Transition Strategies for Alternative Transportation Fuels and Vehicles

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Many Project Contributors

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  – Prof. John Sterman (MIT)

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  – Jessica Laviolette (MIT)
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  – Sandy Winkler (Ford Motor Company)
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  – Jooske van der Graaf (Shell Company)
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  – Britta Gross (General Motors)
  – Cory Welch (National Renewable Energy Labs)
Summary

• **Report latest results from the MIT alternative energy and transportation transition model**
  - New model enhancements
    • Additional AFV platforms
    • Upstream fuel supply chains
    • Enhanced consumer behavior
    • Enhanced representation of OEM R&D, learning, technological spillovers
    • Carbon Capture and Storage
  - Analysis of platform and fuel diffusion
    • Fuel availability and price uncertainty
    • Impact of consumer and OEM responses to carbon prices
    • Impact of consumer and OEM responses to early/late breakthroughs with 2G biofuels and/or CCS

• **Purpose is to**
  - Further develop our conceptual models on transportation transition challenges and opportunities
  - Improve simulation model
  - Explore further critical questions
2/3\textsuperscript{rd}s of all the world’s petroleum is used by transportation


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Reducing Petroleum Consumption a Vital US National Interest

- Declining domestic production
- High and rising import dependence
- Vulnerability to supply disruption, geopolitical instability
- Local air pollution and health effects
- Greenhouse gas emissions
The current transportation model does not scale:
If the projected world population of 9 billion people in 2050 lived the way Americans do today...

- There would be 7.6 Billion motor vehicles on the roads
- Transportation alone would consume 440 million barrels of oil per day
  - Total world oil production today is 82 million bbl/day
- CO₂ emissions from transportation alone would be 62 billion metric tons/year
  - Total world emissions from fossil fuels today ≈ 28 billion tons CO₂/year
- The current model of development and transportation cannot scale to a world of 9 billion, all of whom aspire to live the way we do
  - New energy supply technologies are necessary but not sufficient
  - End-use efficiency improvements are necessary but not sufficient
- A new transportation system is coming.
  - What pathway? How will be a leader?
  - Note only of company but also of national Interest: leadership essential to preserve and enhance domestic innovation, investment, and job creation.

Adapted from: MIT Transportation Initiative, Profs. Barnhart, Jaillet, Sheffi, Sterman, Waitz, Zegras
Mass mobility wave in motion

The Tata Nano: a $2500 car made for a market of one billion people.

Source: MIT Transportation Initiative, Profs. Barnhart, Jaillet, Sheffi, Sterman, Waitz, Zegras
Cutting greenhouse gas emissions enough to stabilize atmospheric concentrations...

Source: Stern Review, Fig. 8.4
Is incompatible with this:

...unless we dramatically innovate in transportation

Source: MIT Transportation Initiative, Profs. Barnhart, Jaillet, Sheffi, Sterman, Waitz, Zegras
Many opportunities exist. Why not widespread?
Technology Disruptions: Traditional Perspectives

- **Personal Stereo**
  - Conventional Technology
  - Alternative Technology

- **Cameras**
  - Conventional Technology
  - Alternative Technology

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Canonical Diffusion Examples versus Network Technologies

- Technological improvements
- Consumer acceptance
- Complement product or market
- Regulation
- Fuel supply & infrastructure
- Service
- Repair
- Conversion
- Stationary applications

Alternative Fuel Vehicle

Color television
Laser printer
Refrigerator
Walkman
VHS player
Document reader/ writer
Alternative Fuel Vehicle Diffusion: Slow and Fragile

Diffusion Patterns of Alternative Vehicle Platforms

- HFCV Scenarios
- Hybrid - US
- SUV - US
- Diesel

Share of Total Adoption vs. Year

NZL (Conversions)

ARG

DOE High

DOE Low

Sweden

UK

US

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Alternative Fuel Vehicle Diffusion: Slow and Fragile

Diffusion Patterns of Alternative Vehicle Platforms

- HFCV
- Hybrid - US
- SUV - US
- Diesel
- CNG

Share of Total Installed Base vs. Year
Many programs to introduce Alternative Fuel Vehicles (AFVs) fail

- **Compressed Natural Gas**
  - So far so good: Argentina
  - Low penetration: Italy
  - Sizzle and fizzle: Canada, New Zealand
  - Stalled: California, Europe (excl Italy)

- **Diesel**
  - High/self-sustaining: Austria, Germany, France
  - Sizzle and fizzle: USA
  - Low penetration: Sweden, Ireland

- **Ethanol**
  - Sizzle and fizzle: Brazil (100% ethanol)
  - So far so good: Brazil (flex fuels)

- **Gas-electric hybrid (e.g. Prius)**
  - So far so good USA

- **Electric**
  - Sizzle and Fizzle USA: EV1, other pure electrics

- **Plug-in Hybrids**
  - Too soon to tell Various (Ford, Toyota, Chevy Volt)
Creating a Market That Does Not Exist: Research Question

- How do AFVs enter the market, gain traction, and sustain themselves?
  - What are viable pathways?
  - Where are important pitfalls?
  - Where lie important policy leverages?
  - What level of coordination is needed? Who? What kind of coordination? How long?
  - What portfolios to build?
MIT System Dynamics Group Approach

• Suite of simulation models of AFV introduction, diffusion, competition
  – Dynamic
  – Spatially explicit
  – Behavioral (realistic depiction of decision making)

• Broad model boundary to avoid unanticipated “side effects”
  – Integration of vehicle technology, competition among AFVs and with ICE, fuel supply technology, consumer behavior, government policies, other key actors and factors
  – Counterfactual analysis

• Grounded in detailed empirical study, quantitative and qualitative data
  – Case studies of prior AFV programs and policies

A Broad Boundary

Consumers
- Vehicle replacement
- Platform consideration
- Platform choice
  - new/used, car/truck
- Trip choice
- Refueling choice
- Topping-off behavior

Automotive Producers
- Platform portfolio
- Production capacity
- Experience from R&D and spillovers
- R&D investment, incl. fuel efficiency
- Marketing

Fuel Retailing
- Entrance/exit
- Location selection
- Fuel station capacity

Fuel Suppliers & Producers
- Entrance/exit
- Price Setting
- Experience
- CCS Investment
- Electric Power Mkt

Policy makers
- Supply subsidies/taxes
- Demand subsidies/taxes
- Campaigns
- Pilot programs
- CO2 taxes/price

Socio Economic Sector Interactions

- Spatial disaggregation
- Electricity Market

Stacked boxes imply multiple vehicle and fuel platforms (Internal combustion engines, HFCVs, hybrids; gasoline / biodiesel/ electricity etc.)
Principal feedbacks

Vehicle Choice Attributes

- Purchase price
- Performance
- Driving Convenience
- Safety
- Operating Cost
- Ecological impact

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Creating an AFV market: California as Laboratory for Experimentation

- **Focus on Central/Southern California**
  - 13.5 Million households
  - 13 Million ICE vehicles
  - 6,500 gasoline fuel stations
- **Behavioral Dynamics**
  - Willingness to consider an AFV in purchase decision depends on marketing, social exposure to AFVs, word of mouth from others (favorable and unfavorable)
  - AFV purchase decision also conditioned by inconvenience of fuel search and risk of no fuel
  - Drivers will go out of their way for fuel – up to a point
  - Drivers worried about fuel availability may top off tanks
Experiment 1: HFCV Diffusion

Liquid/gas fossil

gasoline, ethanol, diesel

conventional ICE/gasoline, hybrid

OEM reinvestment, learning, scale, scope

Consumer Acceptance

hydrogen

fuel-cell

$ $ $
Example: HFCV

• **2006 ICE/Gasoline Technical Parameters**

• **Hydrogen Fuel Cell Vehicles compared to current ICE:**
  - $35,000 production cost
  - Equal Initial performance
  - 35 mi/gge fuel economy
  - 6 gge tank capacity

<table>
<thead>
<tr>
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<th>Initial</th>
<th>Mature</th>
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<td>$35,000 production cost</td>
<td>2.25</td>
<td>1</td>
</tr>
<tr>
<td>Equal Initial performance</td>
<td>1</td>
<td>1.25</td>
</tr>
<tr>
<td>35 mi/gge fuel economy</td>
<td>1.67</td>
<td>3</td>
</tr>
<tr>
<td>6 gge tank capacity</td>
<td>0.3</td>
<td>0.5</td>
</tr>
</tbody>
</table>

• **Hydrogen Fuel Stations**
  - $H_2$ Produced at Station Forecourt via Steam Reformation of Natural Gas
  - $2.10 variable cost per gge H2 output (~$9/mcf natural gas, 70% efficiency)
  - Selection, permitting, construction delays total 2 years

• **Aggressive, coordinated, and persistent policies across the system:**
  - Intensive 15 yr marketing program to build awareness
  - Fleet program involving 500,000 vehicles
  - *Full subsidy of HFCV vehicle price difference with ICE*
  - Intensive R&D programs to lower AFV cost and boost performance prior to roll out
  - Fuel station rollout totaling about 800 stations
  - Fixed $2.50 gge alt fuel retail markup for 10 years, gradual deregulation thereafter
  - $0.50/gallon additional gasoline tax
  - Cost of R&D, marketing program, fleet program, AFV subsidies, fuel station rollout shared between government, auto OEMs and fuel providers

• **Assume no Hindenburgs**
Base Case

Market collapses after subsidies end

Hydrogen Fuel Cell Vehicles on the Road

Chicken and Egg Problem

Hydrogen Fuel Stations

Fuel Station openings

Fuel Availability

Fuel Demand

Adoption Fraction

ICE

HFCV

Spatial snapshot

Rollout Stations

Total 785
Urban 87%
SubUrban 5%
Rural 8%

Fuel Stations

Gasoline
Hydrogen

Spatial snapshot

5,700

Fuel Stations
(Max Scale = 23,000 stations)

2010 2025 2040 2055 2070 2085

Market collapses after subsidies end
Some adoption in urban areas, but poor rural, exurb fuel availability leads to market collapse
Topping Off

We examine the following behavioral assumptions for driver refueling behavior:

1. **Rigid**
   - refill at buffer
   - buffer fixed

2. **Flexible**
   - refill on average at buffer
   - buffer fixed

3. **Adaptive**
   - refill on average at buffer
   - buffer adapts to perceived fuel availability

What is the impact on AFV diffusion?
AFV Driver “Topping off” Creates Self-Reinforcing Fuel Shortages

Perceived Fuel Shortages

Topping Off

Queues at Fuel Stations, Stations Running Out of Fuel

Bank Panic

Driver Anxiety

Gas line during 1979 crisis
• Topping off is individually rational when fuel availability is uncertain.

• But topping off lowers effective vehicle range,
  – Increasing trips to and congestion at fuel stations
  – Increasing chances of “bank run” dynamics (gas lines and panic as in USA 1979, UK/France 2000)

◊ Result: Lower AFV attractiveness and adoption
Successful Policy: Subsidize fuel stations in rural areas

**Base Case**

Adoption Fraction
- **ICE**
- **HFCV**

Spatial snapshot

**Fuel Stations**
(Max Scale = 23,000 stations)
- **Gasoline**
- **Hydrogen**

- Total: 785
- Urban: 87%
- SubUrban: 5%
- Rural: 8%

**Rollout Stations**

**Fuel Station Rollout, Rural Emphasis**

Adoption Fraction
- **ICE**
- **HFCV**

Spatial snapshot

**Fuel Stations**
(Max Scale = 23,000 stations)
- **Gasoline**
- **Hydrogen**

- Total: 785
- Urban: 33%
- SubUrban: 26%
- Rural: 41%

**Rollout Stations**

Spatial snapshot
AFV Adoption Fraction in 2030

Base Case

Base Case with Rural Fuel Station Rollout Emphasis

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Successful Diffusion: Overview

- Population (Max Scale = 60M people) - 26.9M
- Vehicles in Use (LDVs) (Max Scale = 25M Vehicles) - 13.3M
- Installed Base Fraction
  - ICE
  - HFCV
- Fuel Stations (Max Scale = 23,000 stations)
  - Gasoline
  - Hydrogen

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Fuel Consumption and Emissions

- Fuel Consumption (Max Scale = 12B gge)
  - Gasoline
  - Hydrogen
  - BaU

- Cumulative GHG Emissions Well-to-Wheels Per 2010 (Max Scale = 10B T.C02 equiv)
  - Gasoline Supply Chain
  - Hydrogen Supply Chain
  - BaU

- GHG Emissions per Vehicle Mile Traveled, Well-to-Wheels (Max Scale = 6e-4 T.C02/mile)
  - Gasoline
  - Average
  - Hydrogen
  - BaU

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New Vehicle attributes

Vehicle Performance
- ICE
- HFCV

HFCV Tank Capacity
(max scale = 30 kg)
- 6 Kg

Vehicle Production Cost
- ICE
- HFCV

Vehicle Fuel Efficiency
- ICE
- HFCV

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Consumer consideration and vehicle sales

- Assumes aggressive, sustained marketing effort, demonstration fleet program to build awareness, increase consumer consideration of AFVs
- Surplus used conventional vehicles depress used car prices, delay AFV adoption
- “Cash for Clunkers” can speed AFV market success, stimulate new car sales
Experiment 2: Waiting for the oldies to retire: vehicle life strongly affects AFV adoption

AFV diffusion vs. average vehicle life

- Market penetration increases rapidly with a reduction in the replacement time (dynamics result from social exposure effects, infrastructure, technology learning effects ignored)

- Policies that reduce the effective replacement rate of vehicles have a large impact on moving us over the tipping point: “Cash for Clunkers”

- IMPORTANT: “Clunkers” must not only be deregistered but shredded, with materials recycled. Cannot be sold into used markets in the US or other countries.
Experiment 3: Multiplatform Competition

Fuel providers reinvestment, learning, expansion, entry/exit

- Liquid/gas fossil
- Coal
- Nuclear
- Wind, Solar
- Biomass

Power grid

- Gasoline, diesel ethanol

Conventional ICE/gasoline, hybrid

OEM reinvestment, learning, expansion, scale

- PHEV / PBEV
- (P)HFCV

Consumer Acceptance

$ $ $ $ $ $ $ $ $ $ $ $ $ 

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Exploring PHEV and PHFCV Introduction: Basic Assumptions and Data

• Launch in California
• Initial PHEV costs high (realistic), but...
  – Charge-at-home capability
  – Extensive PHEV R&D, marketing. Funding from various parties.
  – Multistakeholder commitment to deploying PHEVS
• Calibration from established data sources; fuel supply chain and (public) PHEV data from Ford and Shell Hydrogen
  – For illustrative purposes: electricity predominantly derived from fossil inputs (coal, natural gas)
Installed Base Dynamics for Multiplatform Competition

Population Growth = 1.5%

25% in stalled base share

Installed Base [M Vehicles]

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Conditions favor successful PHEV diffusion

PHEVs use existing fuel infrastructure

Sustained diffusion through self-reinforcing learning, scale effects
Platform Installed Base Distribution in 2050 for Different Competition Scenarios

![Bar chart showing the installed base distribution for different vehicle types and scenarios in 2050.](chart.png)

- **ICE** (Internal Combustion Engine)
- **PHEV** (Plug-in Hybrid Electric Vehicle)
- **PHFCV** (Plug-in Fuel Cell Vehicle)

### Installed Base [M Vehicles]

<table>
<thead>
<tr>
<th></th>
<th>Small</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ICE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PHEV</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PHFCV</strong></td>
<td></td>
<td></td>
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</tbody>
</table>

Legend:
- Base
- PHEV
- PHFCV_S (250 station rollout)
- PHFCV_L (500 station rollout)
- PHEV+PHFCV_L

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PHEV versus (P)HFCV Diffusion: Preliminary Insights

• Simulations suggest a viable path to widespread, self-sustaining PHEV diffusion
  – PHEV has advantages relative to e.g. HFVC:
    • Fueling infrastructure already deployed; can transition to carbon-neutral via biofuels
    • Self-sustaining diffusion much easier to achieve
  – Nevertheless, diffusion is slow, consistent with history of other automotive technologies
  – Significant investment still required to pass tipping point
    • Marketing; consumer acceptance
    • Cost reduction and reliability improvement through learning, R&D, scale
  – Nontrivial risks:
    • Technical (e.g. battery reliability)
    • Economic (cost)
    • Social (willingness to consider)
Experiment 4: Biofuel Pathways
Biofuels Experiment, Main Assumptions

- **Crop yield grows with 1% per year**
- **Fleet grows, new conventionals are 100% FFV**
  - As well as full awareness by their drivers etc..
- **Market conditions**
  - Mandate is pursued by indicated blending level that changes over time. Producers understand demand as indicated by mandate.
  - Ethanol production for blending and E85 is market driven, but producers receive 50c/gallon subsidy
  - Corn price start in equilibrium at 4.5 $/Bushel
  - Initialized and calibration to US corn land use, yield, price and production data
- **Demographics:**
  - Population growth 1.5%
  - CA to US extrapolation to examine fuel demand impact
- **Timing of 2G Biofuels depends on scenario**
  - One scenario (2G 2015) involves highly optimistic successful availability for commercialization as of 2015 (after which 2G market performance depends on endogenous scaling up and improvements by learning)
Ethanol (Energy) share in gasoline blend

- **E10**
- **E5**

- **Mandate Blend Target**
- **Blend share with mandate**
- **Blend share without mandate**
- **Blend share – no producer subsidy**

Time (Year):
- 2010
- 2020
- 2030
- 2040
- 2050

Y-axis:
- 0
- 0.05
- 0.1
- 0.15

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Principle feedbacks of corn price dynamics
Corn Price under Mandate

Mandate
No Mandate
Counterfactual: Fixed ethanol demand

Time (Year)

$/Bushel

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US Corn Demand for Transport Biofuel

- **Mandate**
- **No Mandate**

The graph shows the projected demand for transport biofuel in MBU/year from 2010 to 2050 under two scenarios: with a mandate (red line) and without a mandate (green line). The demand is expected to increase significantly over the years, with the mandate scenario showing a higher demand compared to the no mandate scenario.
E85 Prevalence for Flex Fuels

E85 consumption suppressed under mandate

No Mandate

Mandate
Total US Ethanol Production

Ethanol Price [c/kwh]

- 2015
- 2040

- Actual
- Projected
- Total

- Mandate
- Mandate + 2G
- No Mandate

Ethanol Production [Quads/year]
Sensitivity Analysis: Biofuel Production

Targets and Productivity
- \( g_{\text{Eth}}^* = 0.2 \text{ [1/yr]} \); \( g_{\text{yield}} = 0.01 \text{ [1/yr]} \)
- \( g_{\text{Eth}}^* = 0.3 \text{ [1/yr]} \); \( g_{\text{yield}} = 0.01 \text{ [1/yr]} \)
- \( g_{\text{Eth}}^* = 0.3 \text{ [1/yr]} \); \( g_{\text{yield}} = 0.02 \text{ [1/yr]} \)

2GBio Introduction
- 2015
- 2025
- n.a.
Example Scenario Impact on GHG Emissions (2050) (No Carbon Pricing)

We perform scenario analysis, with different emission intensities throughout the fuel supply chain, using inputs from multiple expert studies. Note that 2G biofuel estimates in particular vary considerably.

Current Main Sources:
- Tilman et al. 2006
- Searchinger et al. 2008
- Fargione et al. 2008
- EPA 2009
**Fuel Choice and Efficiency by Platform**

*Scenario: Seq.Credit, LandU., No 2GBio*

<table>
<thead>
<tr>
<th></th>
<th>ICE</th>
<th>PHEV</th>
<th>HFCV</th>
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<tbody>
<tr>
<td><strong>Share of total miles by fuel</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2020</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2050</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>

*0.01 Miles/gCO2*
Experiment 5: The Effect of Oil Shocks on PHEV Diffusion

- Liquid/gas fossil
- Coal
- Nuclear
- Wind, Solar
- Biomass
- Gasoline, diesel, ethanol
- Conventional ICE/gasoline, hybrid
- Power grid
- PHEV/PEV
- Consumer Acceptance
- Fuel providers reinvestment, learning, expansion, entry/exit
- OEM reinvestment, scale, scope

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Hypothesis: Higher oil prices improve relative attractiveness of PHEVs

By strengthening self-reinforcing learning, and scale effects
PHEV Diffusion Patterns

Actual Effect: Negligible!
Higher fuel prices lead consumers to choose smaller, more efficient vehicles.

And there is more…
PHEV Market Formation: Overcoming an Established and Resilient Transportation System
Behavioral Responses Have Been Observed

**US Vehicle Distance Traveled**

Road Vehicle Miles (Trillions/year)

<table>
<thead>
<tr>
<th>Year</th>
<th>1983</th>
<th>2008</th>
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<tr>
<td>Miles</td>
<td>1.5</td>
<td>3</td>
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</table>

**Vehicle Weight & Performance**

- Weight (lbs)
- 0 to 60 (sec.)

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<tbody>
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<td>Time</td>
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<td>13</td>
<td>12</td>
<td>11</td>
<td>10</td>
<td>9</td>
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**Car and Light Truck Sales**

- Car
- Truck

<table>
<thead>
<tr>
<th>Year</th>
<th>1980</th>
<th>2008</th>
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<td>Annual</td>
<td>1980</td>
<td>2008</td>
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<tr>
<td>Monthly</td>
<td>1980</td>
<td>2008</td>
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Vehicle average fleet efficiency responds to real prices with a very long delay. Prices jump in 1973, but efficiency remains nearly constant until 1980. Prices fall to about $20/bbl by 1986 and efficiency gains stall in 1992 as automakers use technical improvements to boost performance instead of mileage, and as consumers switch to larger vehicles and SUVs.
Experiment 6: Varying CO2 Prices

- Liquid/gas fossil
- Coal
- Nuclear
- Wind, Solar
- Biomass

Fuel providers reinvestment, learning, expansion, entry/exit

Power grid

- Gasoline, diesel, ethanol
- Conventional ICE/gasoline, hybrid
- PHEV / PBEV
- (P)HFCV

Consumer Acceptance

OEM reinvestment, learning, expansion, scale, scope

$ $ $ $ $ $ $ $ $ $
Automotive Responses to CO2 Price

Relative Fuel Economy New Vehicles

![Graph showing the relationship between CO2 price and relative fuel economy for small and large vehicles over time. The actual average fuel economy depends on consumer choice and fleet replacement.](image-url)
$50/tCO2 carbon tax has moderate impact on platform installed base shares

Vehicle Installed Base in 2050 (Millions)

Note: PHFCV’s do best in absence of 2Gbiofuels
CO2 Emissions from transportation under varying CO2 Scenarios

CO2 Emissions (California) [MTCO2e/year]

<table>
<thead>
<tr>
<th>Year</th>
<th>Scenario Details</th>
<th>EL</th>
<th>Petro</th>
<th>H2</th>
<th>ETH</th>
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<tr>
<td>2020</td>
<td>I. 2GBio + AFVs + SeqCr/LanduCorn</td>
<td>433</td>
<td>258</td>
<td>342</td>
<td>247</td>
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<tr>
<td></td>
<td>II. As I + CO2_50</td>
<td>325</td>
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<tr>
<td></td>
<td>III. As II + Hydro-El (California EL Mix)</td>
<td>247</td>
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<td>IV. As II + Late Tax</td>
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<td>V. As I + CO2_100</td>
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<td></td>
<td>VI. As I, no 2GBio</td>
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</tbody>
</table>

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Other Analysis Performed, in Progress, and Planned

- Extensive model testing
- Further PHEV analysis
  - Base scenario using: CAFE, (CA) renewable fuel standards, Waxman-Markey, etc..
  - Sensitivity to technical, economic, behavioral uncertainties (e.g. CCS, biofuel commercialization timing)
  - Policy analysis
- Competition with and interactions between PHEV & other AFVs
  - Alternative PHEV technologies
  - Conventional hybrids
  - Biofuels/biodiesel
  - HFCV, H-ICE
  - Pure electric (e.g. BetterPlace)
- Fuel supply chain scenarios:
  - Biofuels: 2nd Generation (cellulosic; waste inputs)
  - H₂ from sustainable sources (e.g. Nocera process, biofuels)
  - Electricity peak and base load, battery supply chains, storage
- C-Price and CCS Scenarios
- Interactions among all items above
- Other regions
AFV Diffusion: Counterintuitive Dynamics

- Focusing initial fuel station rollout on urban areas, where initial AFV demand likely highest, leads to urban focus, market failure.

- More costly exurb/rural focus builds sustainable, profitable AFV and alt fuel market, with greater urban market share, larger NPV for all key actors (Auto OEMs, fuel providers, consumers, government and environment).

- A more efficient AFV can slow or prevent adoption due to negative impact of lower fuel demand on alt fuel profitability and infrastructure investment.

- Plug-in Hybrids not vulnerable to infrastructure dynamics; diffusion more rapid and durable, assuming technical risks overcome.

- Success rapidly reduces gov’t fuel excise tax revenues; fuel tax must rise over time to maintain revenues (and compensate for drop in world oil price induced by lower consumption).

- Faster AFV sales leads to surplus used conv. vehicles. Low used car prices limit AFV diffusion. Early decommissioning of conventional cars (Cash for Clunkers) a high-leverage policy.

- Others…
Summary: Transition strategies for alternative transportation fuels and vehicles

- Understanding AFV diffusion requires sensitivity to
  - Technical, economic and socio-behavioral factors
  - Understanding counterintuitive dynamics
  - Worse-before better dynamics

- Effective policy making and market success requires coordinated/shared understanding, long-term commitment
  - Value and challenge of coordination among key stakeholders
    - Auto OEMs (entrants)
    - Fuel providers, electric utilities, power producers
    - Fed, state governments

- The modeling process is designed to enable learning with, and coordinate across different market players