SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS
INSTITUTE OF TRANSPORTATION STUDIES

FUTURE TRANSPORTATION AND ENERGY CHALLENGES

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Energy Research – Five Years and Beyond

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CONTEXT

- Direct combustion of fuels for transportation and heating accounts for about 2/3 of primary energy use and GHG emissions, and a large fraction of air pollutant emissions.
- World transportation sector 97% dependent on oil.
- # vehicles projected to triple worldwide by 2050
- In US, ~28% of GHG emissions are from transportation (CA ~40%; 15% worldwide); transportation is rapidly growing GHG source in the US and globally.

ADDRESSING TRANSPORTATION ENERGY CHALLENGES

Climate change, Air quality, Energy security

Transportation Efficiency

- Vehicle fuel economy
- Congestion relief
- Road design
- Intelligent Transportation Systems (ITS)

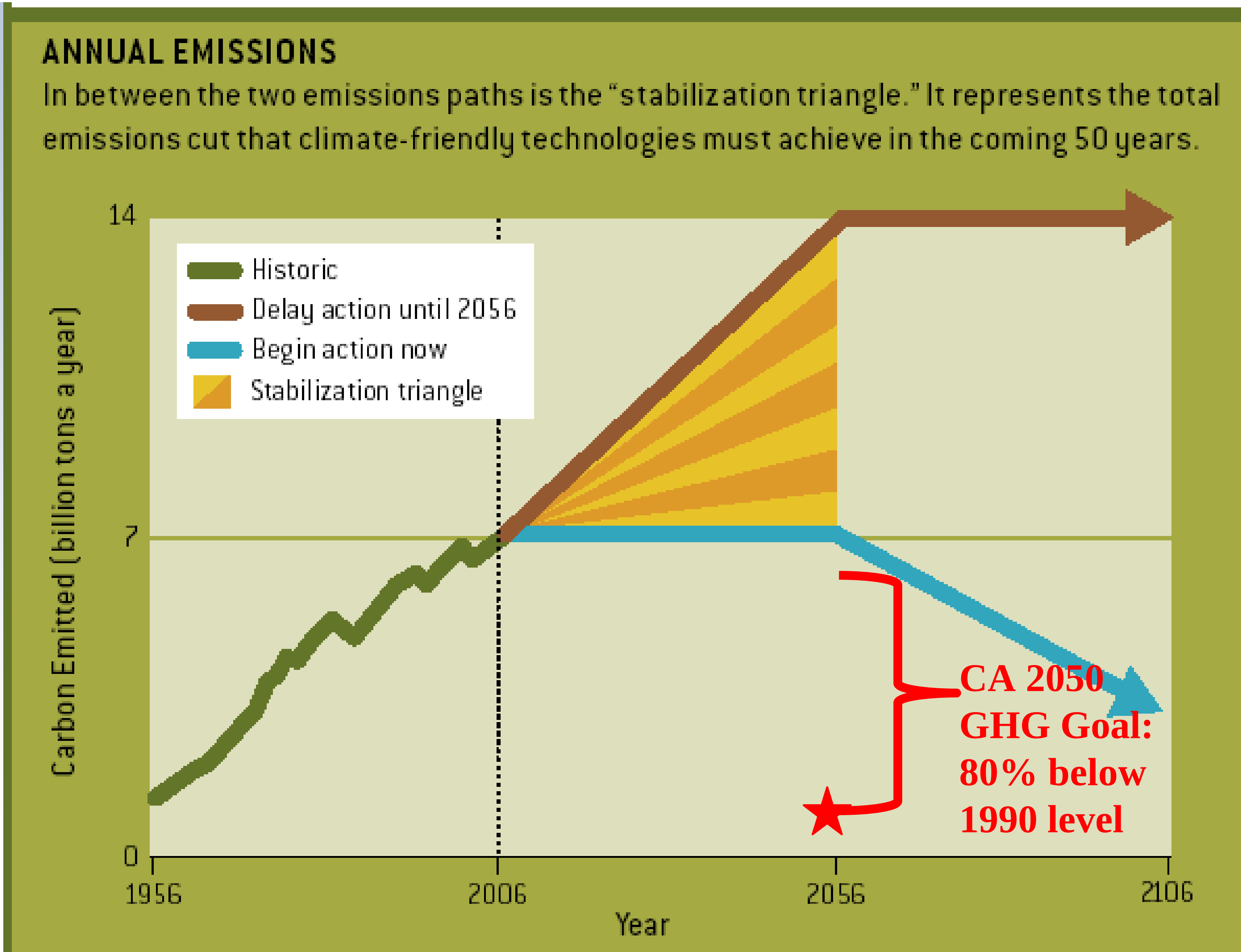
Alternative Fuels & Vehicle Technology

- Hydrogen
- Biofuels
- Electric drive vehicles
- Advanced ICE engines
- Low-carbon liquid fuels

Reduced Vehicle Miles Traveled (VMT)

- Carpooling
- Mass transit
- Urban design

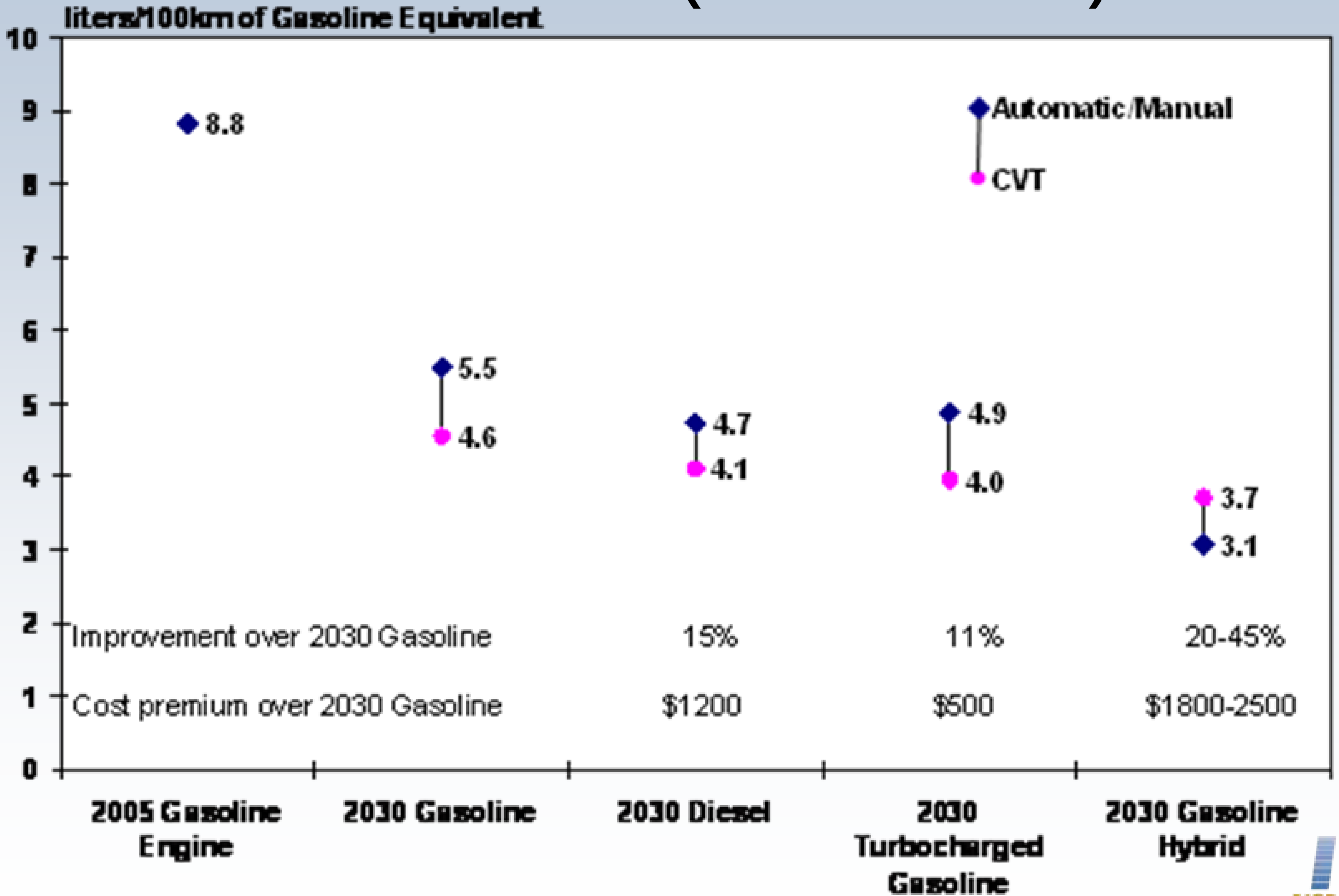
STABILIZATION WEDGES (Pacala, Socolow)



15 WAYS TO MAKE A WEDGE

Doubling vehicle efficiency could become one “wedge”, zero-carbon fuels another

POTENTIAL FOR VEHICLE ENERGY EFFICIENCY (ICEVS 2X +)



SOURCE: Heywood (2007).

REDUCING VMT

"Recent studies show that substantial reductions in travel and emissions of pollutants and greenhouse gases are possible (10%-30%, compared to the future base case), but only with combined transportation investment, land use, and travel pricing policies."

R. A. Johnston et al. 2007. Review of U.S. and European Regional Modeling Studies of Policies Intended to Reduce Highway Congestion, Fuel Use, and Emissions

UC DAVIS ITS

Reducing VMT and GHGs via Smart Growth

The GHG reductions that can be achieved through smart growth programs are difficult to quantify, as many factors contribute to patterns of development and to GHG emissions.

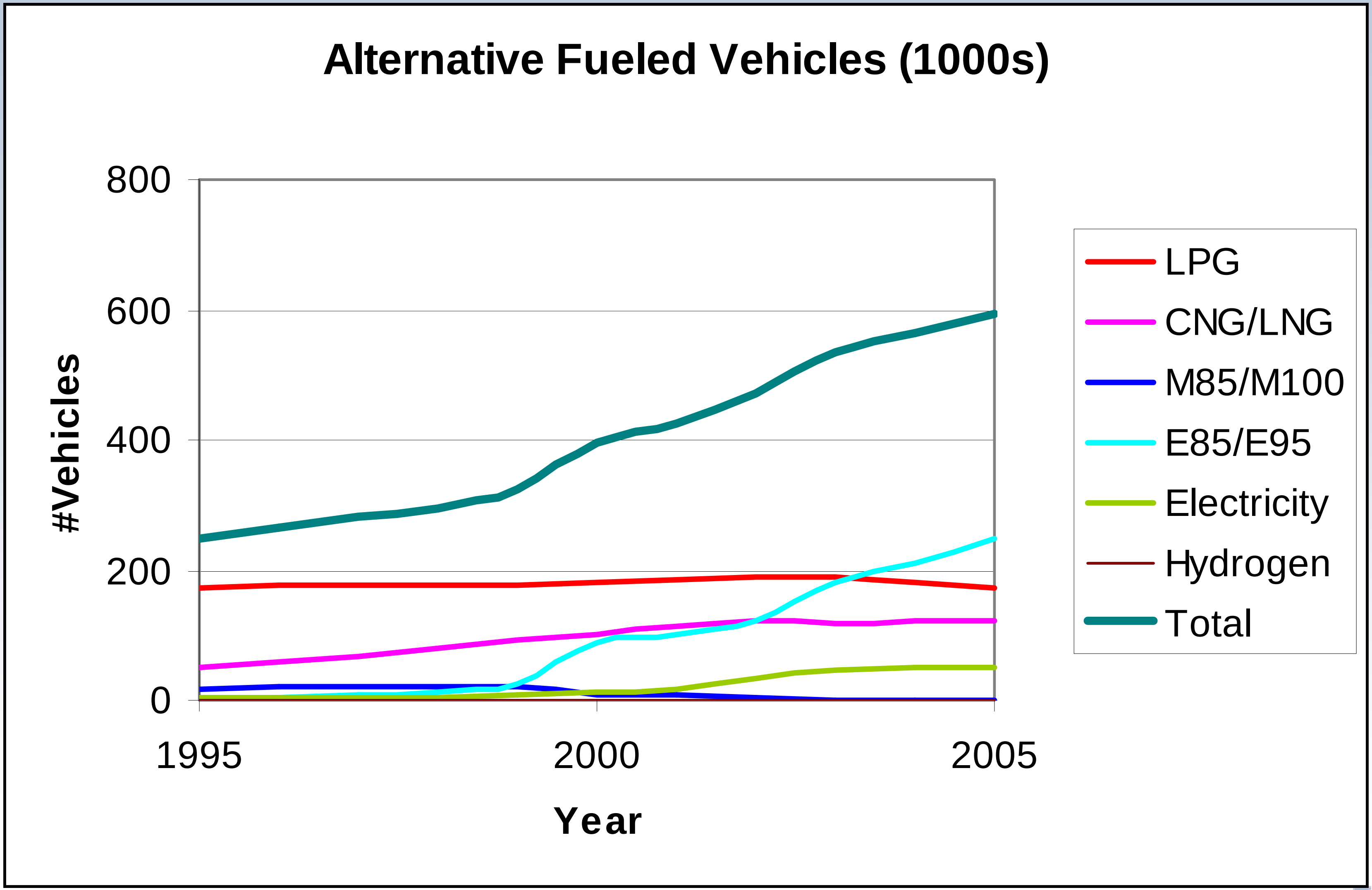
Several studies have attempted to quantify the benefits of “smart growth”. In one case, the NRDC compared two Nashville area towns. Though both towns were suburban and automobile oriented, residents of Hillsboro, with higher land-use density and better transportation accessibility than Antioch, emitted 25 percent less GHG per capita than residents of Antioch. This was principally a result of less vehicle travel in Hillsboro. In another case, an EPA assessment estimated that a smart growth community in midtown Atlanta, called Atlanta Station, would create 62 percent less GHG emissions than a sprawl development.

State and Local Net Greenhouse Gas Emissions Reduction Programs, Pew Climate Center

POTENTIAL FOR ALTERNATIVE FUELS

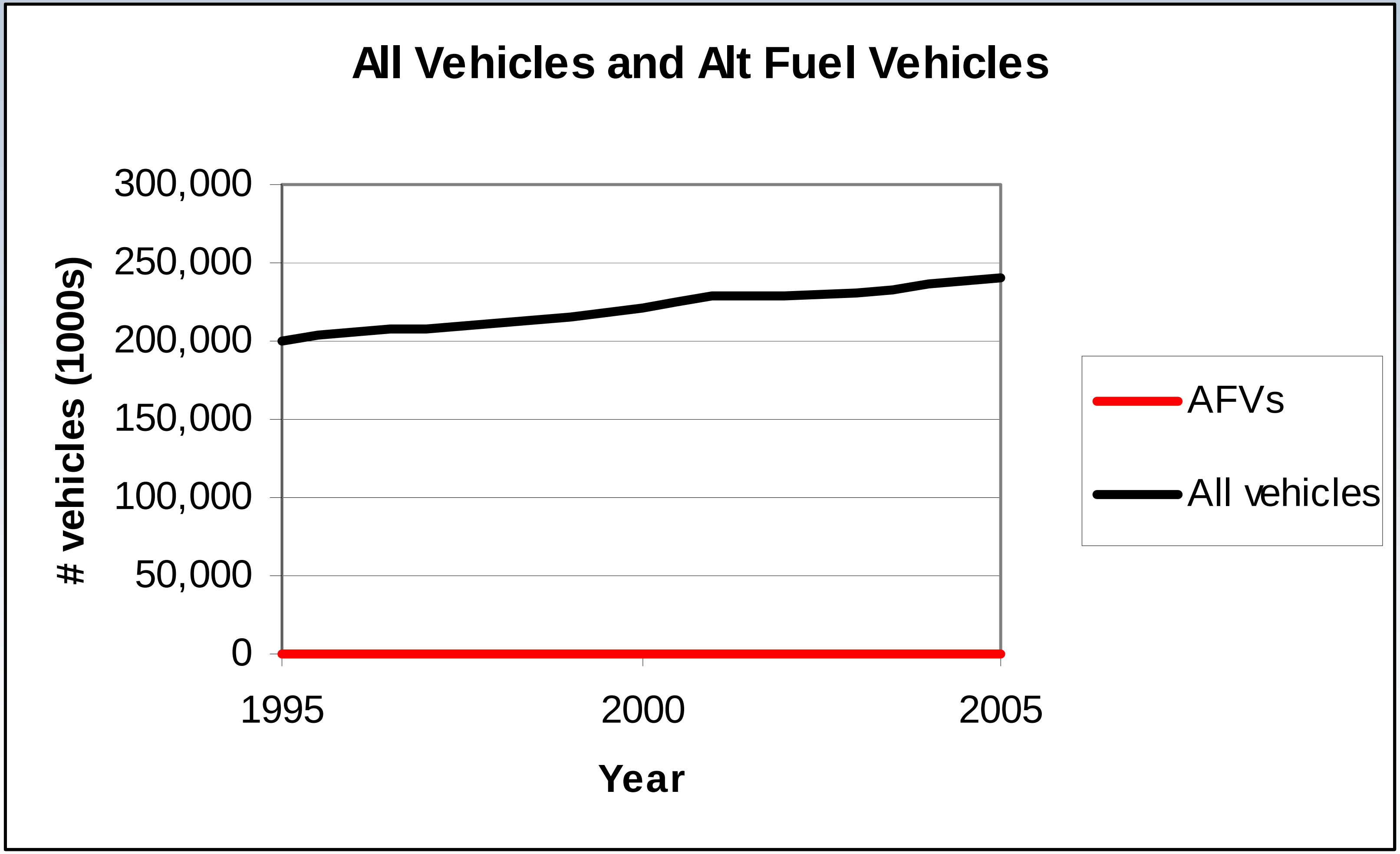
- **Growing imperative for alternative fuels**
  - Oil supply security
  - Climate Change
- **Search for solutions by policymakers, industry**
  - Innovative Policy Landscape
- **Continuing tech progress in variety of alt fuel and vehicle technologies**
  - Biofuels
  - Electricity (Plug-in Hybrid vehicles, Battery vehicles)
  - H2/Fuel Cell Vehicles
  - Fossil-based fuels w/Carbon Capture and Sequestration

History of alternative fuel vehicles (US)



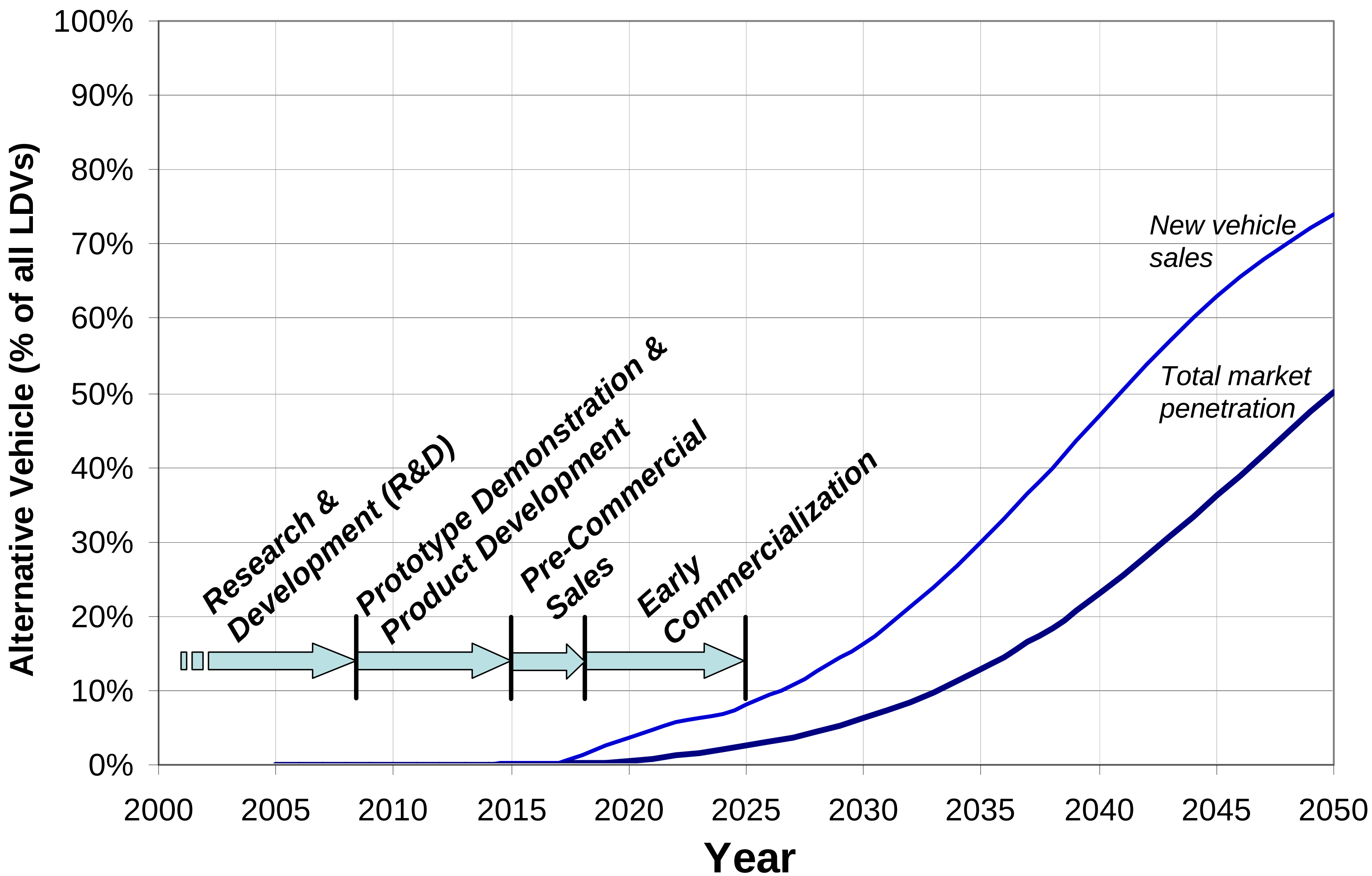
References: Davis, Transportation Energy Data Book (2008)

History of alternative fuel vehicles (US)



Will the future be different? MAYBE..

VEHICLE COMMERCIALIZATION TAKES TIME



Source: Cunningham, Gronich and Nicholas, presented at the NHA Meeting, March 2008.

STAGES OF VEHICLE COMMERCIALIZATION

For a revolutionary new vehicle concept (e.g. FCVs)

- **R&D** (10+ yrs)
- **Production Development** (5-7 yrs, 2009-2015)
  - Vehicle line and powertrain concept chosen – focus on system development, durability, integration, marketing
  - **Adv. Prototype Demo** (during development phase, 100's veh's) – Gather public feedback and reaction to revolutionary vehicle
- **"Pre-Commercial Sales"** (2015-2018, 10,000's veh's)
  - Early market development, some vehicles with fleets
  - Vehicle and fuel incentives in place (necessary)
- **"Early Commercialization"** (2018 +, 100,000's veh's)
  - Traditional sales & marketing take over, subsidies reduced
  - Multiple product lines begin to emerge

Source: Cunningham, Gronich and Nicholas, presented at the NHA Meeting, March 2008.

INTRODUCING INNOVATIONS IN VEHICLES

time constants: 20-60 years

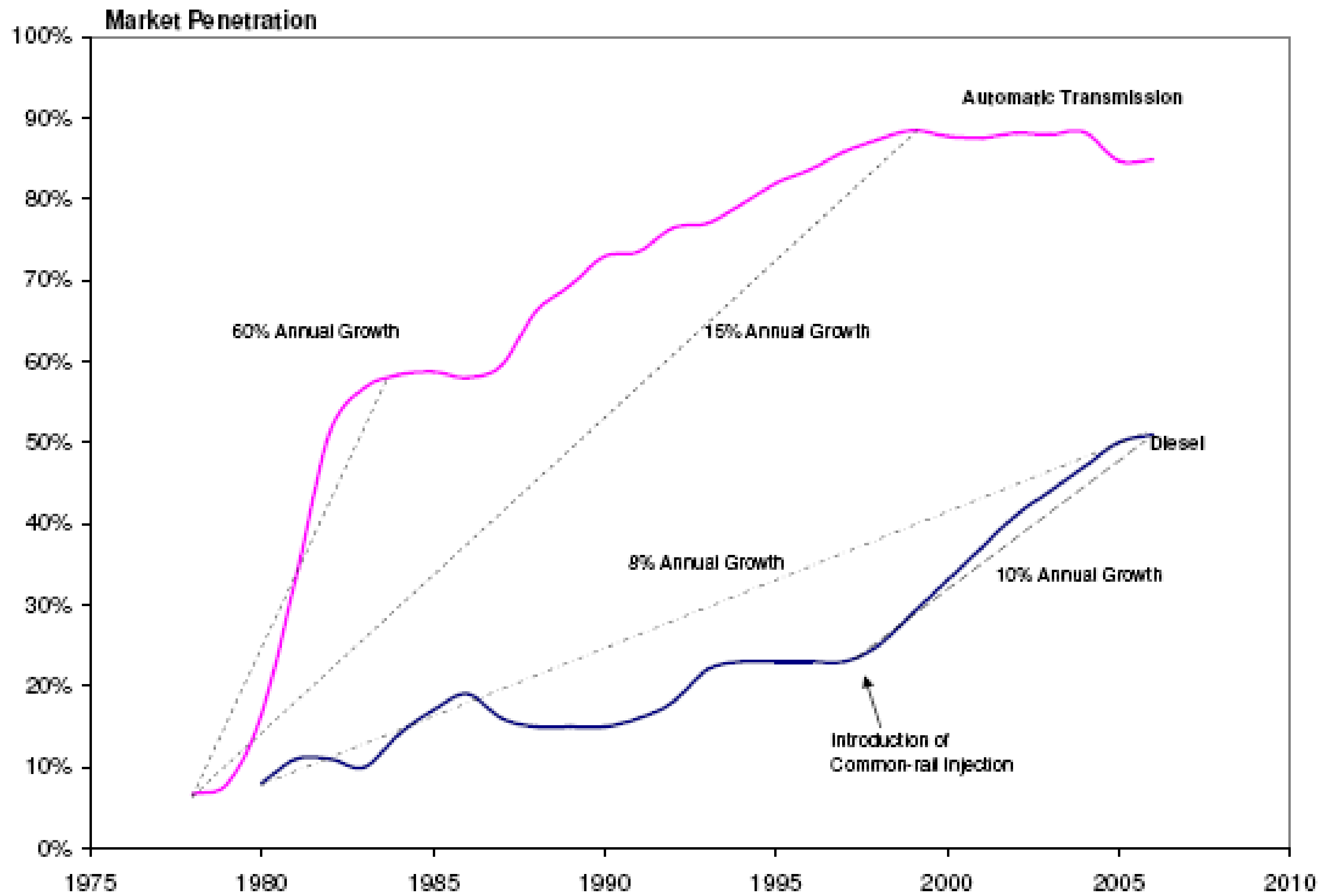
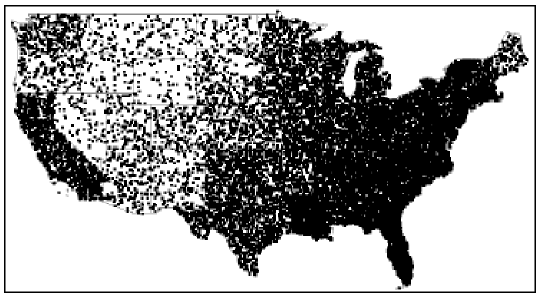


Figure 60: Market penetration rates of different vehicle technologies. Source: Automatic transmission penetration data from EPA [2006a]; Diesel penetration data from ACEA [2007].

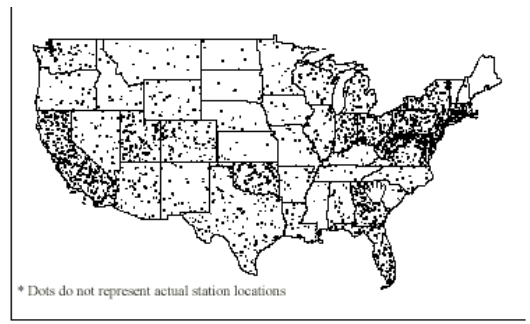
REFUELING STATIONS FOR GASOLINE & ALTERNATIVE FUELS

Gasoline



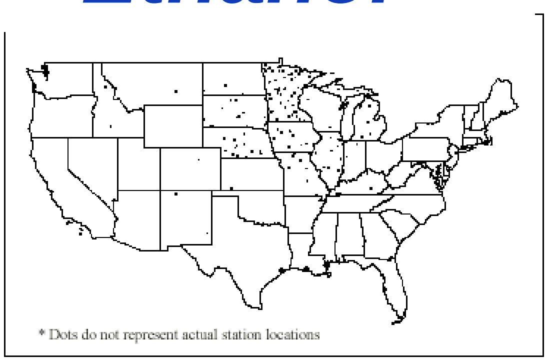
* Please note one dot = 10 stations and does not represent actual locations.

CNG



Data Source: Alternative Fuels Data Center, "U.S. Refueling Site

Ethanol



Data Source: Alternative Fuels Data Center, "U.S. Refueling Site

Methanol

Data Source: Alternative Fuels Data Center, "U.S. Refueling Site

~100+ H_2 refueling stations worldwide

HISTORICAL DATA: MAJOR US TRANSPORTATION INFRASTRUCTURES

time constants: 30-70 years

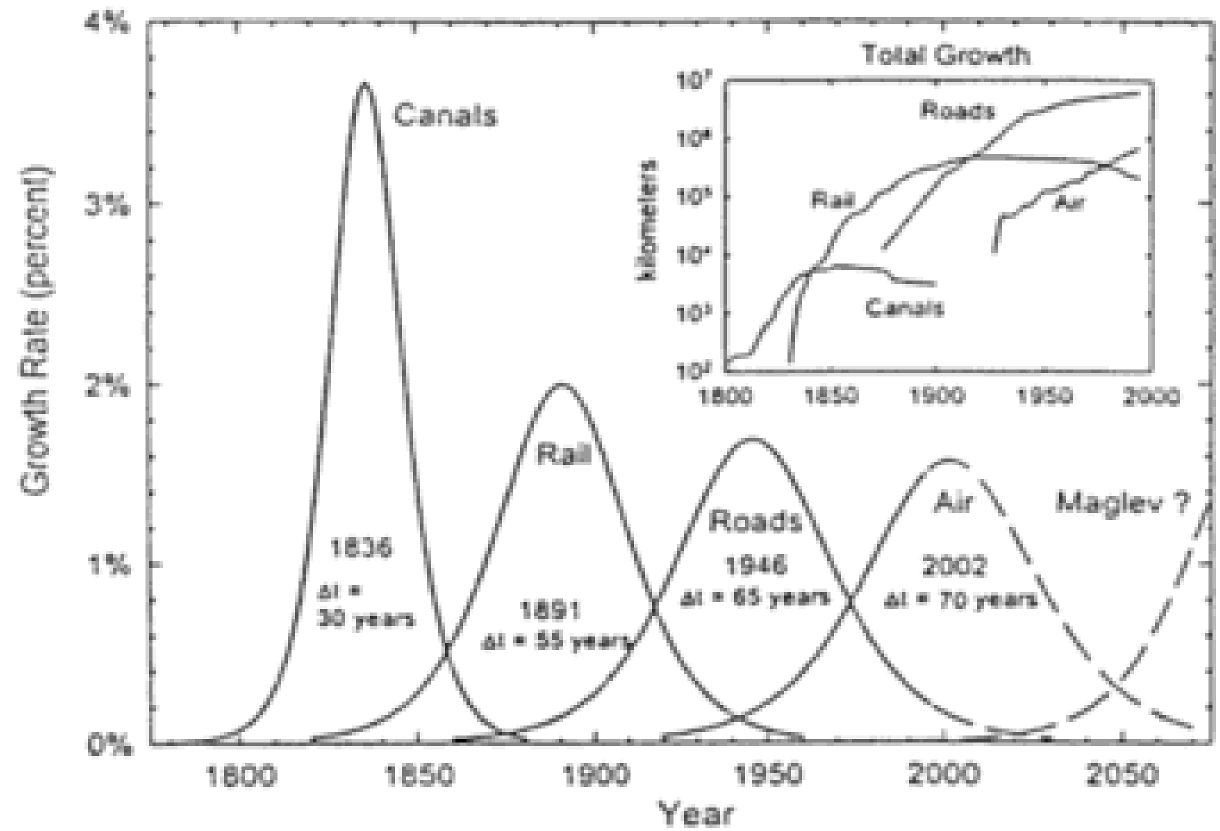


FIGURE 3.8 Penetration of major U.S. transportation infrastructures. SOURCE: Adapted from Marchetti (1985); Ausubel (1996).

TRANSITIONS TAKE TIME

- Tech and cost issues for key technologies
  - Fuel cells
  - Advanced batteries
  - Low-C fuel conversion pathways (Biofuels, renewables, fossil w/Carbon Capture and Sequestration)
- Market adoption of vehicle innovations
  - Historically, 20-60 years from R&D to >35% of fleet
- Building new transportation infrastructure
  - Historically, 30-70 years
- Policy driving major change ($\geq$10 years?)

SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS

INSTITUTE OF TRANSPORTATION STUDIES

UC Davis STEPS Program Overview

STEPS Program Goals & Objectives

- The overarching goal of the program

  The development & application of tools and methods that allow for robust comparisons of different fuel / vehicle pathways.

- The objectives of the program include
  - Comparative analysis research. Conduct interdisciplinary research on multiple pathways
  - Knowledge dissemination. Communicate research to sponsors, scientific community, and policy makers
  - Education. Educate next generation of engineers, scientists, business and policy decision-makers

STEPS Program Scope

HYDROGEN

- Fuel Cell Vehicles
- H2-ICE Vehicles

BIOFUELS

- Bio-ICE Vehicles
- Hybrid Vehicles

ELECTRICITY

- Battery-electric
- Plug-in hybrids

FOSSIL FUELS

- Business as usual
- Low-carbon cases

Project Areas:
Markets, Infrastructure, Lifecycle Analysis, Policy, Vehicle Technology

GOAL:
Development & application of tools and methods that allow robust comparisons of different fuel / vehicle pathways.

Program Numbers

- Sponsors: 22 (16 industry, 6 gov)
- Faculty & researchers: 16
- Graduate Students: 26 (22 PhD, 4 MS)
- Collaborating departments:

  Environmental Science & Policy, Civil Engineering, Biological & Agricultural Engineering, Mechanical and Aeronautical Engineering, Economics, Agriculture & Resource Economics, Plant Sciences

Program Sponsorship

Energy Industry

- BP
- Chevron
- ConocoPhillips
- Indian Oil Co
- PG&E
- Shell Hydrogen
- TOTAL

Government

- US EPA
- US DOE
- US DOT
- CalTrans
- CalEPA
- NRCan

Automotive Industry

- BMW
- DaimlerChrysler
- Ford
- General Motors
- Honda
- Nissan
- Subaru
- Toyota
- Volkswagen

Simple Transition Model

Analyze alternative vehicle/fuel scenarios to 2050, for adoption of new transportation technologies that could enable deep cuts in oil consumption and greenhouse gas emissions.

1) **H2 SUCCESS** H2 & fuel cells play a major role beyond 2025

2) **EFFICIENCY** Currently feasible improvements in gasoline internal combustion engine technology are introduced

3) **BIOFUELS** Large scale use of biofuels, including ethanol and biodiesel.

4) **PORTFOLIO** More efficient ICEVs, biofuels and hydrogen FCVs are implemented

Metrics for scenario evaluation

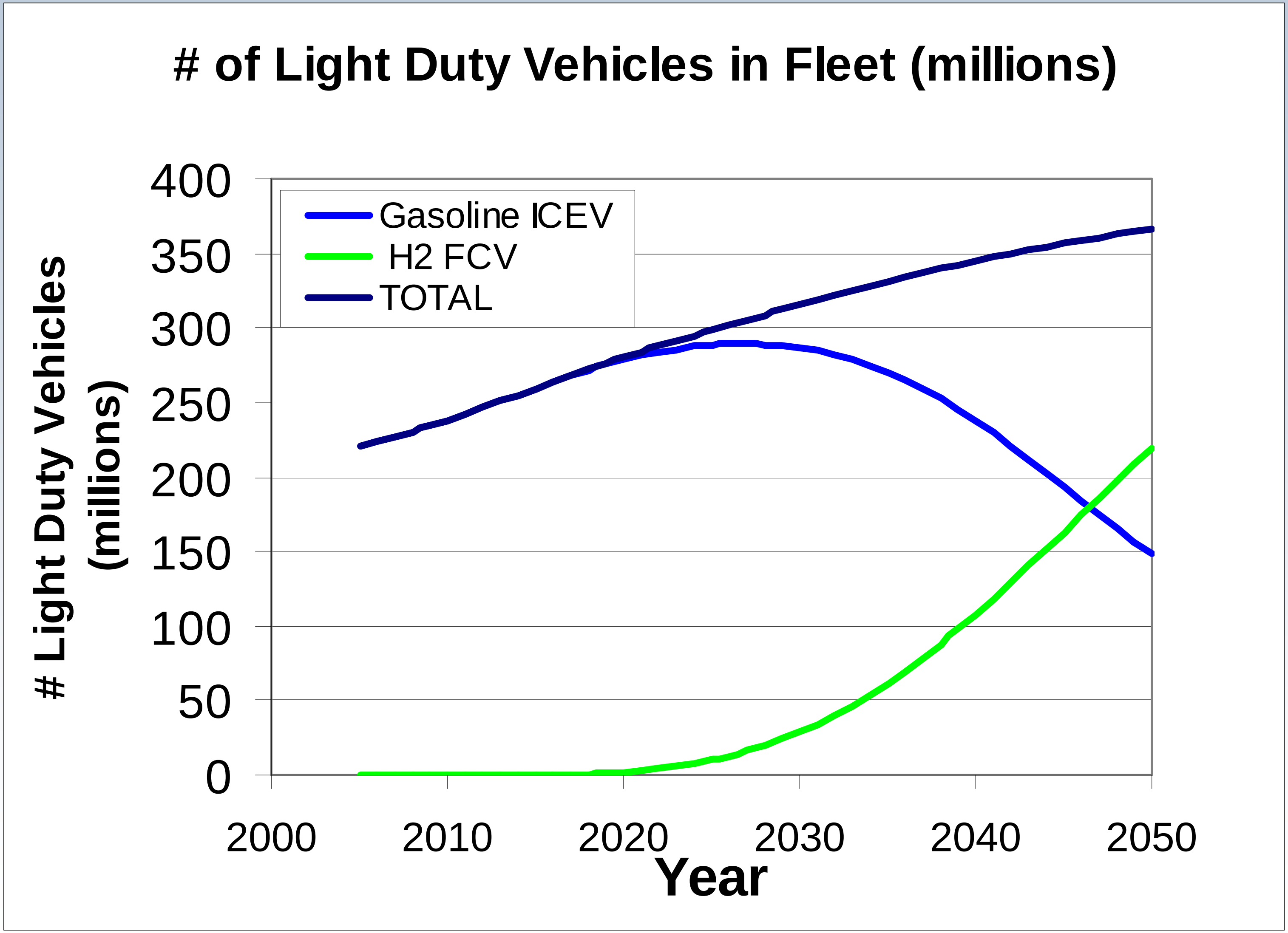
Estimate of **greenhouse gas (GHG) emissions** and **gasoline consumption** with each strategy relative to a **REFERENCE** case where no advanced technologies are implemented.

Transitions to Alternative Transportation Technologies: A Focus on Hydrogen

Pre-publication version available from National Academies website

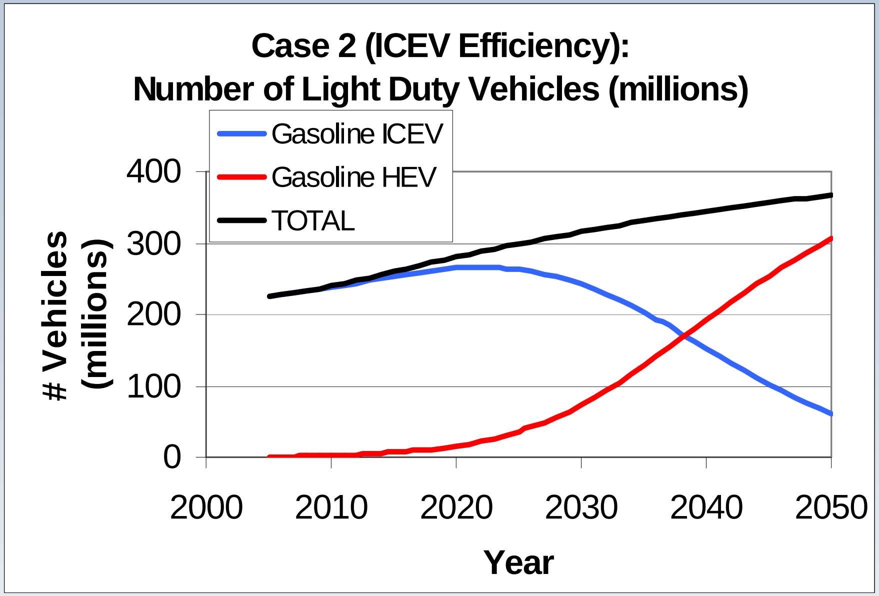
http://www.nap.edu/catalog.php?record_id=12222

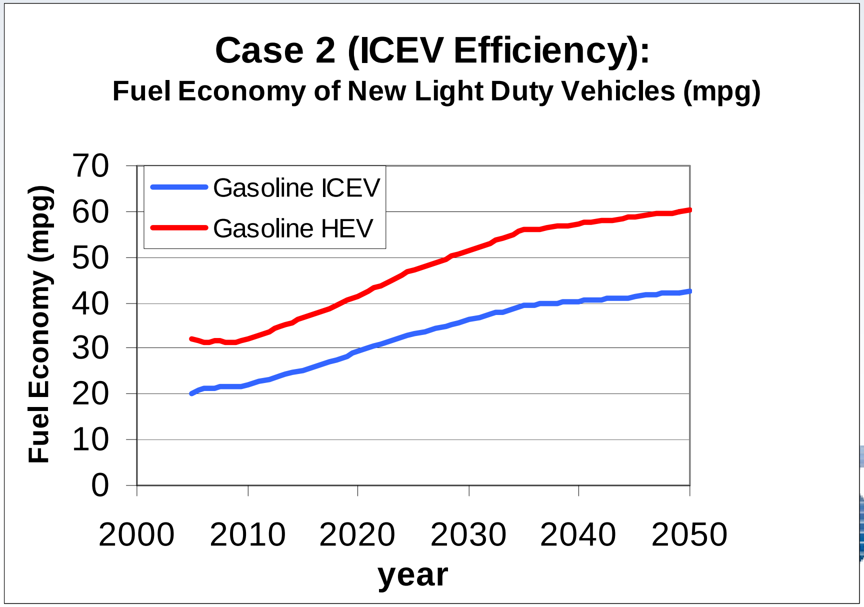
Case 1: H2 Success



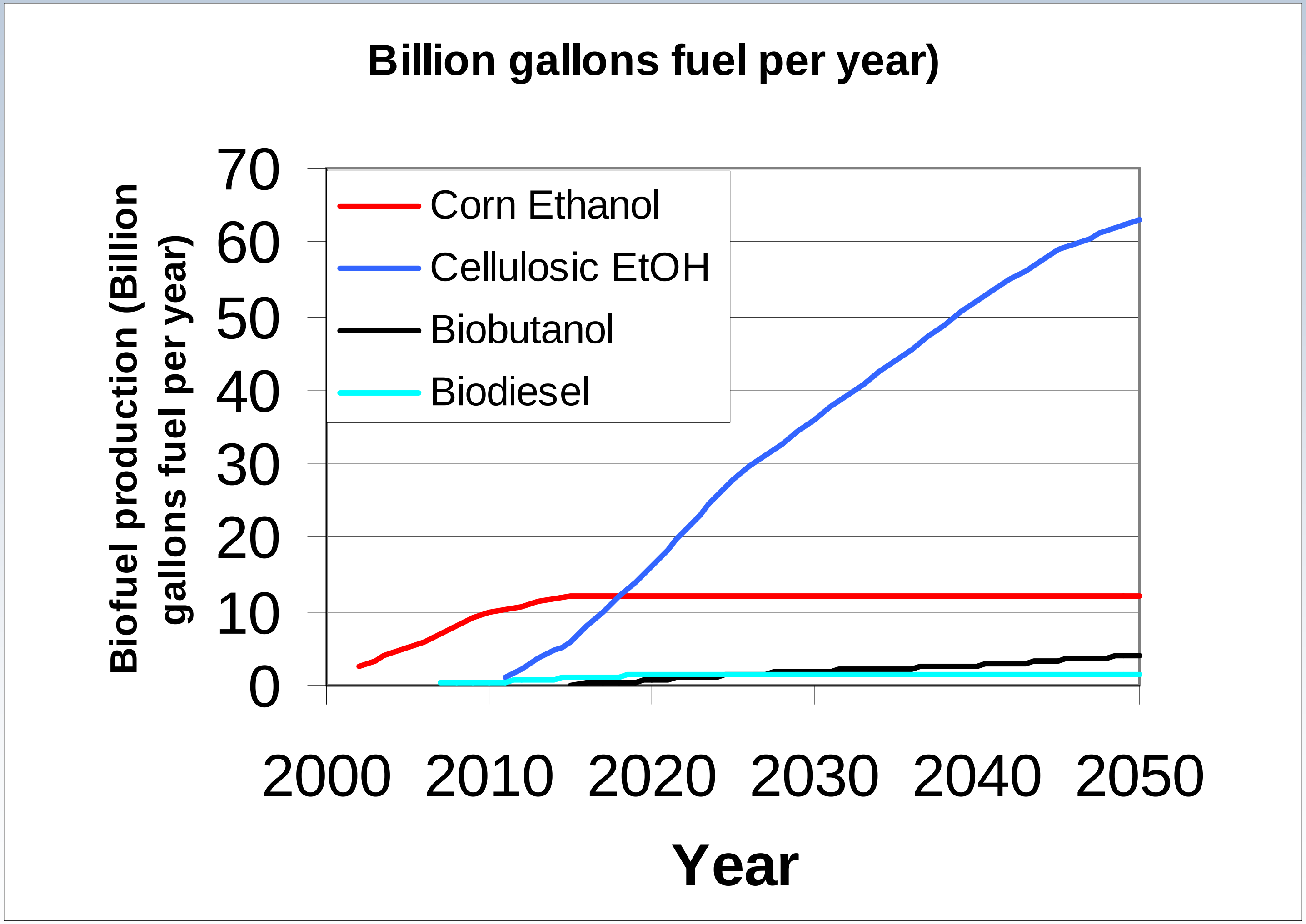
Case 2: ICEV Efficiency

- Currently available improvements in gasoline internal combustion engine technology used to increase efficiency
- The fuel economy of gasoline vehicles assumed to improve
  - 2.7 %/year from 2010-2025
  - 1.5 %/year from 2026-2035
  - 0.5%/year from 2036-2050
- Gasoline HEVs dominate; no FCVs



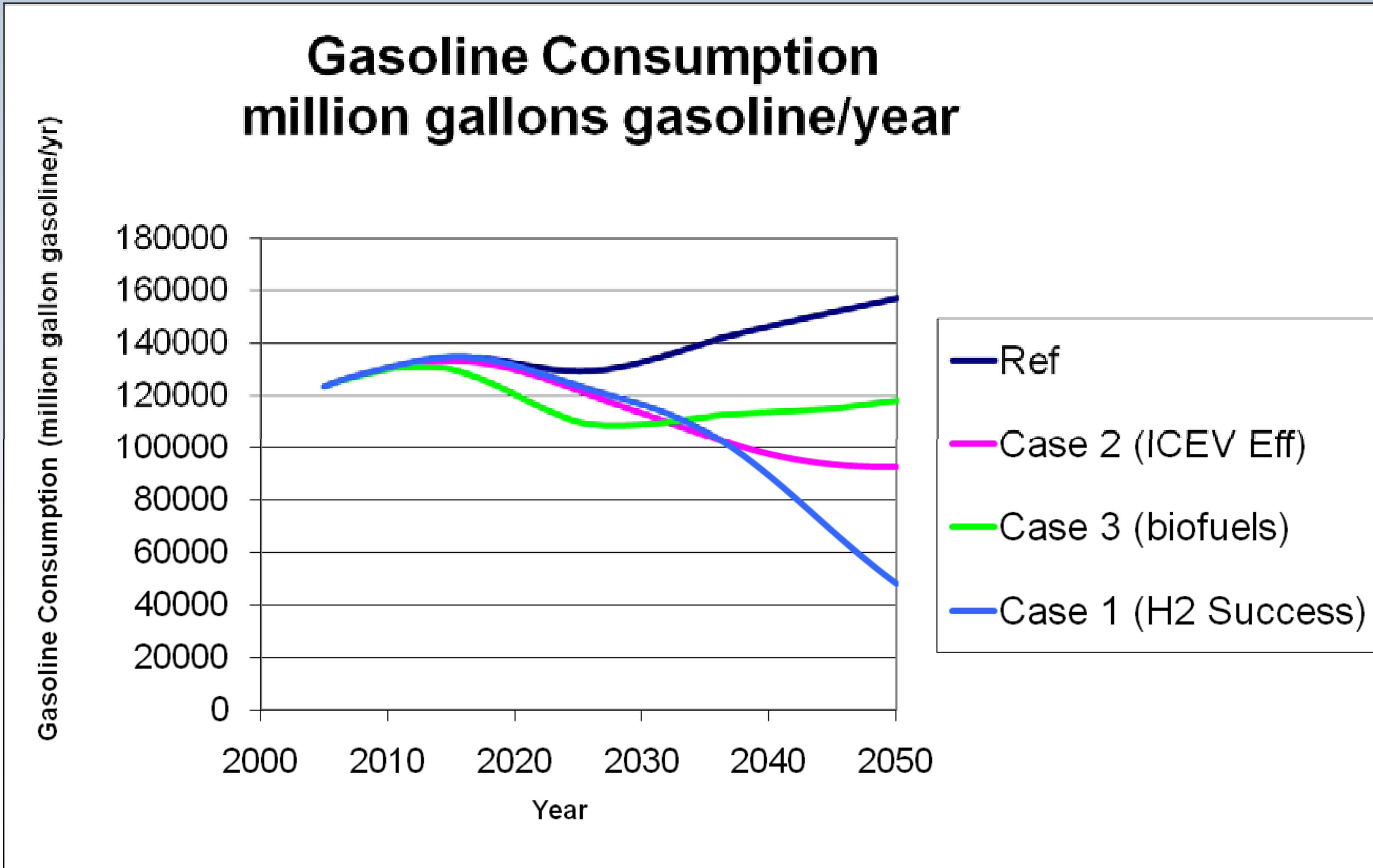


Case 3: Annual Biofuel Production

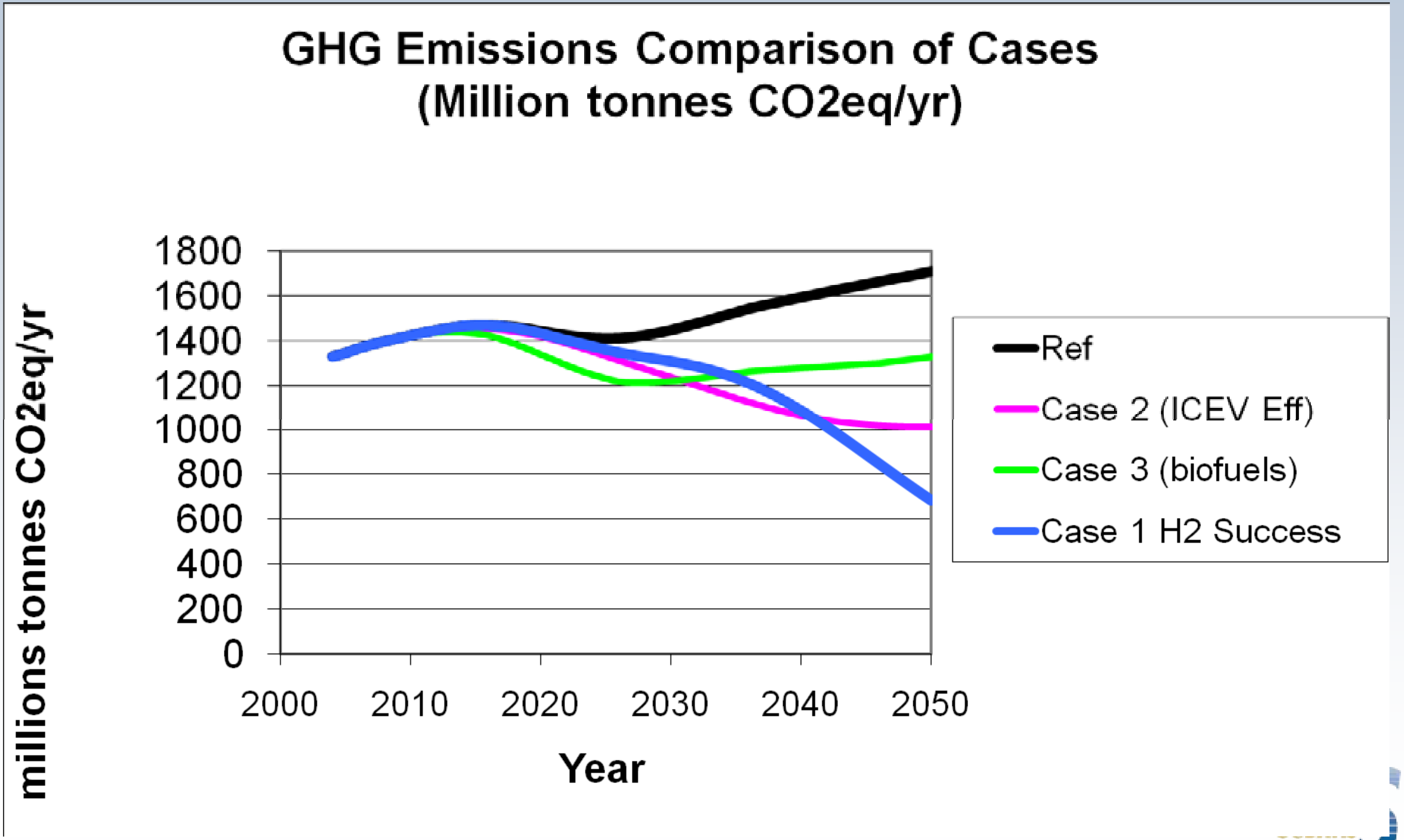


Biofuel success case has same amount of corn ethanol as Ref Case, but more cellulosic ethanol production + other biofuels

COMPARISON OF SINGLE PATHWAY STRATEGIES : Oil Use

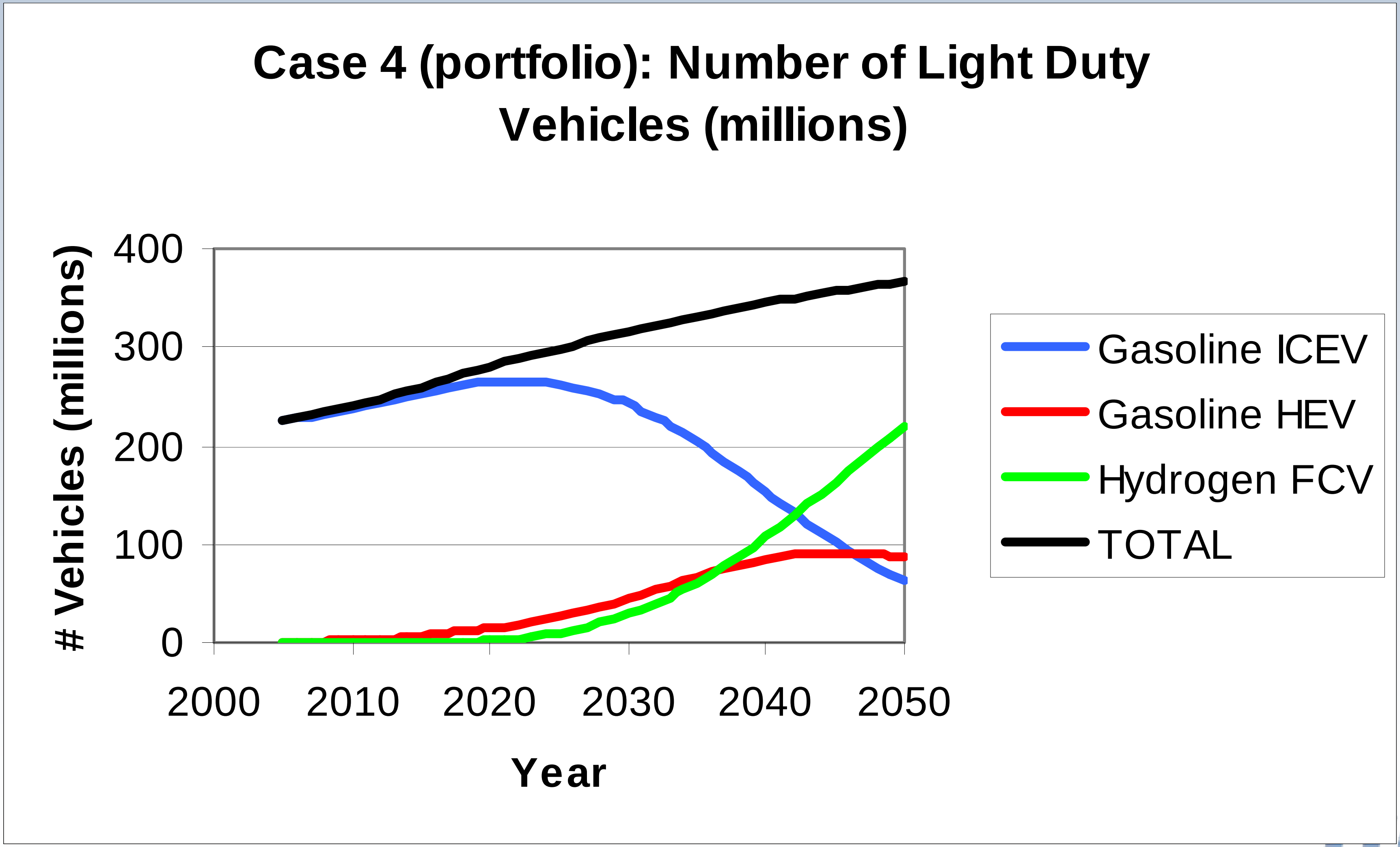


COMPARISON OF SINGLE PATHWAY STRATEGIES : GHG Emissions

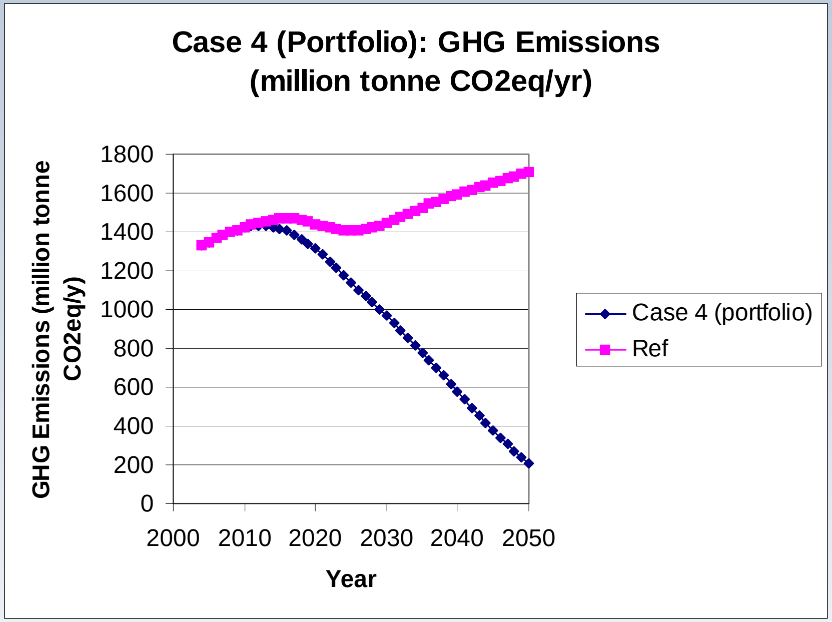


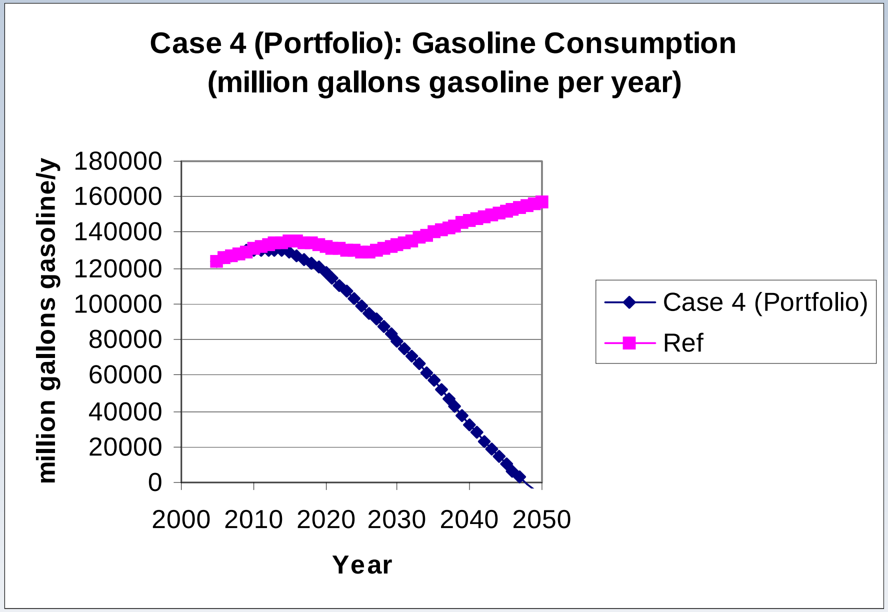
Case 4: Portfolio Approach

Efficient ICEVs + Biofuels + H2 FCVs



Case 4: Portfolio
H2 FCVs +Efficient ICEVs + Biofuels





49% reduction in GHG vs. ref case by 2035

88 % reduction in GHG vs. ref case in 2050

59% reduction in gasoline use vs. ref case by 2035

99% reduction in gasoline use vs. ref case in 2050

Common themes: early scenario results

- Meeting long term GHG reduction goals will be extremely challenging
- Portfolio approach attractive (silver bullet scenarios not as attractive or feasible)
- Combination of approaches needed
  - In the near term improving energy efficiency is key,
    - Even if we triple fuel economy and reduce travel through smart growth, the explosive growth in # vehicles will limit reductions in oil use and GHG emission
  - For deep GHG reductions, need efficiency + decarbonized fuels

Pursuing a portfolio approach for vehicles/ transportation fuels

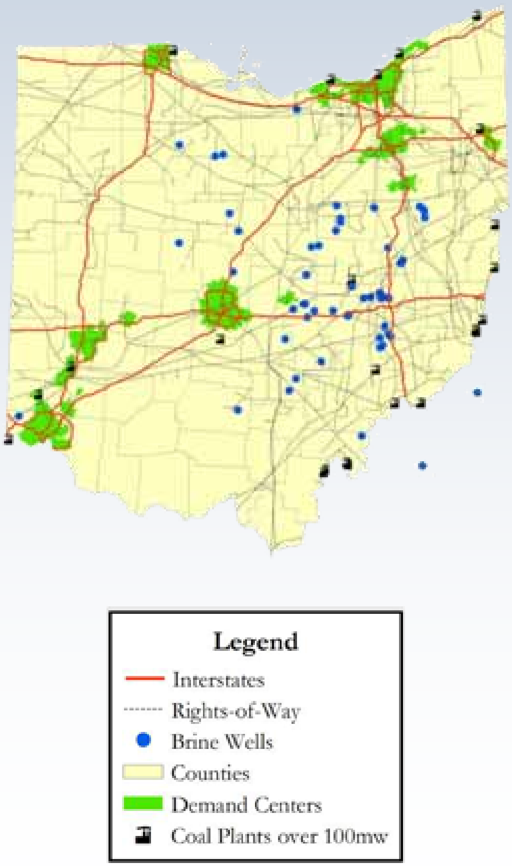
  - Attractive (at societal level), because we may need many solutions
  - Difficult (at the individual actor level) because of limited number of people, capital
- **Hypotheses**:
  - "Fuel du jour" is not a viable approach
  - A robust suite of policies supporting development of a variety of fuels/vehicles over the next few decades is needed.
  - It's too early to "down-select"

EXPLORE NEW PARADIGM FOR TRANSPORTATION FUEL SUPPLY

- Regional transportation fuel supply systems
- Interactions with the electric sector

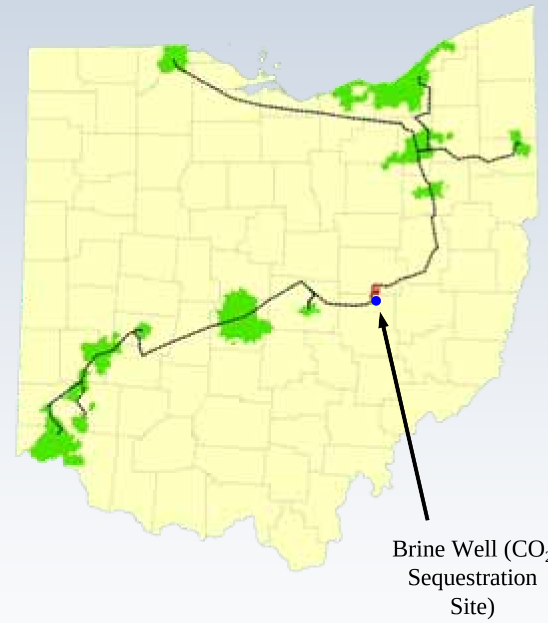
Optimized Design using Spatial Data for Regional Infrastructure Modeling

GIS Database



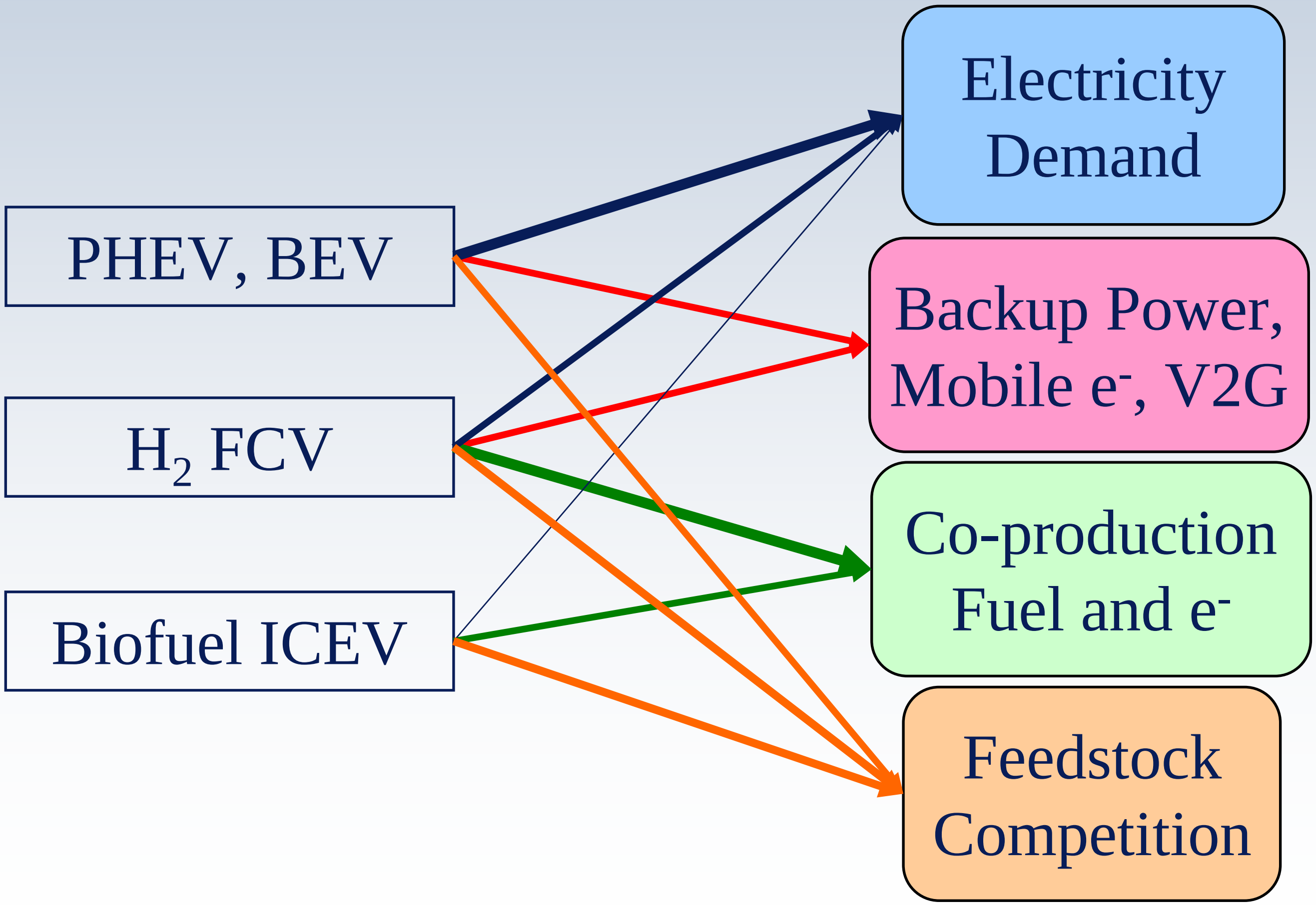
Identify Shortest Pathways Between Demand Centers and Coal Facilities

Optimal Supply Network



Transportation and the Electric Sector

Advanced vehicles and fuels will have important impacts on the electric sector



Concluding Thoughts

- "Big picture" scenarios suggest the potential for greatly reducing CO_2 emissions and oil use over the next 50 years.
- Alt fuels and vehicles can play major role, along with VMT reduction, transportation efficiency.
- Rapid progress is occurring in many key technologies for alternative fuels and vehicles.
- But many uncertainties remain as to the timing, cost, and environmental impacts of alt fuel/vehicle technologies.
- Portfolio approach is attractive strategy in meeting long term goals.
- Durable, consistent policies needed.
- Better tools are needed to understand LCA impacts and sustainability issues for alt fuels.

Near term actions toward long term goals

- RD&D on game-changing technologies
  - Adv. Batteries
  - Fuel cells and H2 storage
  - Renewable energy production systems
  - Carbon capture and sequestration
- Demonstrate <u>several</u> promising approaches
- Better Understand System Level Opportunities for new design and logistics
  - Regional transportation fuel supply systems
  - Interactions with the electric sector
- Better understand climate implications of fuel/vehicle pathways through LCA

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