# SA050

# *GPRA Analysis: Impact of Program Targets on Vehicle Penetration and Benefits*

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*Co-PI:* **Changzheng Liu**

**2015 U.S. DOE Hydrogen and Fuel Cells Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting**

***June 9, 2015***

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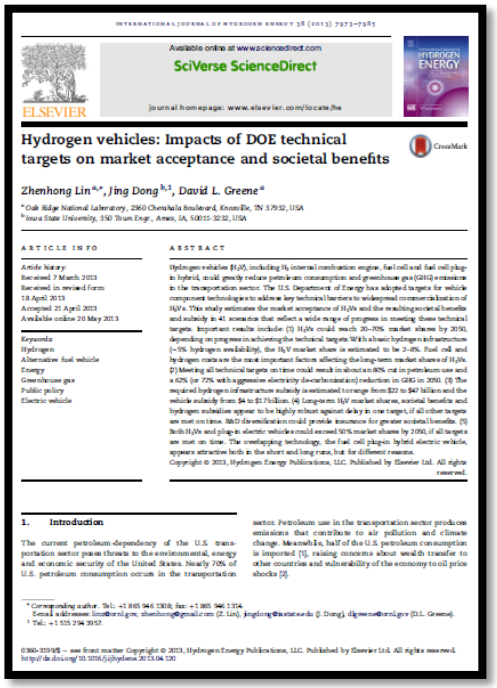
# OVERVIEW

| **Timeline** | **Barriers*** |
|---|---|
| • Project start date: Oct. 2013<br>• Project end date: Sept. 2015 | • Future Market Behavior<br>• Inconsistent Data, Assumptions and Guidelines<br>• Insufficient Suite of Models and Tools<br>• Unplanned Studies and Analysis<br><br>**from 2011-2015 VTP MYPP* |
| **Budget (DOE FCTO share)** | **Partners** |
| • FY14 funding: $75k<br>• FY15 funding: $120k | • Argonne National Laboratory<br>• Ford Motor Company<br>• National Renewable Energy Laboratory<br>• Oak Ridge National Laboratory<br>• SRA International Inc.<br>• University of California, Davis<br>• University of Tennessee |

# OBJECTIVE: Quantify impacts of FCTO program targets on market penetrations and societal benefits of fuel cell vehicles

## "WHY"

- NAS (2013) study
  - Low carbon transition is beneficial (benefits>>costs)
  - progress of fuel cell technologies & infrastructure deployment are key
- Government Performance and Results Act (GPRA) requirement
- Lin, Dong, Greene (2014): FCTO program targets can significantly contribute to both the magnitude and robustness of societal benefits of such a transition.
- New analysis warranted due to progress in technology & infrastructure



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Hydrogen vehicles: Impacts of DOE technical targets on market acceptance and societal benefits

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ABSTRACT

Hydrogen vehicles ($H_2V$), including $H_2$ internal combustion engine, fuel cell and fuel cell plug-in hybrid, could greatly reduce petroleum consumption and greenhouse gas (GHG) emissions in the transportation sector. The U.S. Department of Energy has adopted targets for vehicle component technologies to address key technical barriers to widespread commercialization of $H_2V$s. This study estimates the market acceptance of $H_2V$s and the resulting societal benefits and subsidy in 45 scenarios that reflect a wide range of progress in meeting these technical targets. Important results include: (1) $H_2V$s could reach 20–70% market shares by 2050, depending on progress in achieving the technical targets. With a basic hydrogen infrastructure (~5% hydrogen availability), the $H_2V$ market share is estimated to be 2–8%. Fuel cell and hydrogen costs are the most important factors affecting the long-term market shares of $H_2V$s. (2) Meeting all technical targets on time could result in about a 80% cut in petroleum use and a 62% (or 72% with aggressive electricity de-carbonization) reduction in GHG in 2050. (3) The required hydrogen infrastructure subsidy is estimated to range from $22 to $47 billion and the vehicle subsidy from $4 to $7 Trillion. (4) Long-term $H_2V$ market shares, societal benefits and hydrogen subsidies appear to be highly robust against delay in one target, if all other targets are met on time. R&D diversification could provide insurance for greater societal benefits. (5) Both $H_2V$s and plug-in electric vehicles could exceed 50% market shares by 2050, if all targets are met on time. The overlapping technology, the fuel cell plug-in hybrid electric vehicle, appears attractive both in the short and long runs, but for different reasons.

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1. Introduction

The current petroleum-dependency of the U.S. transportation sector poses threats to the environmental, energy and economic security of the United States. Nearly 70% of U.S. petroleum consumption occurs in the transportation sector. Petroleum use in the transportation sector produces emissions that contribute to air pollution and climate change. Meanwhile, half of the U.S. petroleum consumption is imported [1], raising concerns about wealth transfer to other countries and vulnerability of the economy to oil price shocks [2].

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## "HOW"

- Estimate FCV market share and the resulting reduction in petroleum use and GHG emissions
- Consider competition from all relevant powertrain technologies
- Collaboration on vehicle & infrastructure data



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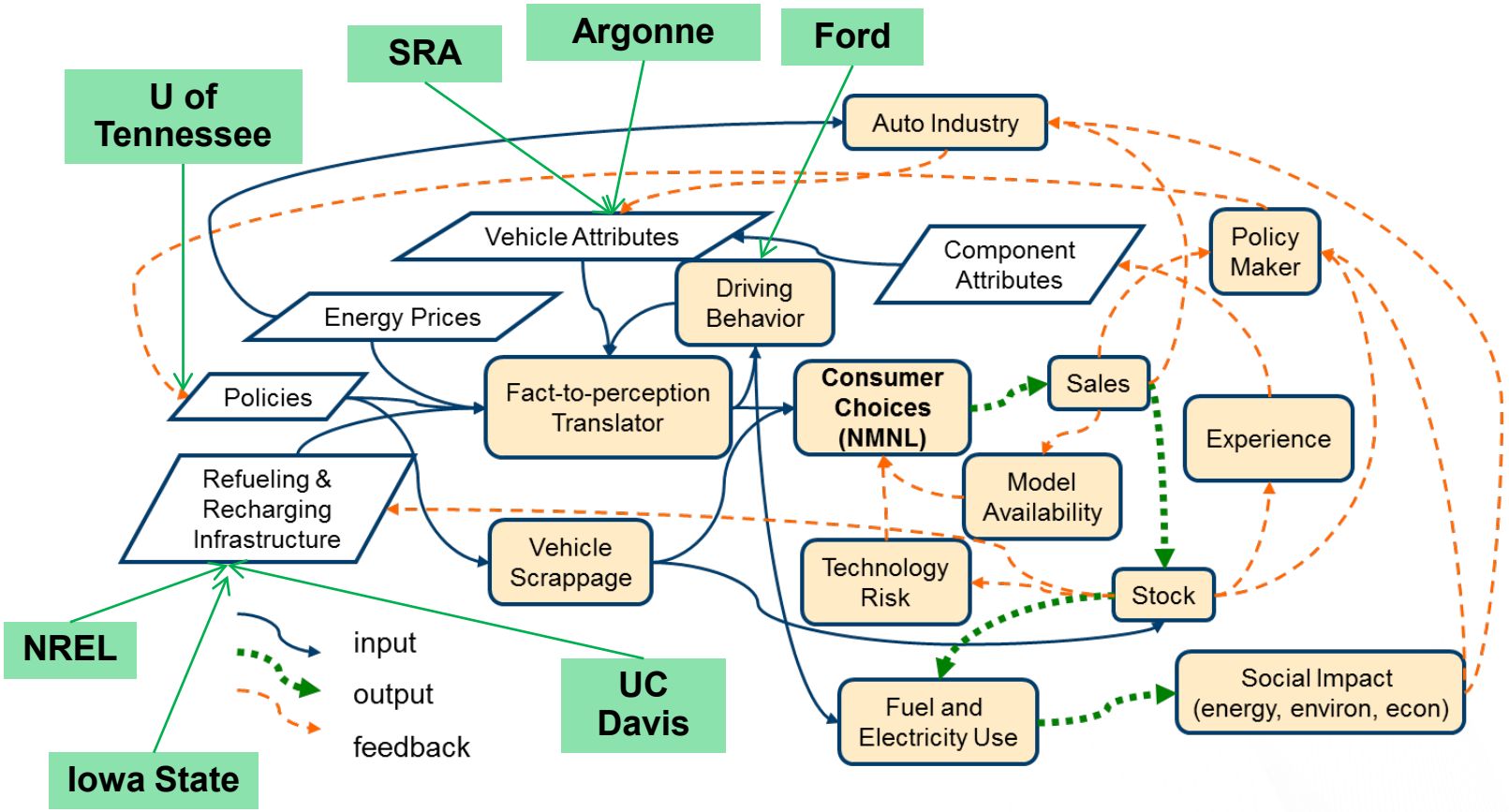
# RELEVANCE*

- **Supports U.S. DRIVE goals:**
  - "Enable reliable fuel cell electric vehicles with performance, safety and costs comparable to or better than advanced conventional vehicle technologies, supported by viable hydrogen storage and the widespread availability of hydrogen fuel. " -- http://www.uscar.org/
- **Directly supports FCTO activities*:**
  - System Analysis, Market Transformation
- **Indirectly supports FCTO activities*:**
  - Fuel cells, onboard $H_2$ storage
- **Addresses the following FCTO Barriers*:**
  - **Future Market Behavior**: integrated analysis of market dynamics; endogenously estimate effect of technology, infrastructure, demographics and policies on technology penetration.
  - **Inconsistent Data, Assumptions and Guidelines**: Utilize cross-lab assumptions and estimates on powertrain cost, fuel economies, infrastructure deployment.
  - **Insufficient Suite of Models and Tools**: systematical linkage of component (fuel cell, storage), vehicle system, and $H_2$ infrastructure; model validation with historical sales and price data
  - **Unplanned Studies and Analysis:** new target assumptions on fuel cell cost and storage cost are requested by DOE and led to additional case studies.

*Reference: Vehicle Technologies Multi-Year Program Plan 2011-2015:
http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/vt_mypp_2011-2015.pdf

# APPROACH (1): based on the ORNL MA3T model; collaborate on data and component methods with labs, universities and companies.

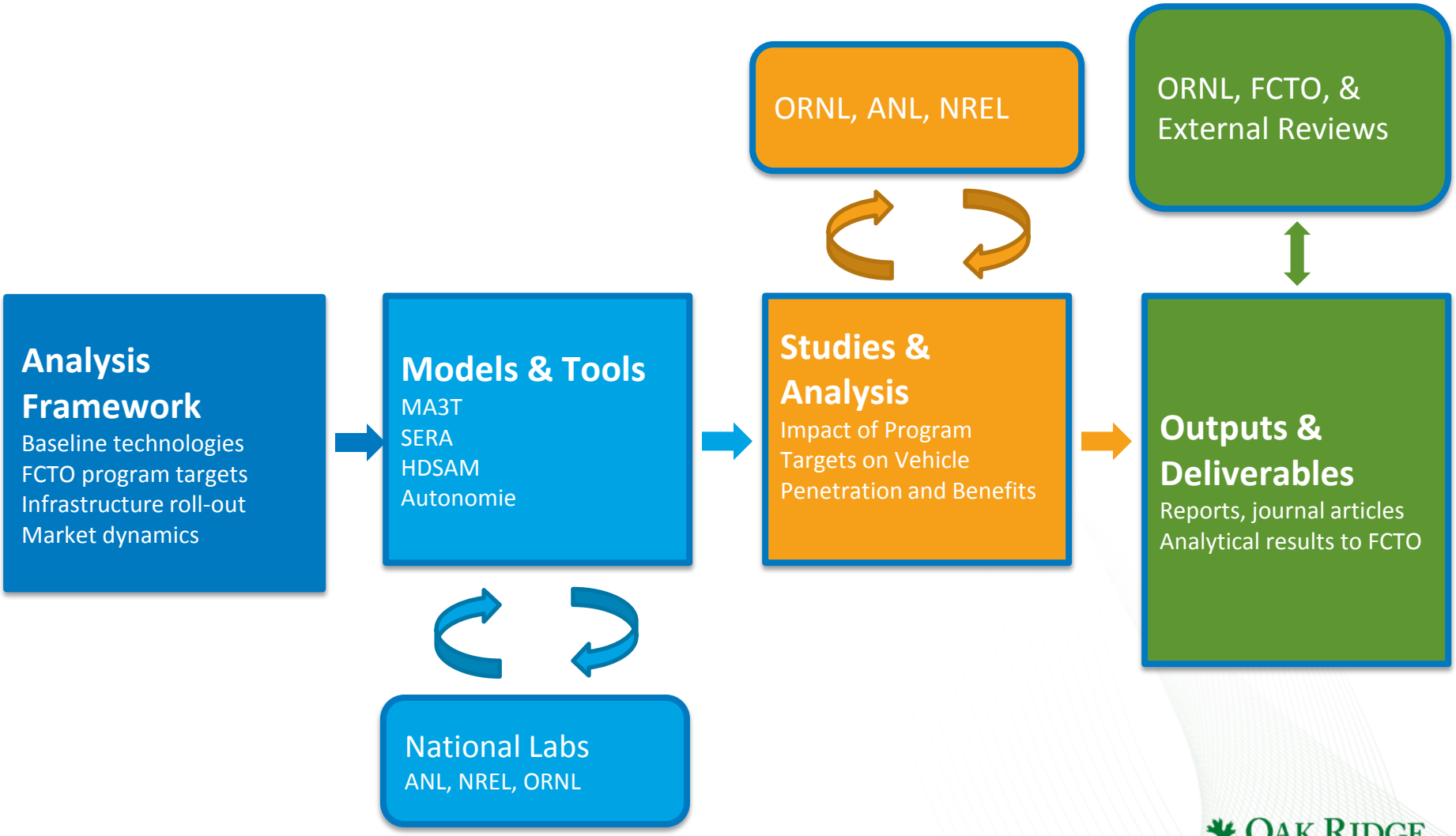



**ORNL: Market Acceptance of Advanced Automotive Technologies (MA3T)**

- **Endogenously estimate market share of FCVs among competing LDV technologies**
- **Up to 300 vehicle choices; 9000+ consumer segments**
- **Range limitation, $H_2$ refueling availability**
- **Technology learning, make&model availability**

# Approach – Project Overview

## *GPRA Analysis: Impact of Program Targets on Vehicle Penetration and Benefits*

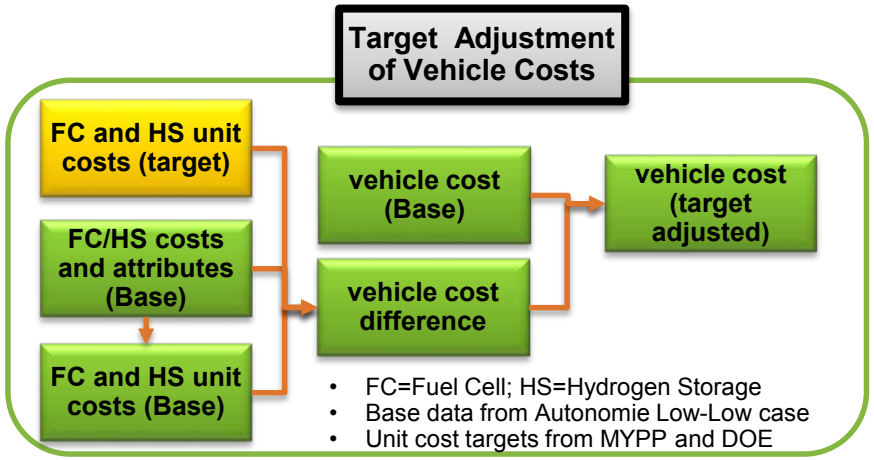


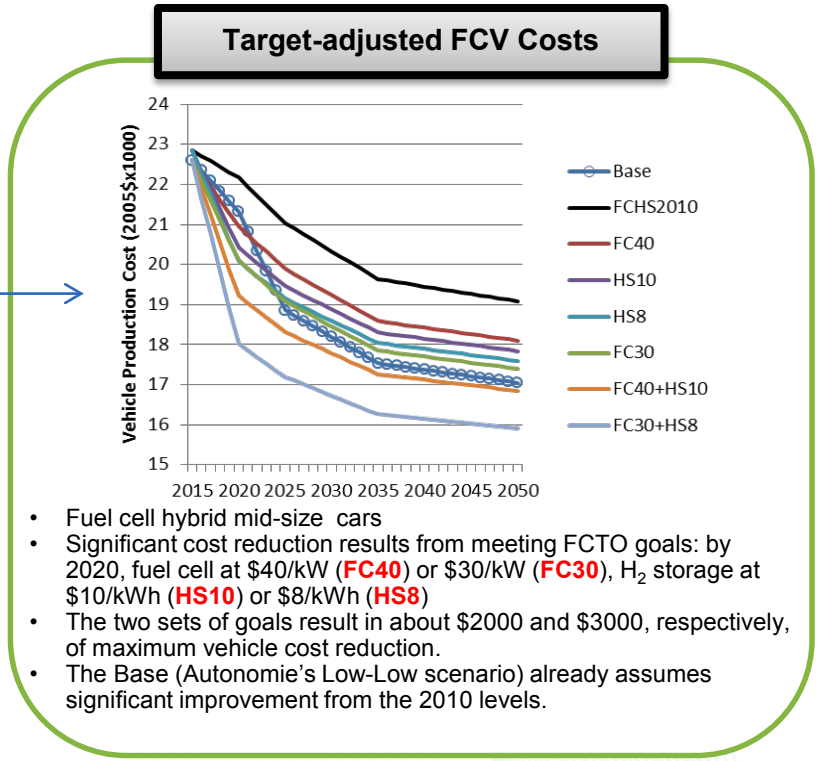
# Approach (2): FY2015 MILESTONES

| Milestone Description | Month/Year | Status |
|---|---|---|
| **Update fuel cell vehicle data and hydrogen cost data** | 12/31/2014 | Complete |
| **Construct appropriate hydrogen station roll-out scenarios** | 03/31/2015 | Complete |
| **Coordinate assumptions and data with program offices, national labs and/or industry** | 06/30/2015 | Complete |
| **Results reported to the broader GPRA study** | 09/30/2015 | On Schedule |

# ACCOMPLISHMENT (1): Key assumptions of 44 alternative scenarios

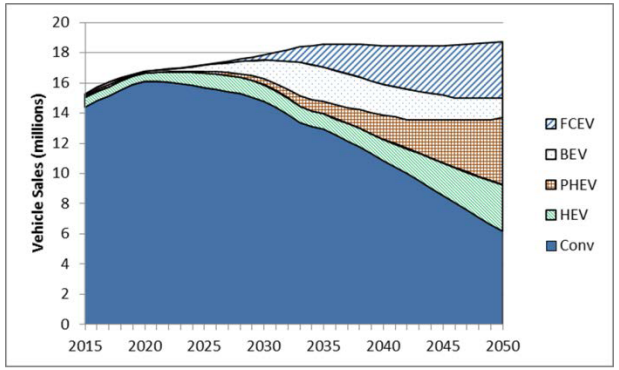
- Fuel cell cost targets: $40/kW by 2020 (official), $30/kW by 2020.
- $H_2$ storage targets: $10/kWh by 2020 (official), $8/kWh by 2020
- Two oil price scenarios from EIA AEO 2014
- Two $H_2$ station roll-out scenarios from NREL SERA
- Three $H_2$ price levels: $8, $4, $2/kg



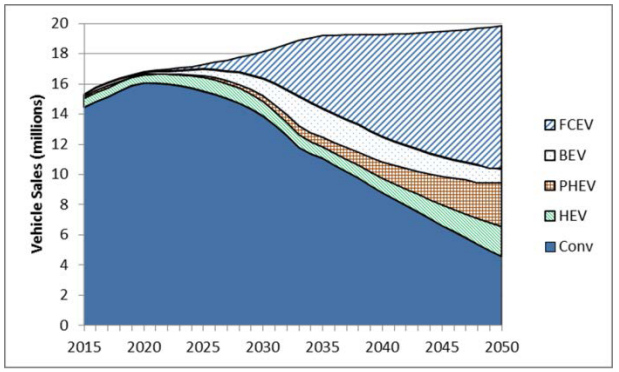
# ACCOMPLISHMENT (2): FCV sales impact of program targets depends on oil price, infrastructure roll-out speed and hydrogen price, but found overall significant

**LDV Market Share (Base)**



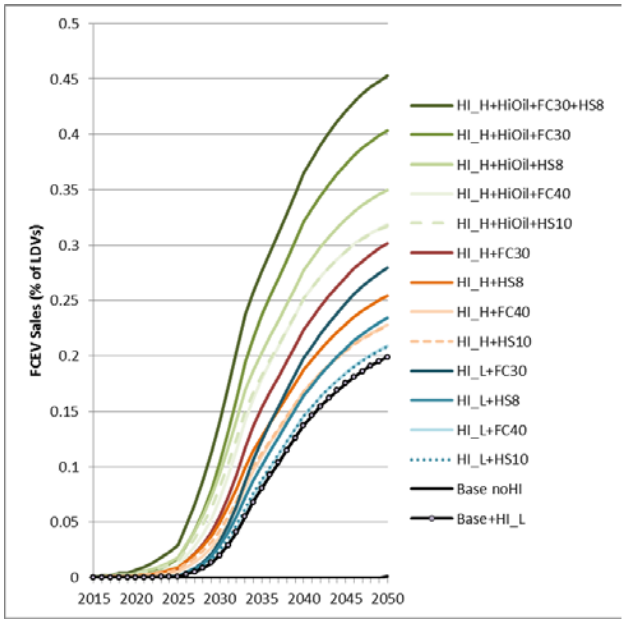

- Base: no DOE program intervention and slow hydrogen infrastructure roll-out. FCVs reach 3% by 2031 with 2% $H_2$ station availability.

**LDV Market Share (FCTO)**

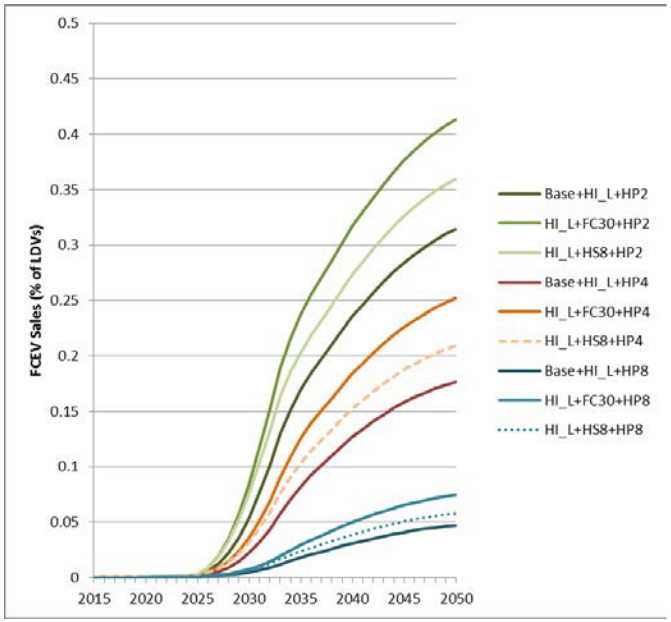



- FCTO case: fuel cells and on-board storage both meeting the DOE targets. FCVs reach 3% by 2026 with 10% $H_2$ station availability.

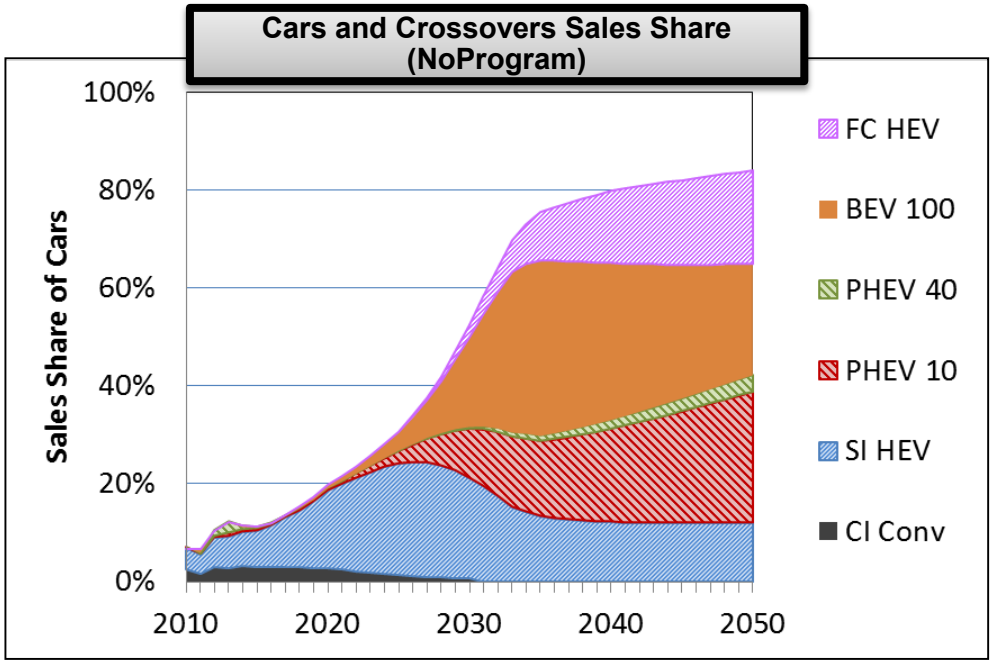
**Sales Impact of Program Targets by Oil Price and Station Role-out Speed**



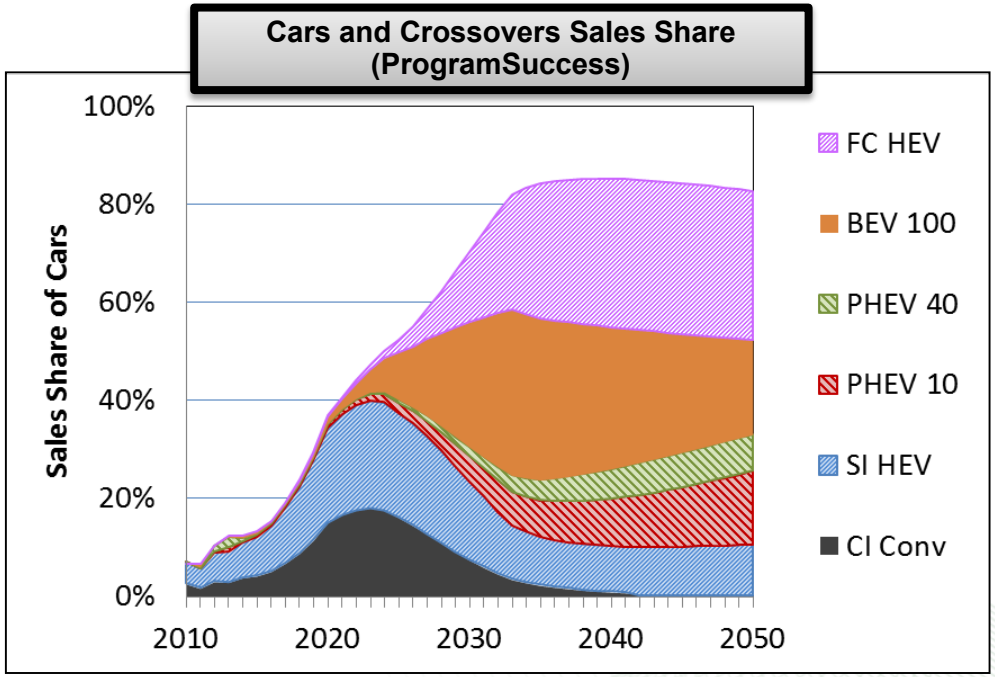

**Sales Impact of Program Targets by Hydrogen Price**



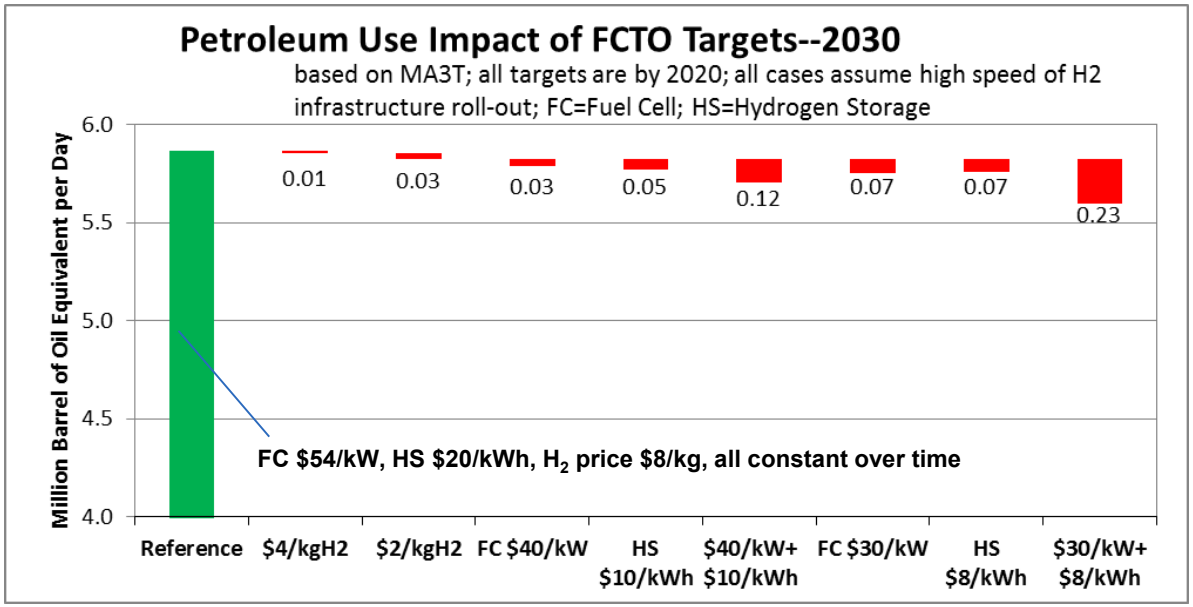
## ACCOMPLISHMENT (3): FCVs, BEVs and long-range PHEVs benefit the most from the program targets.

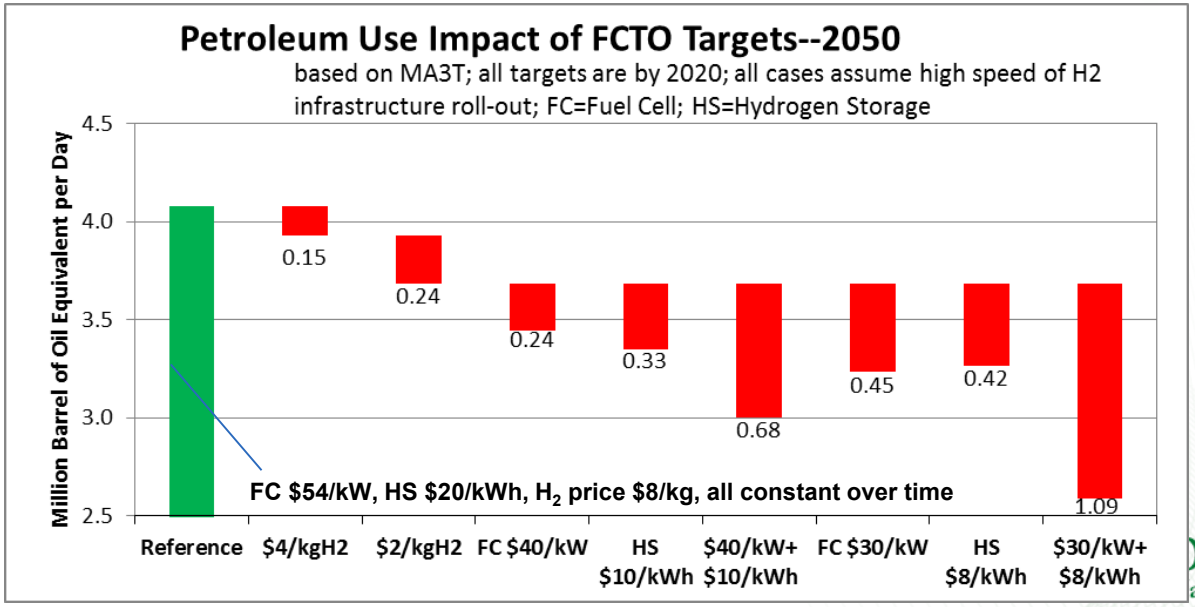



- **Part of the VTO-FCTO-BETO BaSce study**
- "**NoProgram**"
  - associated with "Low-Low" scenario of the most recent Autonomie vehicle simulation data on fuel economy and costs, representing no active pursue of DOE VTO or FCTO program activities.
- **"ProgramSuccess"**
  - associated with the "High-High" scenario of Autonomie, representing program targets of VTO and FCTO as if they are met on time.

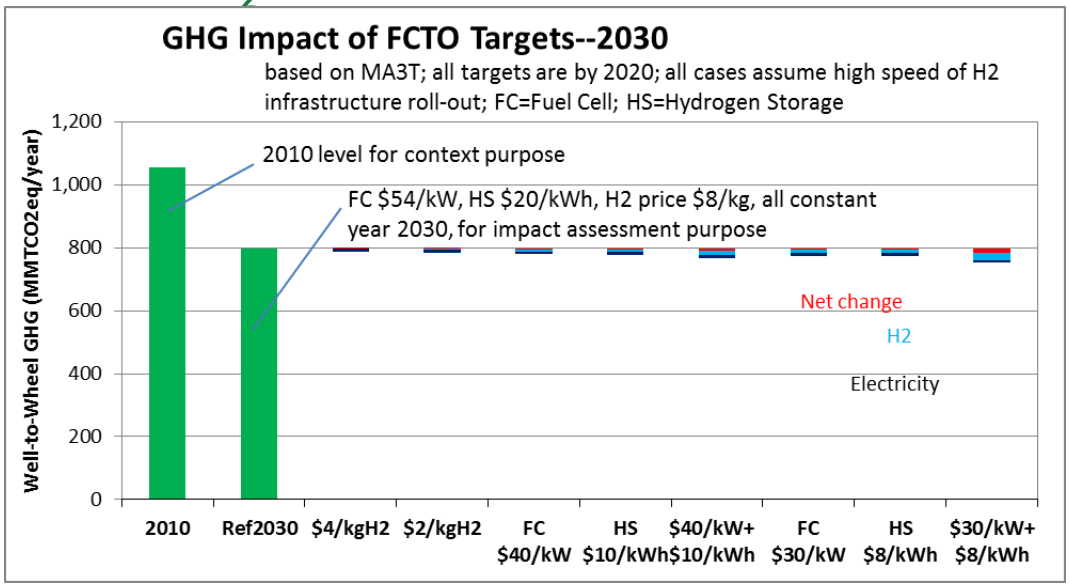


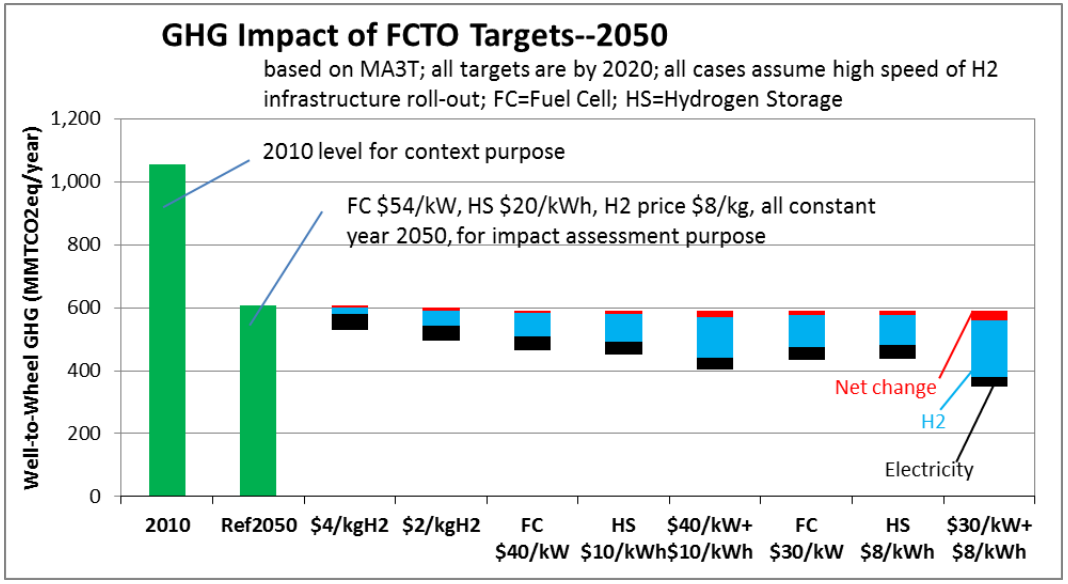
# ACCOMPLISHMENT (4): The FC $30/kW and HS $8/kWh targets reduce petroleum use by 0.23 MMbpd by 2030, 1.1 MMbpd by 2050



# ACCOMPLISHMENT (5): The FC $30/kW and HS $8/kWh targets reduce GHG emissions by 12-31 MMtCO2e by 2030 and 29-163 MMtCO2e by 2050, depending on supply share of renewable $H_2$




- Assume 0.51 kgCO2/kWh electricity based on AEO estimated 2015 U.S. average grid carbon intensity
- Assume 9.22 kgCO2/kg$H_2$ based on central reforming of natural gas at current technology without carbon capture and sequestration.
- Both assumptions are made for simplification; more GHG benefits are expected from decarbonization of electricity and $H_2$ supply.

# Accomplishment(6):

- **Responses to reviewer comments**
  - **This project was not reviewed last year.**
- **Technology Transfer Activities:**
  - **Not applicable**

# COLLABORATION AND COORDINATION

- U.S. Department of Energy
  - Assumption and data coordination
  - Travel data analysis
- Argonne National Laboratory
  - Vehicle data
  - PEV sales
  - Input standardization and model comparison
- Ford Motor Company
  - Composite distribution of daily travel distance and cross-region PEV feasibility analysis
- Georgia Institute of Technology
  - Travel data analysis
- Iowa State U
  - Range uncertainty, charging behavior, utility factor, infrastructure optimization
- National Renewable Energy Laboratory
  - $H_2$ infrastructure scenarios
- SRA International Inc.
  - Historical vehicle price and attributes data
- University of California, Davis
  - Cluster analysis of $H_2$ infrastructure
  - Travel behavior
- University of Tennessee
  - Energy security
  - ZEV incentive impact
  - AFV infrastructure planning issues
- ORNL Related activities
  - The old PG goal study
  - $H_2$ station economics analysis
  - Optimal onboard storage pressure
  - Market dynamics models: MA3T, Lave-Trans
  - Oil Security Metrics Model (OSMM)
  - Electric range optimization

# PROPOSED FUTURE WORK

- **FY2015**
  - **Finish running all cases**
  - **Report results to multi-office GPRA study**
- **FY2016**
  - **Update data on fuel cell vehicle attributes, hydrogen prices and infrastructure**
  - **Update energy prices (especially with a low oil price scenario)**
  - **More explicit representation of cluster strategy**
  - **Identify business opportunities for specific regions and consumer segments**
  - **Design and run case studies**
  - **Publication**

# SUMMARY:

- ✓ Relevance
  - ✓ inform R&D decisions; reveal market barriers, bottlenecks and dynamics.
- ✓ Approach
  - ✓ the ORNL MA3T model; collaborate on data and methods with labs, universities and companies.
- ✓ Technical accomplishments and progress
  - ✓ 44 scenarios of uncertainty on oil price, $H_2$ price and infrastructure roll-out speed
  - ✓ FCV sales impacts found significant, dependent on oil price, station roll-out speed and H2 price
  - ✓ Petroleum reduction benefit of program targets are significant, especially in the long run. The FCTO targets reduce petroleum use by 0.12 MMbpd or 2% by 2030, 0.68 MMbpd or 16% by 2050
  - ✓ GHG reduction benefit of program targets are significant only in the long run and with decarbonization of H2 supply. The FC $40/kW and HS $10/kWh targets reduce GHG emissions by 0.8%-2% by 2030 and 3%-18% 2050, depending on supply share of renewable $H_2$
- ✓ Collaborations
  - ✓ Industry: SRA, Ford
  - ✓ Government labs: Argonne National Laboratory, National Renewable Energy Laboratory
  - ✓ Universities: UC Davis, University of Tennessee, Iowa State University, George Tech
- ✓ Proposed Future Work
  - ✓ Data updates, cluster strategy, business models and consumer segmentation

# ACKOWLEDGEMENTS

**Fred Joseck**
*Systems Analysis Project Manager*
*Fuel Cell Technologies Office*
*US Department of Energy*

## Contact

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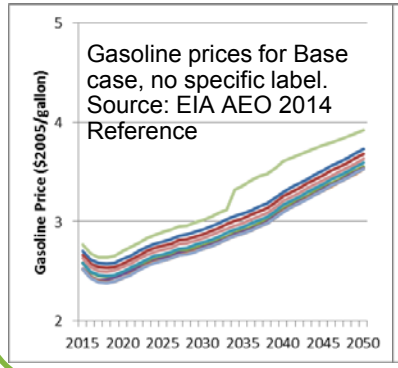
**(865) 946-1308**
**linz@ornl.gov**

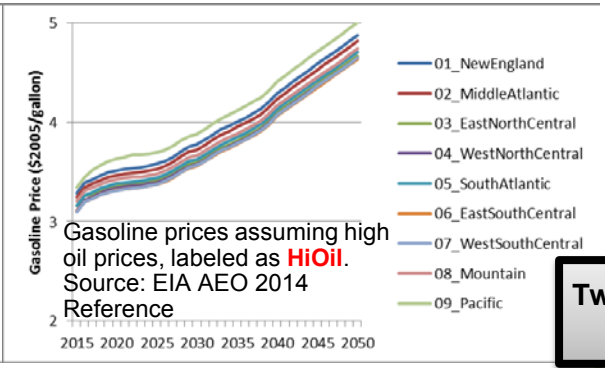
# Technical Back-Up Slides

# Acronym Definition

| Acronym | Definition |
|---|---|
| BEV | Battery electric vehicle |
| Conv | Conventional ICE vehicle |
| FC | Fuel cell |
| FC40, FC30 | Fuel cell cost reduced to $40/kW and $30/kW by 2020, respectively |
| FCV or FCEV | Fuel cell vehicle |
| GHG | Greenhouse gas |
| GPRA | Government Performance and Results Act |
| HEV | Hybrid electric vehicle |
| HI_L, HI_H | Low and high, respectively, speed of hydrogen infrastructure roll-out |
| HiOil | High oil |
| HP2,HP4,HP8 | Hydrogen price at $2, $4, $8 per kg $H_2$, respectively |
| HS | Hydrogen storage (onboard) |
| HS10, HS8 | Hydrogen onboard storage cost reduced by 2020 to $10/kWh and $8/kWh, respectively |
| ICE | Internal combustion engine |
| LDV | Light duty vehicle |
| MA3T | Market Acceptance of Advanced Automotive Technologies |
| PHEV | Plug-in hybrid electric vehicle |

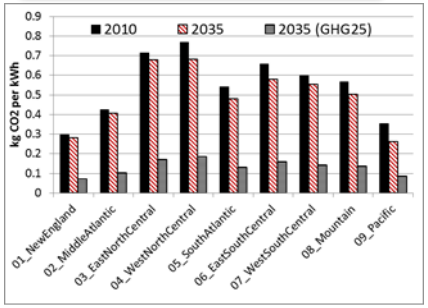
# ACCOMPLISHMENT (1): assumptions of alternative oil prices, grid carbon intensities and $H_2$ station availability are based on credible external efforts.



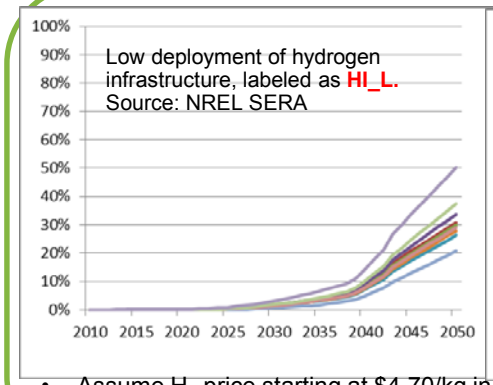



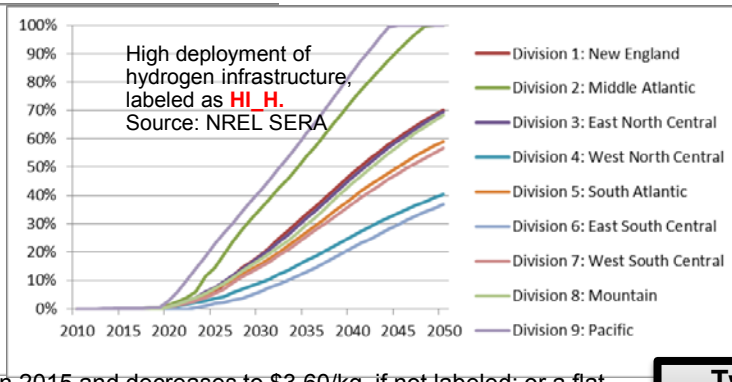

**Two Scenarios of Oil Prices**

**Two Scenarios of Grid Decarbonization**




- Grid decarbonization scenarios affects program benefit estimates
- 22 EIA Electricity Market Modules are matched to 9 census divisions based on electricity sales




- Assume $H_2$ price starting at $4.70/kg in 2015 and decreases to $3.60/kg, if not labeled; or a flat $8/kg, $4/kg or $2/kg, labeled as **HP8**, **HP4** and **HP2**, respectively.
- California and the Pacific region lead the nation in $H_2$ infrastructure deployment.

**Two Scenarios of $H_2$ Infrastructure Roll-out**



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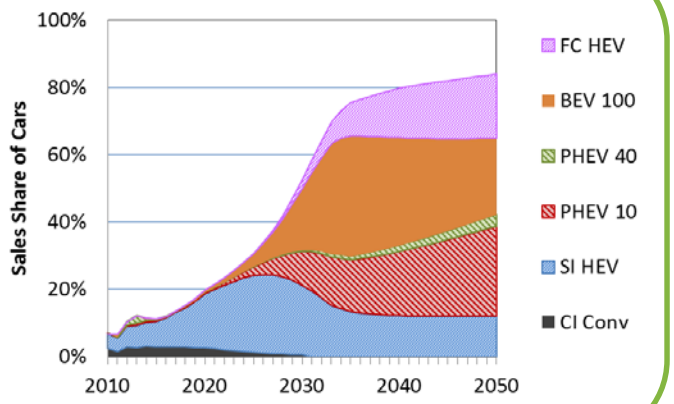
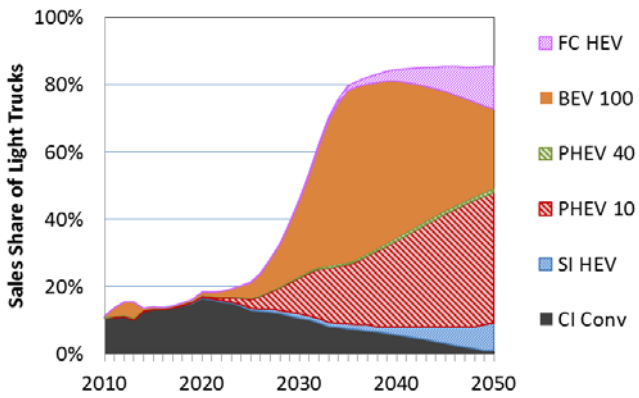
# ACCOMPLISHMENT (3): "NoProgram" and "ProgramSuccess" cases completed.

- Long-run effect of program targets: FCV, BEV and long-range PHEV gain shares; HEV and short-range PHEV lose shares; SI Conv largely holds its share.

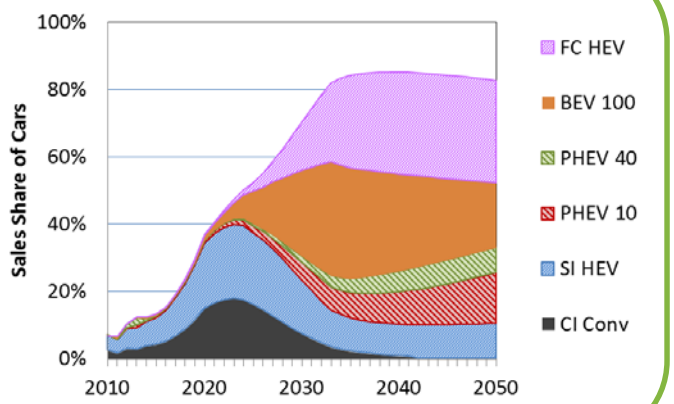
**Cars and Crossovers (NoProgram)**



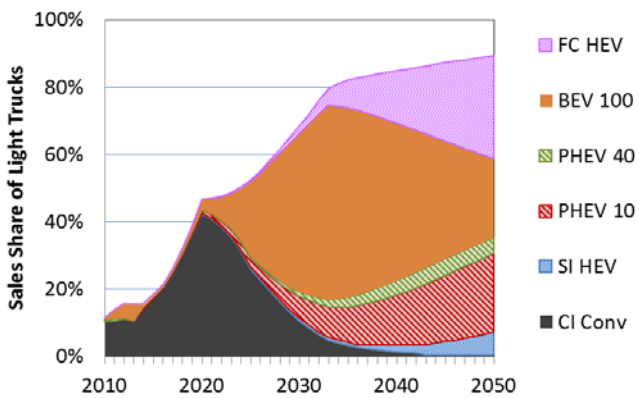

**SUVs and Pickups (NoProgram)**




**Cars and Crossovers (ProgramSuccess)**




**SUVs and Pickups (ProgramSuccess)**




- Assumptions: "NoProgram" is associated with "Low-Low" scenario of the most recent Autonomie vehicle simulation data on fuel economy and costs, representing no active pursue of DOE VTO or FCTO program activities. "ProgramSuccess" is associated with the "High-High" scenario of Autonomie, representing program targets of VTO and FCTO as if they are met on time.

# Published results

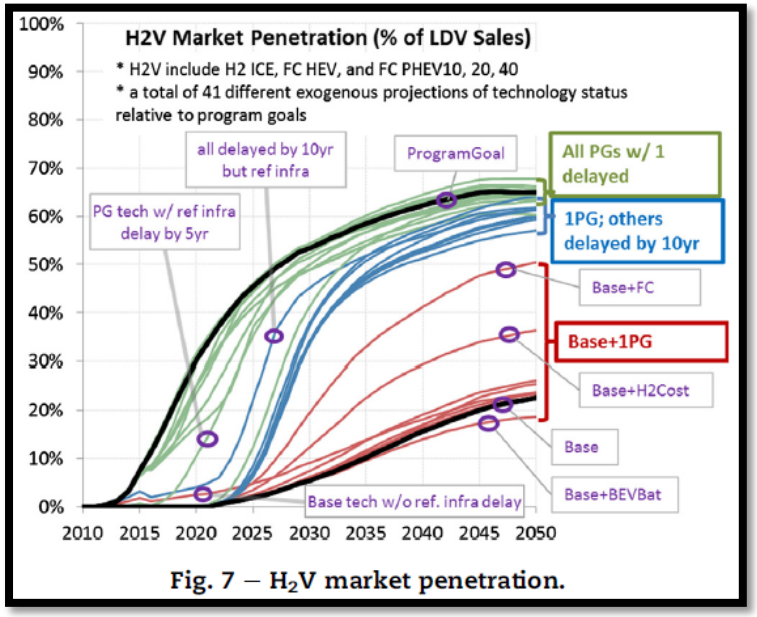



Fig. 7 – $H_2V$ market penetration.

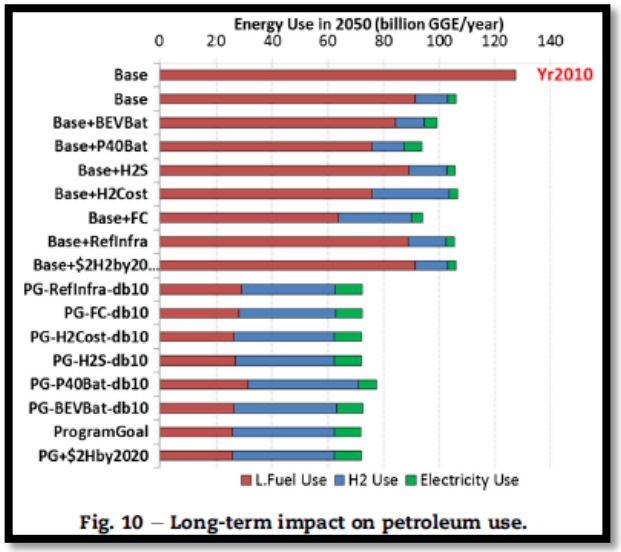



Fig. 10 – Long-term impact on petroleum use.

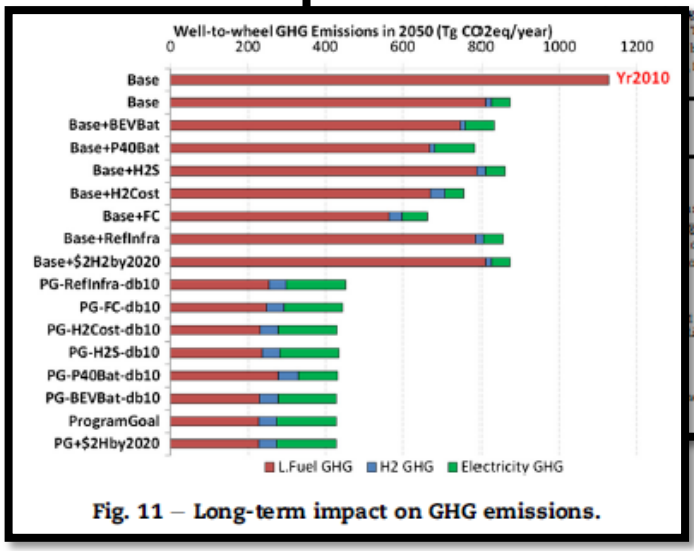
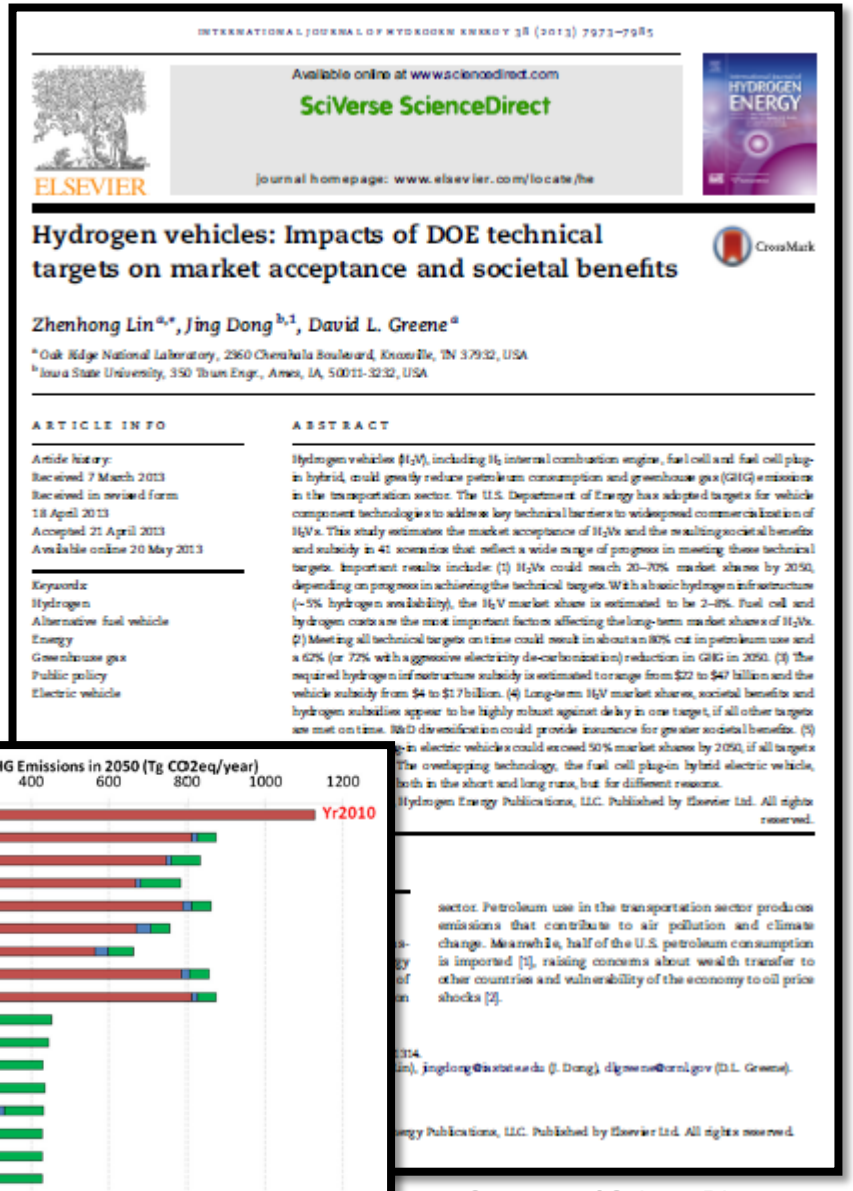



Fig. 11 – Long-term impact on GHG emissions.



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**Hydrogen vehicles: Impacts of DOE technical targets on market acceptance and societal benefits**

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ABSTRACT

Hydrogen vehicles ($H_2V$), including $H_2$ internal combustion engine, fuel cell and fuel cell plug-in hybrid, could greatly reduce petroleum consumption and greenhouse gas (GHG) emissions in the transportation sector. The U.S. Department of Energy has adopted targets for vehicle component technologies to address key technical barriers to widespread commercialization of $H_2Vs$. This study estimates the market acceptance of $H_2Vs$ and the resulting societal benefits and subsidy in 41 scenarios that reflect a wide range of progress in meeting these technical targets. Important results include: (1) $H_2Vs$ could reach 20–70% market shares by 2050, depending on progress in achieving the technical targets. With a basic hydrogen infrastructure (~5% hydrogen availability), the $H_2V$ market share is estimated to be 2–8%. Fuel cell and hydrogen costs are the most important factors affecting the long-term market shares of $H_2Vs$. (2) Meeting all technical targets on time could result in about an 80% cut in petroleum use and a 62% (or 72% with aggressive electricity de-carbonization) reduction in GHG in 2050. (3) The required hydrogen infrastructure subsidy is estimated to range from $22 to $47 billion and the vehicle subsidy from $4 to $17 billion. (4) Long-term $H_2V$ market shares, societal benefits and hydrogen subsidies appear to be highly robust against delay in one target, if all other targets are met on time. R&D diversification could provide insurance for greater societal benefits. (5) ...g-in electric vehicles could exceed 50% market shares by 2050, if all targets ... The overlapping technology, the fuel cell plug-in hybrid electric vehicle, ... both in the short and long runs, but for different reasons.




... sector. Petroleum use in the transportation sector produces emissions that contribute to air pollution and climate change. Meanwhile, half of the U.S. petroleum consumption is imported [1], raising concerns about wealth transfer to other countries and vulnerability of the economy to oil price shocks [2].


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# Approach: vehicle costs and fuel economies are based on ANL's Autonomie outputs

- Vehicle cost = retail price / markup factor
- Shown fuel economies for PHEVs are for charge sustaining mode