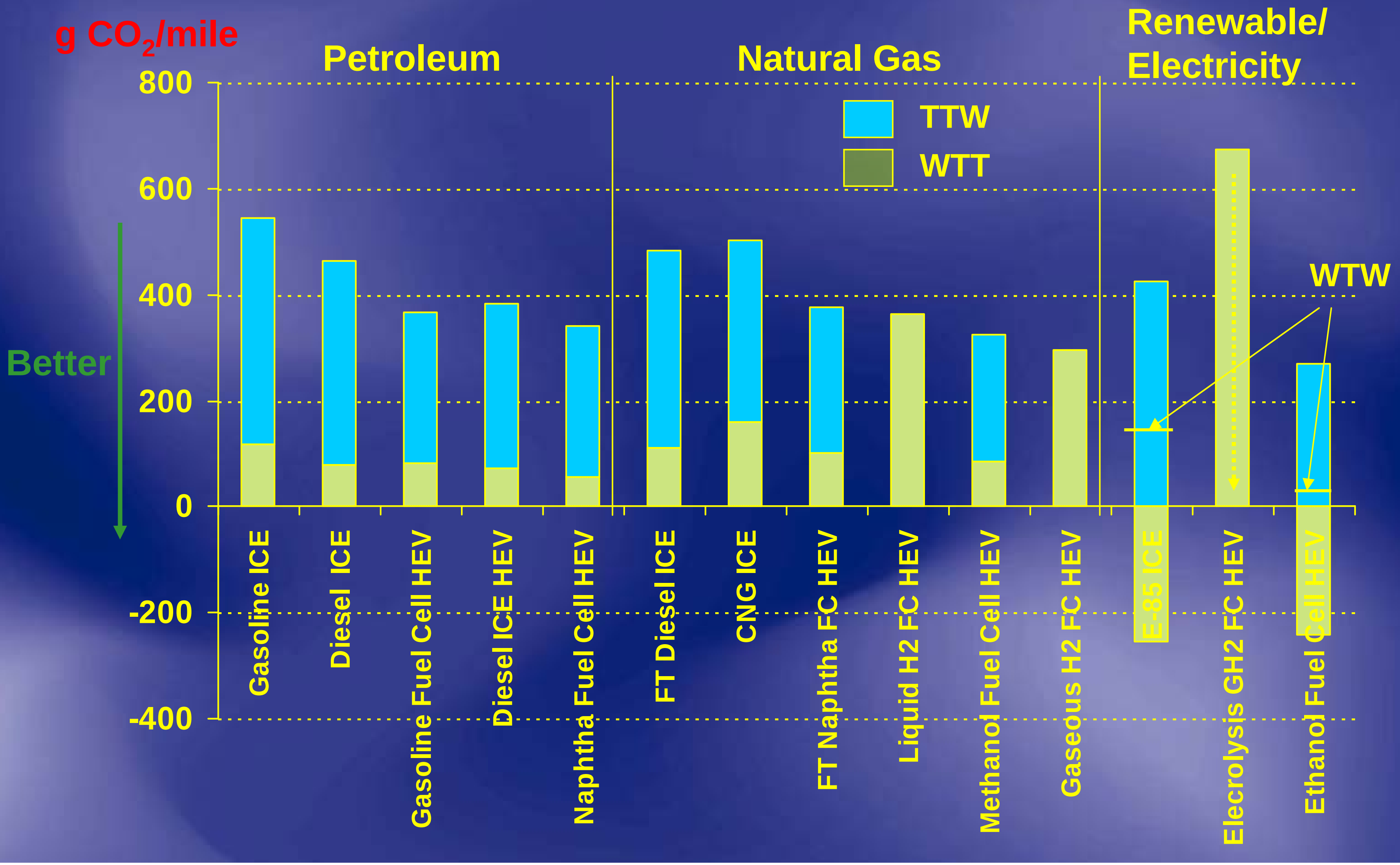
bp   Shell   ExxonMobil   ARGONNE   GM

Argonne National Laboratory is operated by The University of Chic

Well-to-Wheel Greenhouse Gases



Well-to-Tank + Tank-to-Wheel Greenhouse Gases



Well-to-Wheel Study Conclusions

- Fuel cell vehicles powered by clean gasoline offer greatly reduced greenhouse gas emissions vs. today's powertrains/fuels
- Diesel hybrid is very competitive and a clear leader among non-fuel cell powertrains/fuels
- CNG does not appear to offer any benefit vs. conventional fuels for internal combustion engine (ICE) vehicles
- Methanol fuel cell vehicles do not offer an advantage vs. gasoline fuel cell vehicles
- Renewable fuels and nuclear power offer the lowest greenhouse gas emissions

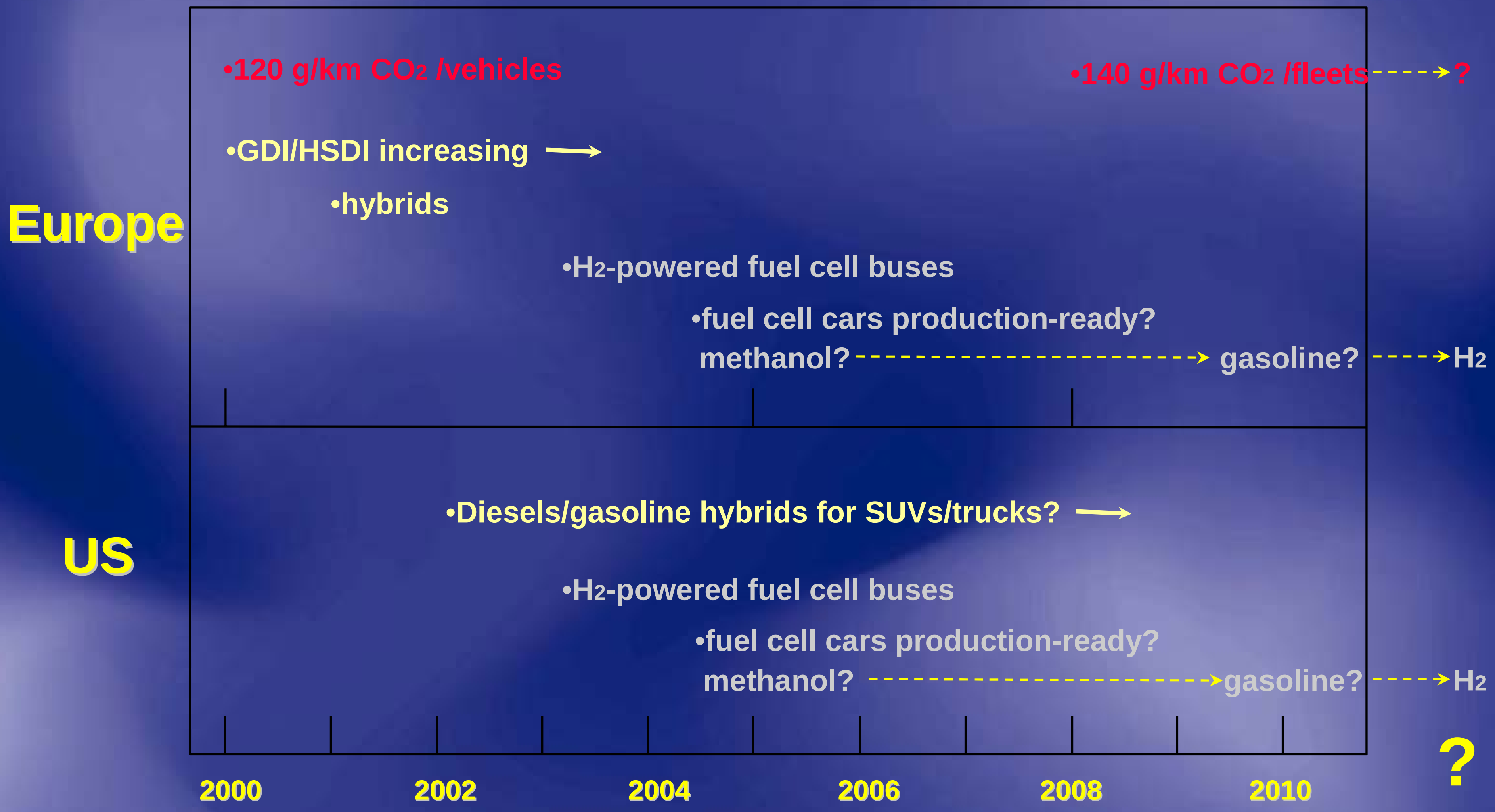
Future Automotive Fuels Summary (1)

- ICEs will be challenged to meet CO_2 targets without significant vehicle weight/size reduction + cost increase
- Gaseous fuels offer regulated emissions benefits, but not much for overall energy consumption/CO_2. LPG attractive for cars/light duty, but CNG best used in PSVs/commercial fleets?
- Battery EVs provide ZEV (Zero Emission Vehicle) option, but likely to remain impractical, due to fundamental energy storage constraints, except for niches (local use)

Future Automotive Fuels Summary (2)

- Fuel Cells offer the potential of zero vehicle tailpipe emissions, even better efficiency and lower CO_2, well-to-wheels
- FCEV prototypes currently heavy, complex and expensive, but promising long-term potential for weight/size/cost reduction
- Direct Hydrogen FCEVs ultimately the best option, but cost-effective on-board hydrogen storage needed
- Meanwhile, hybrids likely to help meet initial CO_2 targets, extend the reign of ICEs and provide a transitional path to FCEVs

Anticipated Technology Developments



Europe

- 120 g/km CO_2 /vehicles
- 140 g/km CO_2 /fleets - - - -> ?
- GDI/HSDI increasing →
- hybrids
- H_2-powered fuel cell buses
- fuel cell cars production-ready?

methanol? -> gasoline? - - - - -> H_2

US

- Diesels/gasoline hybrids for SUVs/trucks? →
- H_2-powered fuel cell buses
- fuel cell cars production-ready?

methanol? -> gasoline? - - - - -> H_2

Transition to Sustainability

Cogeneration

Hybrid Vehicles

Cleaner Fuels

Fuel Cell Vehicles

Energy & Emission Efficiency

Methanol

Hydrogen

Gas to Power

CO_2 Sequestration

Reduce Carbon

Wind

pv Solar

Thermal Solar

Renewables

Past **Present** **Future**