Objectives

SAND2010-6156P

- Use dynamic models of infrastructure systems to analyze the impacts of widespread deployment of hydrogen technologies
- Identify potential system-wide deficiencies that would otherwise hinder infrastructure evolution, as well as mitigation strategies to avoid collateral effects on supporting systems
- Analyze the feedback effects of competing alternative transportation options

We model the dynamics of emergent fuel-vehicle systems

- Our focus is on the feedback and dynamics of future transportation system options.
  - Primary energy source, fueling infrastructure, and vehicles need to be considered together
  - Feedback and competition between transportation and energy alternatives will effect the evolution of transportation systems
  - The differing time scales for change need to be considered

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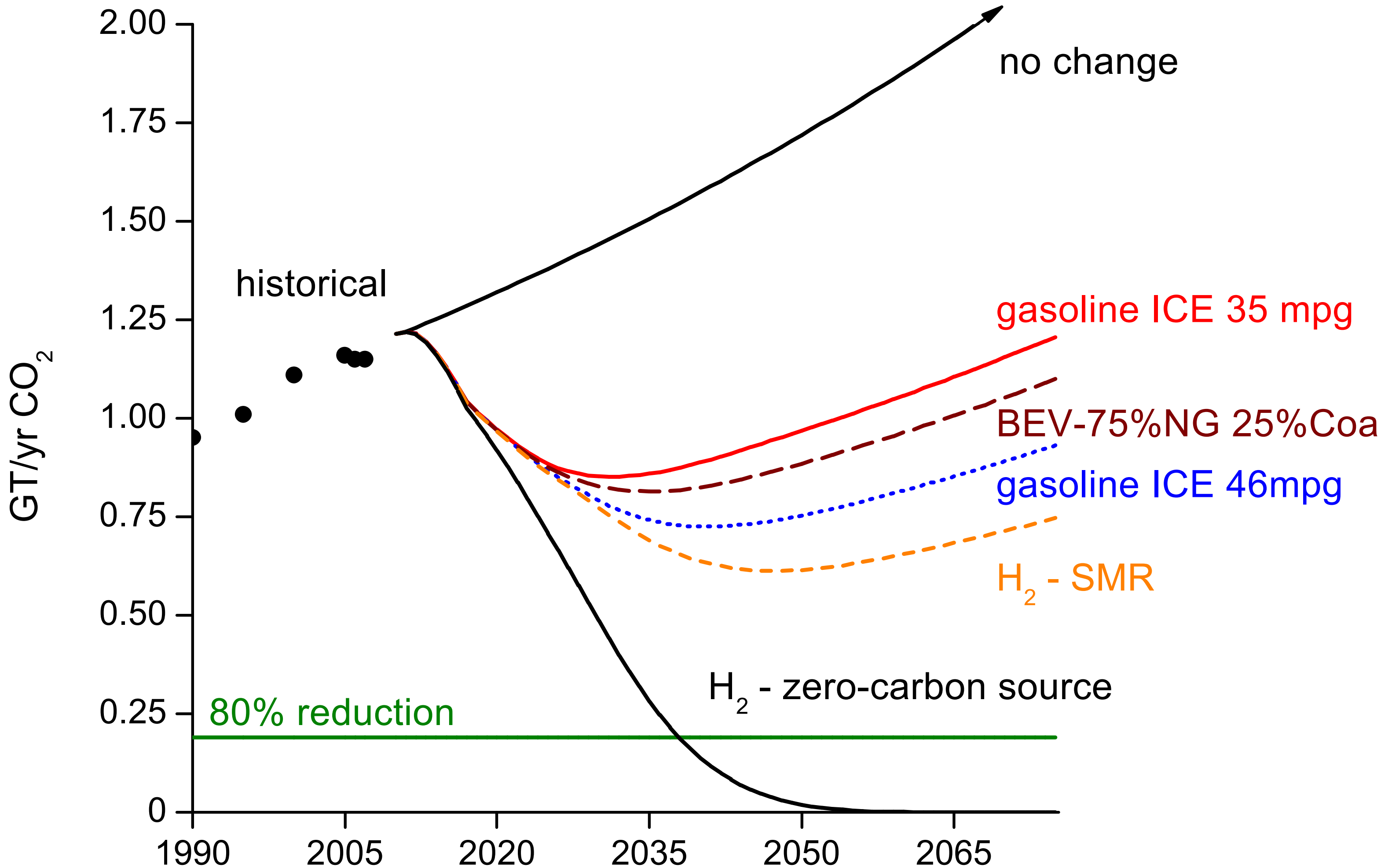
Elimination of carbon from the fuel-vehicle system is required to meet US CO_2 target



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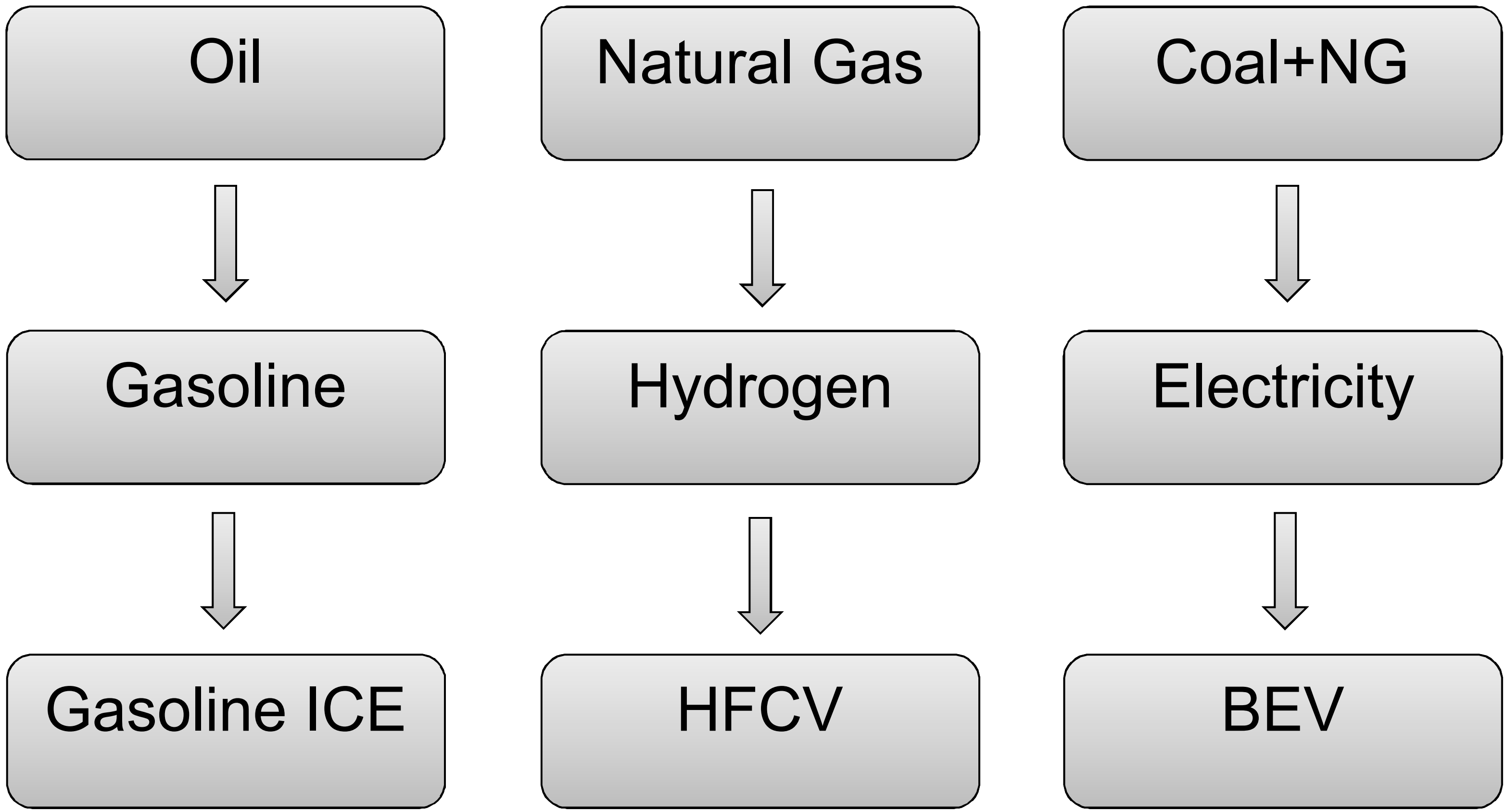
Alternative fuel pathways will interact



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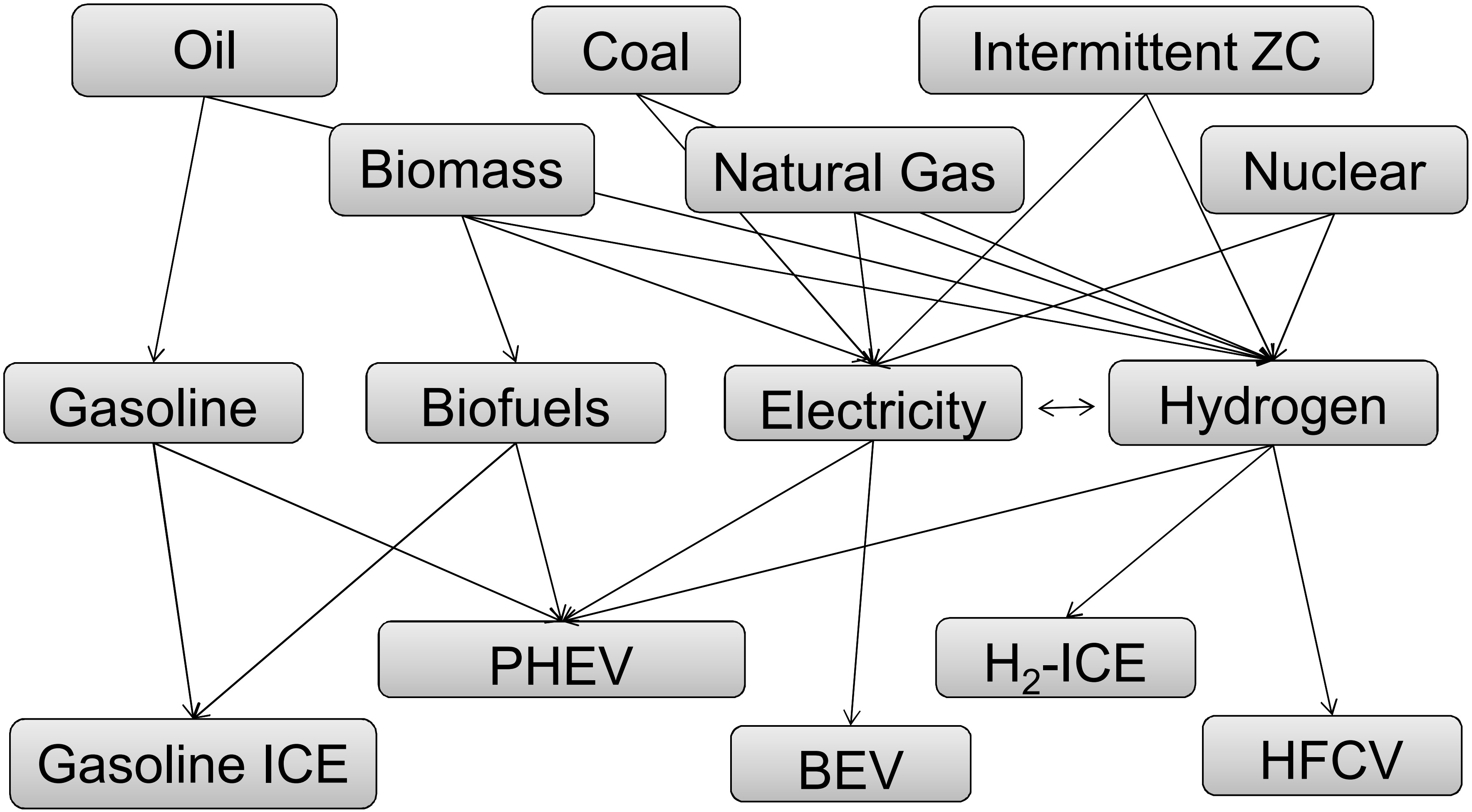

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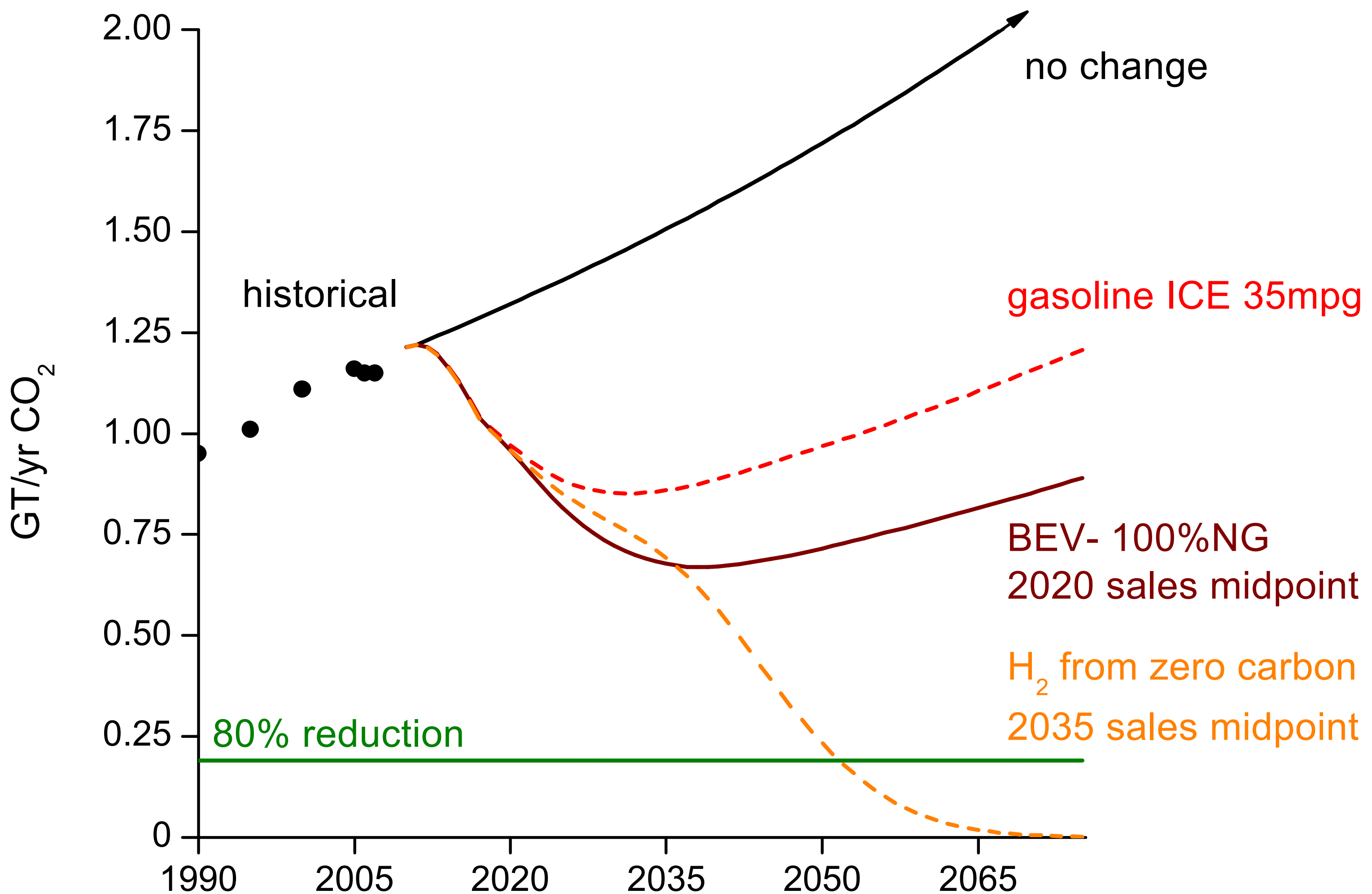
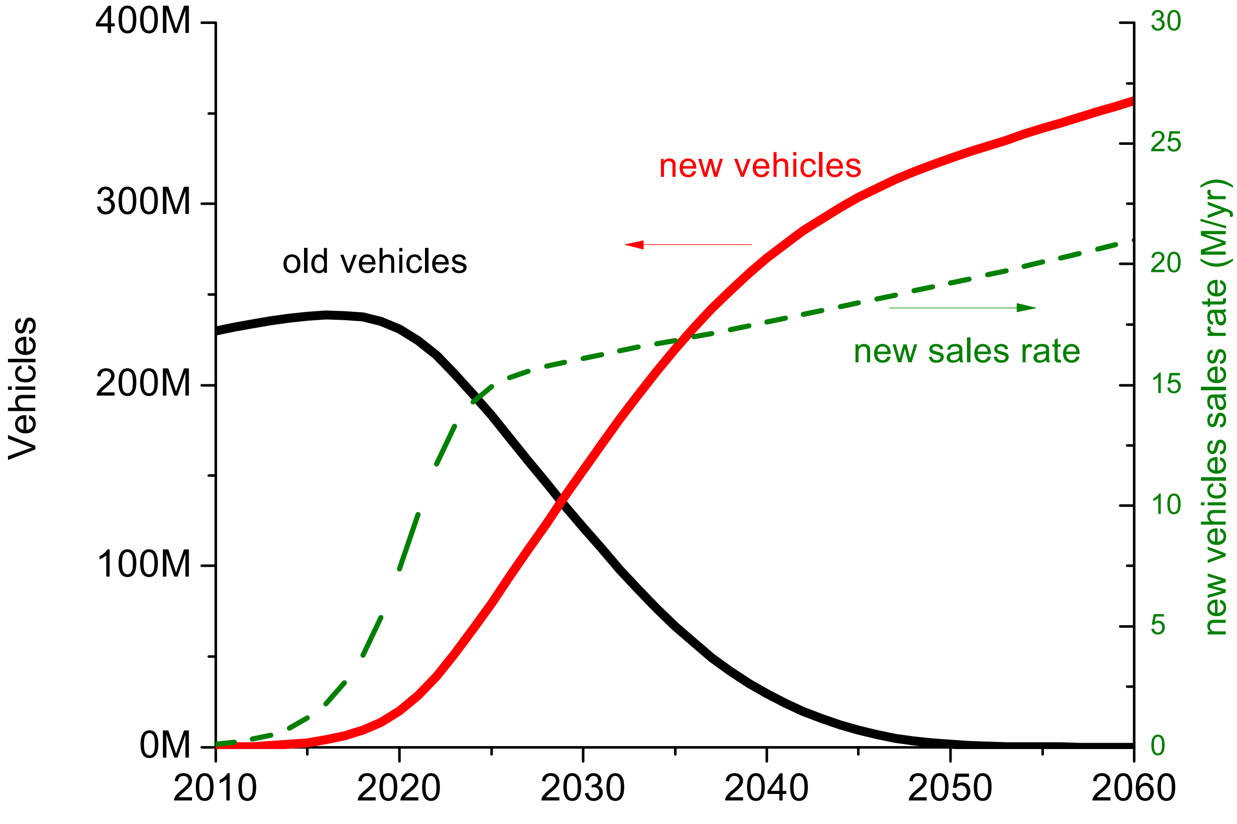
The type of fuel-vehicle system is more important than the speed of implementation



The turnover rate for the installed vehicle fleet is slow



- 50% of sales in 2020 are of "new" type
  - Note: The Prius was introduced in the US in 2001. In 2010 the market share of all hybrids is only 2.2%

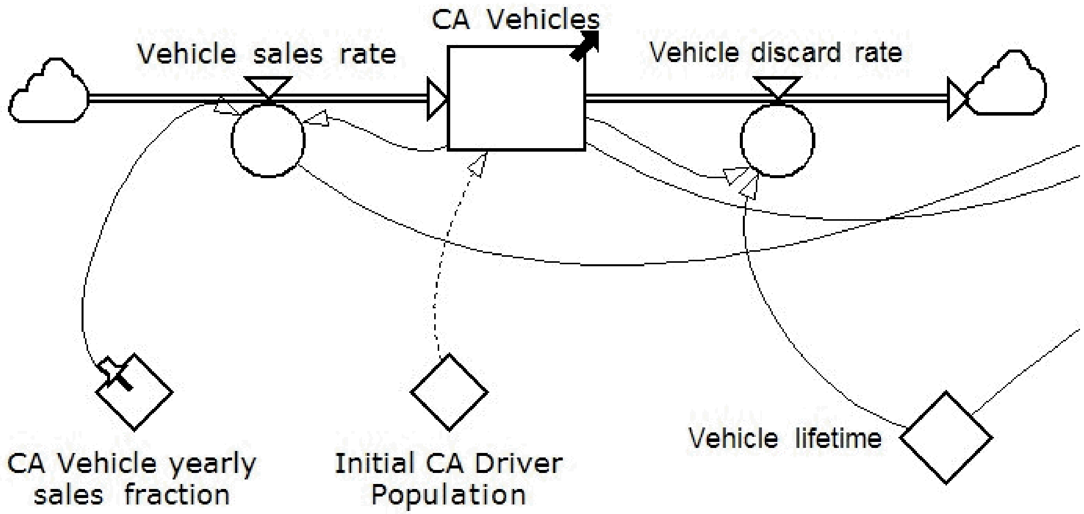
(+) Fueling infrastructure capacity only needs to grow with fleet

(-) Difficult to have serial technology transitions

Approach

- System dynamics: Methodology
  - Choose a region to define the system
  - Pose detailed questions
    - What are the impacts of large-scale H_2-fueled vehicle market penetration?
    - What is the impact of a carbon tax on alternative vehicle penetration?
    - Can stationary FC systems provide distributed H_2 production?
- System dynamics: Analysis
  - Formulate SD models of infrastructure components and interrelations to a sufficient level of detail to see interactions and dependencies
  - Powersim software allows quick generation of code and interfaces and can solve system of ODEs. It allows insight into the dynamic behavior of complex systems.

System dynamic models are built on the concept of "stock and flows"



$$\frac{dV}{dt} = s \cdot V - \frac{V}{\tau}$$

- From simple differential equations and time delays, the model can reproduce complex behavior

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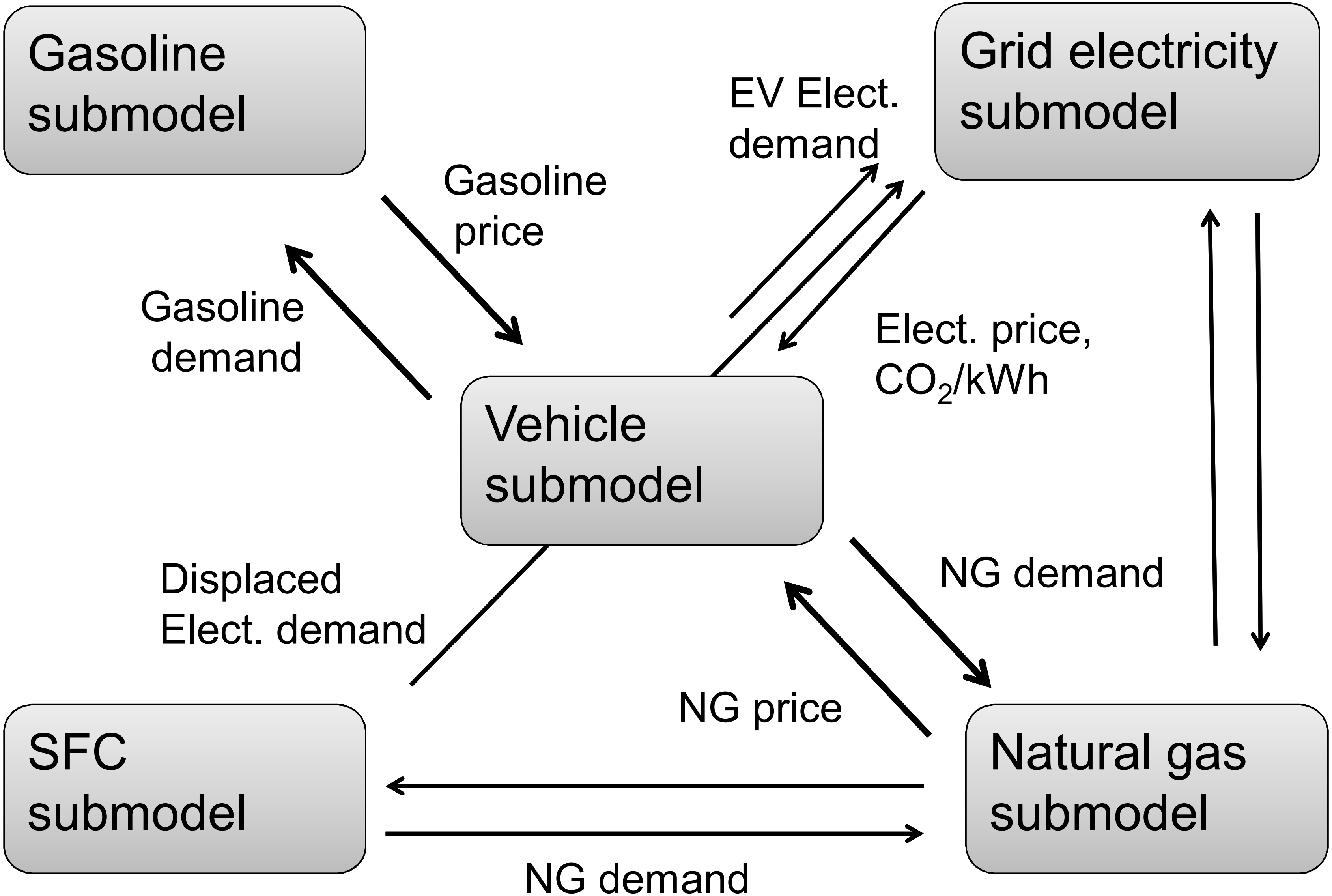

Gasoline submodel
Grid electricity submodel
EV Elect. demand
Gasoline price
Gasoline demand
Elect. price, CO_2/kWh
Vehicle submodel
Displaced Elect. demand
NG demand
NG price
SFC submodel
Natural gas submodel
NG demand

Model provides a tool for exploring a range of conditions

- Key model input parameters
  - Vehicles:
    - HFV mileage
    - HFV and PHEV learning curves
    - battery vs plug-in
    - daily charging profile
    - gasoline mileage improvements (CAFE or advanced ICE)
    - H_2 production alternatives (low-carbon)
    - sales/discard rates
  - NG:
    - Import capacity
    - domestic production
    - demand growth (other than vehicles or electric)
    - elasticity
  - Other:
    - carbon tax

Model provides a tool for exploring a range of conditions

- Key model input parameters
  - SFC:
    - electric efficiency
    - combined heat/cooling factors
    - matching of heat, cooling, & electric loads with demand
    - H_2 co-production
    - fixed & variable costs of electricity & H_2
    - penetration rate in new & retrofit buildings by type
  - Grid electricity:
    - Baseload, marginal, & new generation
    - growth in demand
    - changes in nuclear, coal, NG, & renewable generation

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Model Demo- Introduction

Model Demo- HFV mileage

Model demo- Carbon tax

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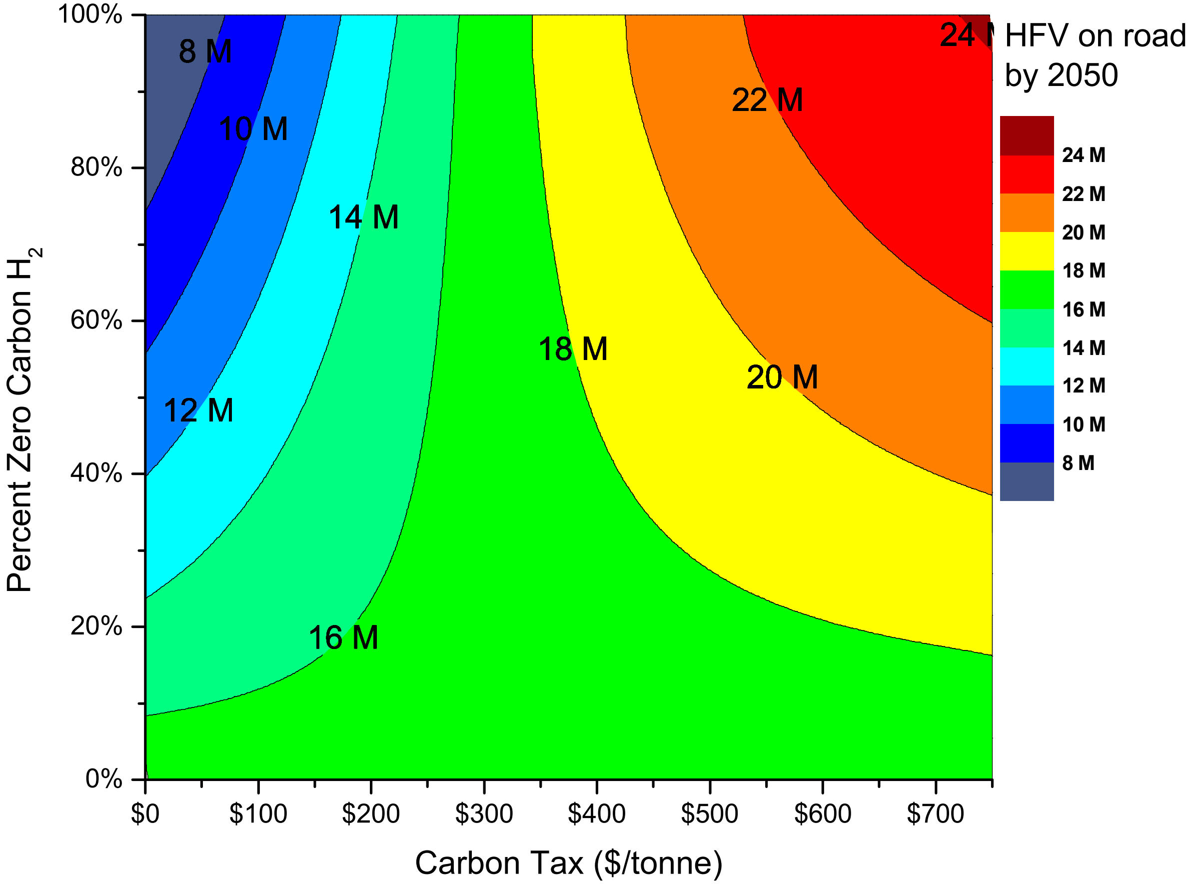
Higher price of zero-carbon H_2 requires a carbon tax to spur HFV sales

- Contours of HFV quantity on road by 2050 based on 1000 simulations
- Hydrogen supply:
  - Zero-carbon H_2 at $6/kg
  - SMR H_2 at ~$4/kg before C-tax
- At low penetration of zero-carbon H_2, carbon tax has little impact on HFV sales
- Higher carbon tax stimulates increase in zero-carbon hydrogen fueled vehicles



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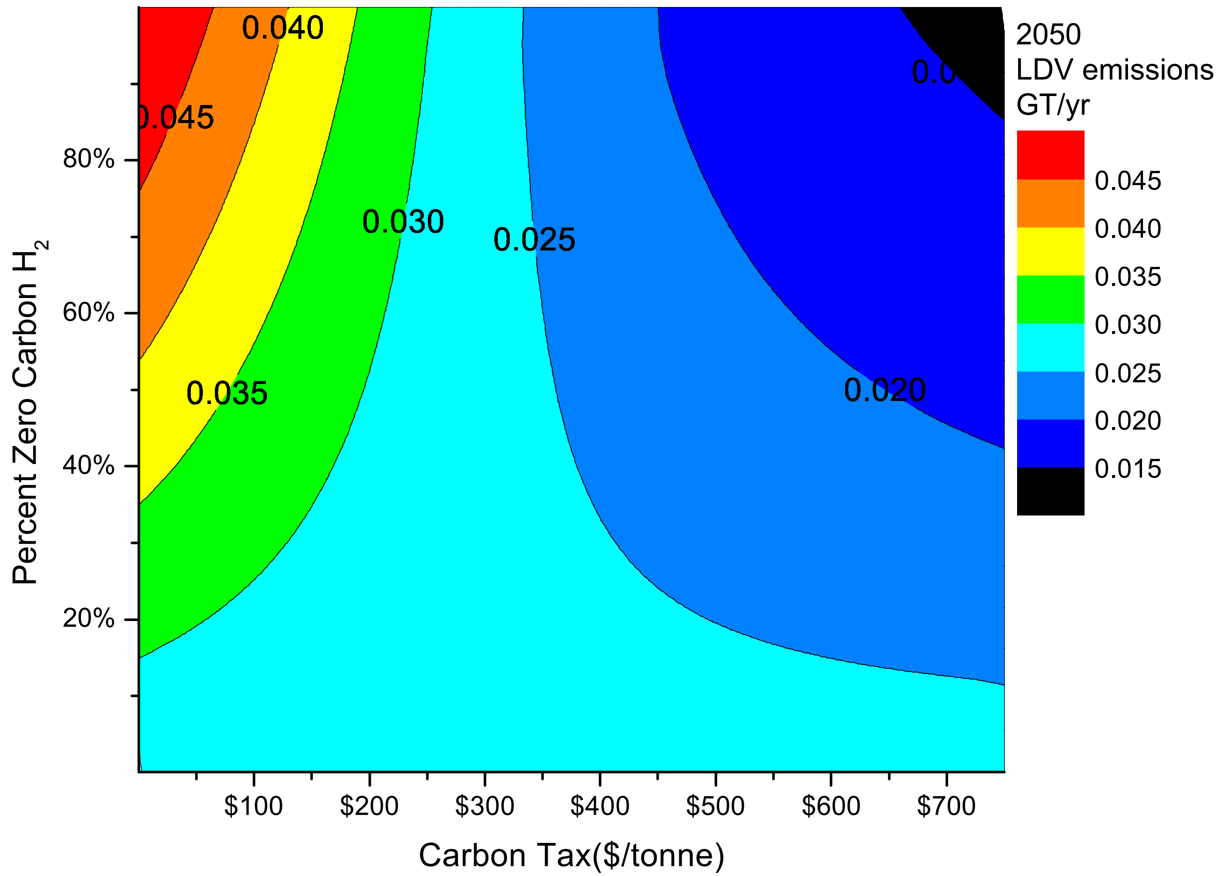
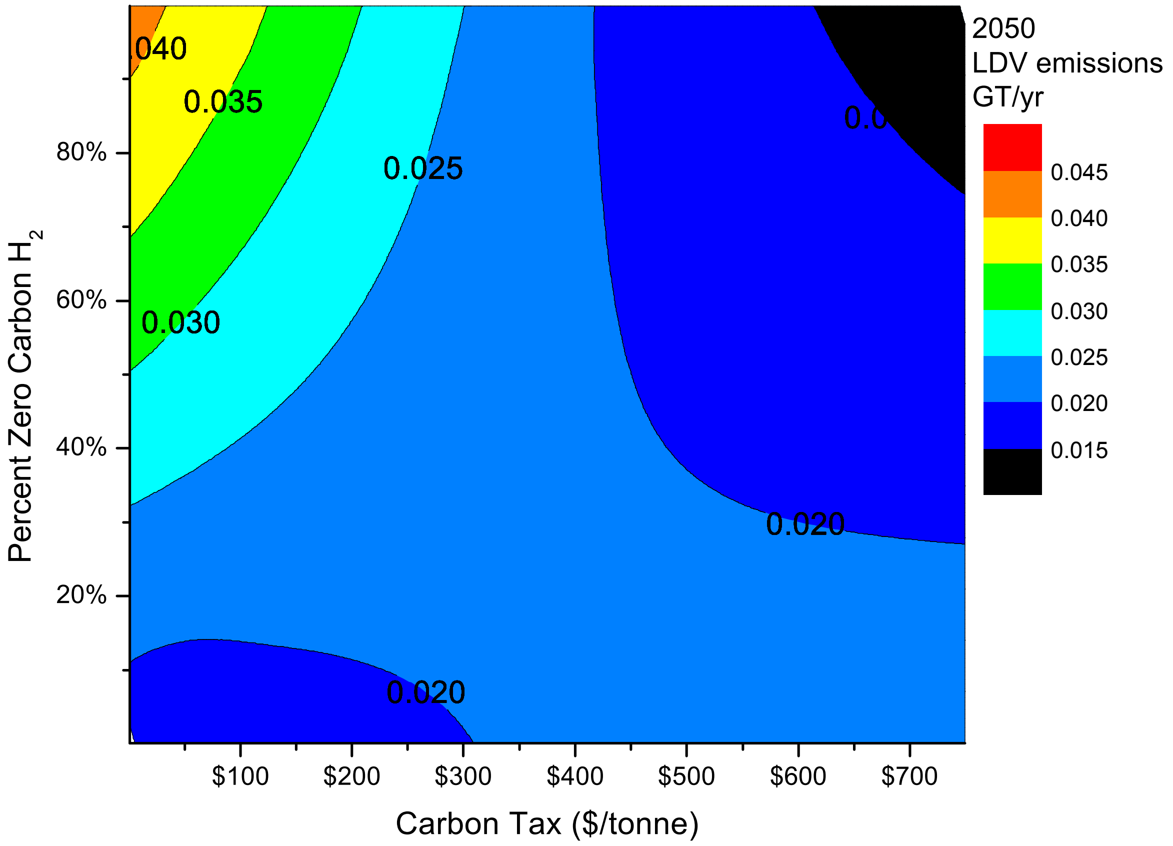
Carbon tax does not effect emissions without a zero-carbon option

- Contours of LDV emissions in 2050
- 80% reduction from 1990 goal is 0.019 GT/yr
- H_2 Supply:
  - Zero-carbon H_2 at \$6/kg
  - SMR H_2 at ~\$4/kg before C-tax



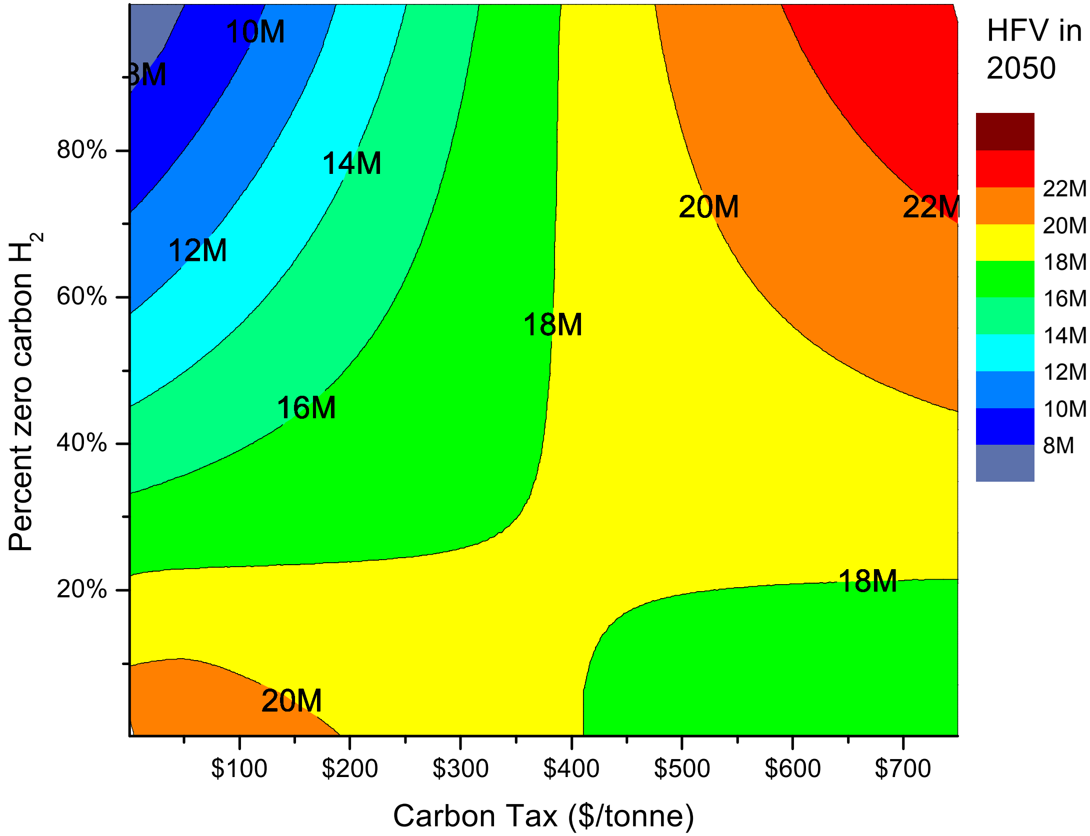
Adding other sources of zero-carbon fuels gives lower emissions

- Add 3-fold higher zero-carbon electricity than CA RPS default case (33GW by 2020)
- Emissions are lower than the default case
- Emissions at large carbon taxes and no zero-carbon H_2 rise slightly due to increasing dependence on natural gas for electricity



Adding other sources of zero-carbon fuels gives lower emissions

- Add 3-fold higher zero-carbon electricity than CA RPS default case (33GW by 2020)
- Hydrogen vehicle sales are higher due to cost of zero-carbon electricity.



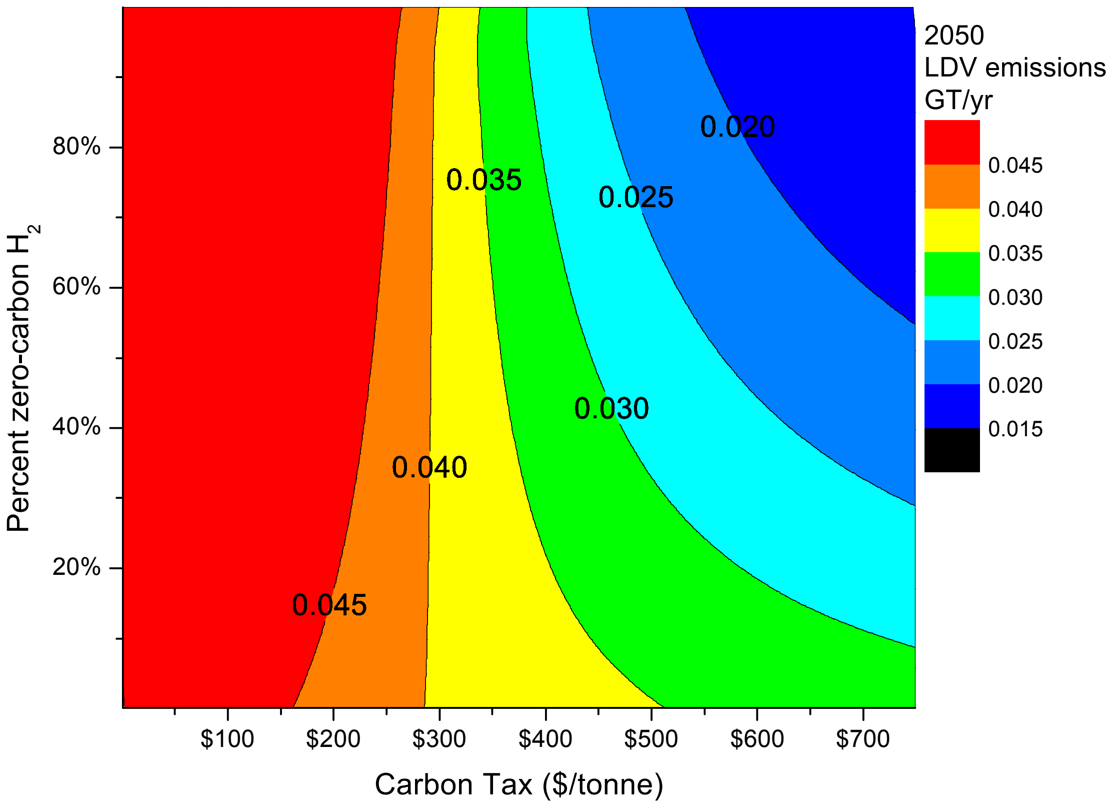
Summary

- H_2 Fueled Vehicles can significantly reduce CO_2 emissions
  - Requires large HFV penetration ~50% of CA fleet by 2050
  - Zero-carbon fuels are needed to meet emissions targets in 2050 and beyond
- H_2 produced from SFC could potentially supply 11% of HFV fleet demand in 2050
  - Approximately 2 Million vehicles
- Stationary FC systems have a small effect on CA's CO_2 emissions
  - Effect of SFC systems with a maximum of 35% relative fuel savings is limited by the potential for CHP systems in CA buildings
  - An optimistic penetration for SFC is 16% of total electricity generation
  - Overall reduction in CO_2 is ~2%
- Preliminary simulations show that the reduction of CO_2 emissions by SFC can be significant when displacing coal generation

Supplemental Slides

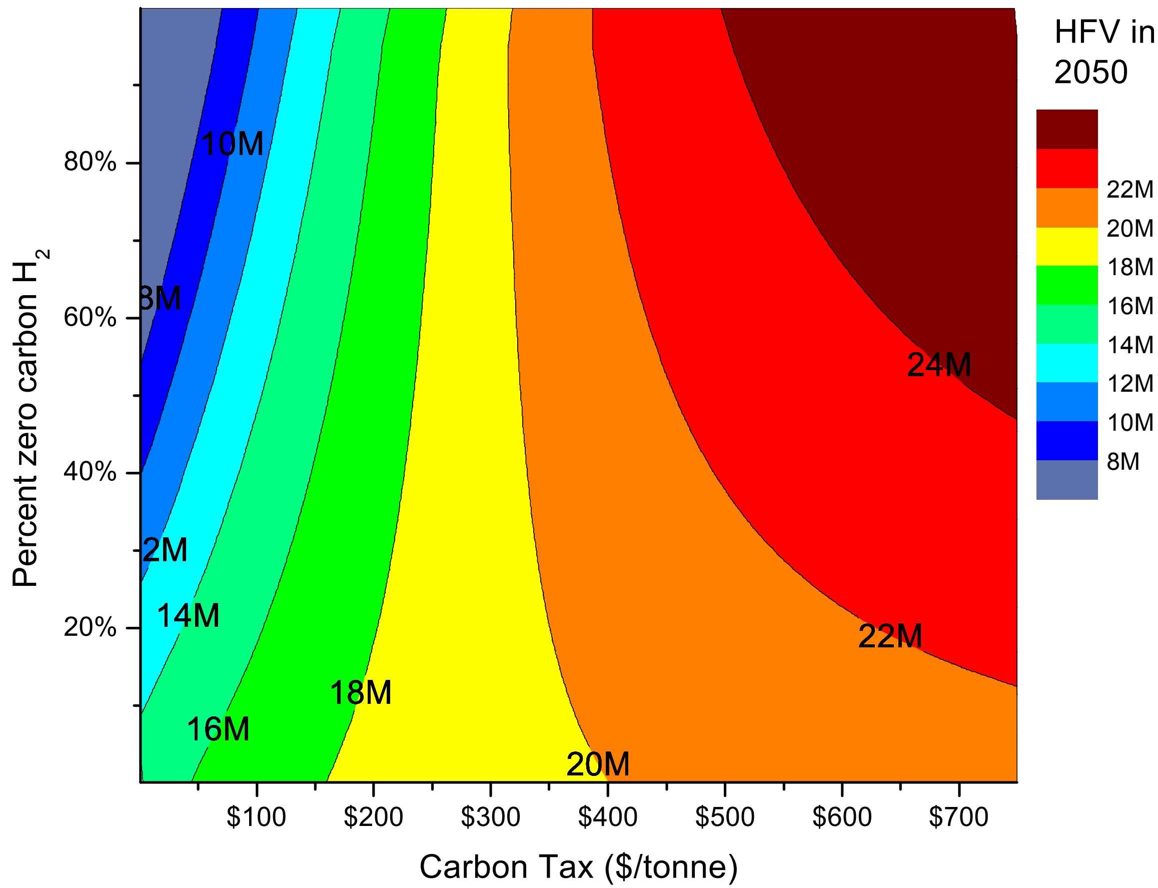
Very high carbon tax is required to offset coal-fired power

- Using coal in place of natural gas increases emissions
- High carbon tax is required to achieve the emissions of default case
- Achieving a low emissions target is very difficult



Regions with coal electricity and zero-carbon hydrogen are sensitive to carbon pricing

- Hydrogen vehicle penetration is sensitive to carbon tax, especially at high levels of zero-carbon hydrogen



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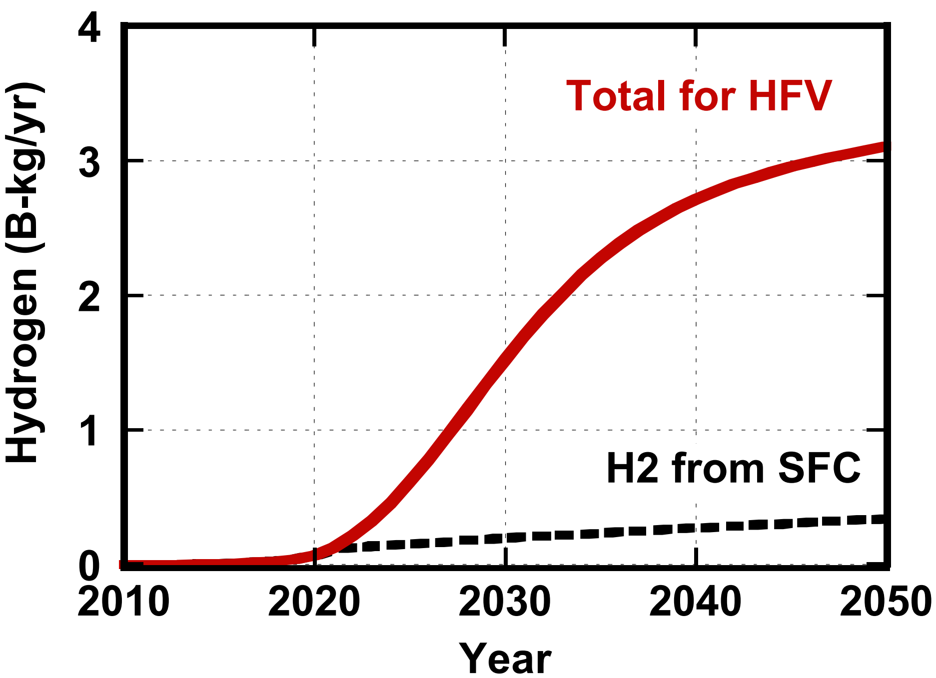
Penetration of SFC systems can provide significant H_2 for vehicles

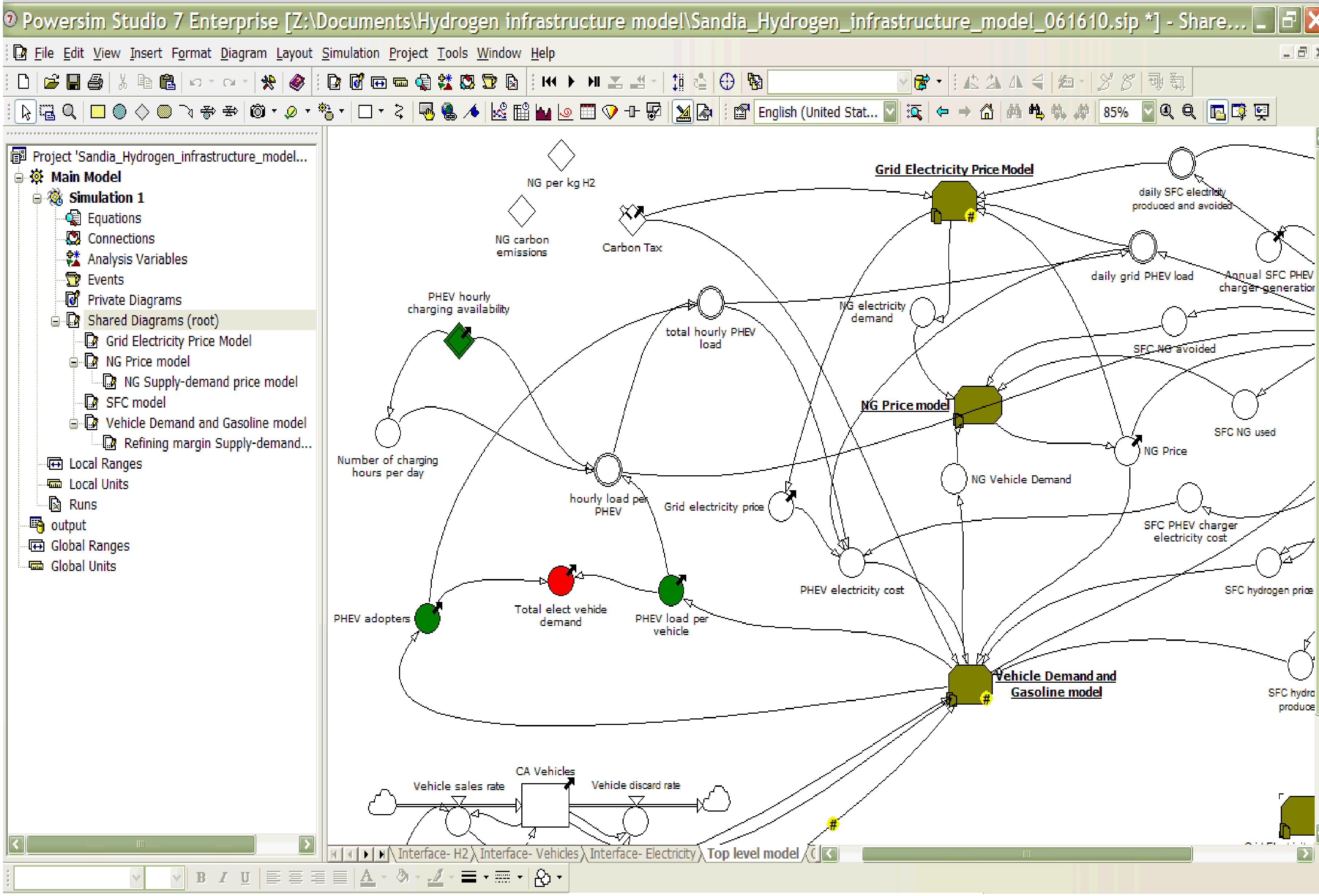


H_2 from SFC

- H_2 available:
  - Fraction of NG input = 15%
    - Assume 85% H_2 utilization in FC
  - Reduced electricity efficiency of FC from 47% to 40%
- SFC provide 11% of H_2 demand
  - Supply 2 Million H_2 vehicles

SFC dedicated to EV charging

- Cost effectiveness is dependent on SFC capital and maintenance costs
- Effect on CO_2 emissions is minimal in regions with NG as marginal supply
- Caveat: utility distribution concerns are not addressed by model



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