Advancing Technology for America's Transportation Future

A National Petroleum Council Study

presented by:
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&
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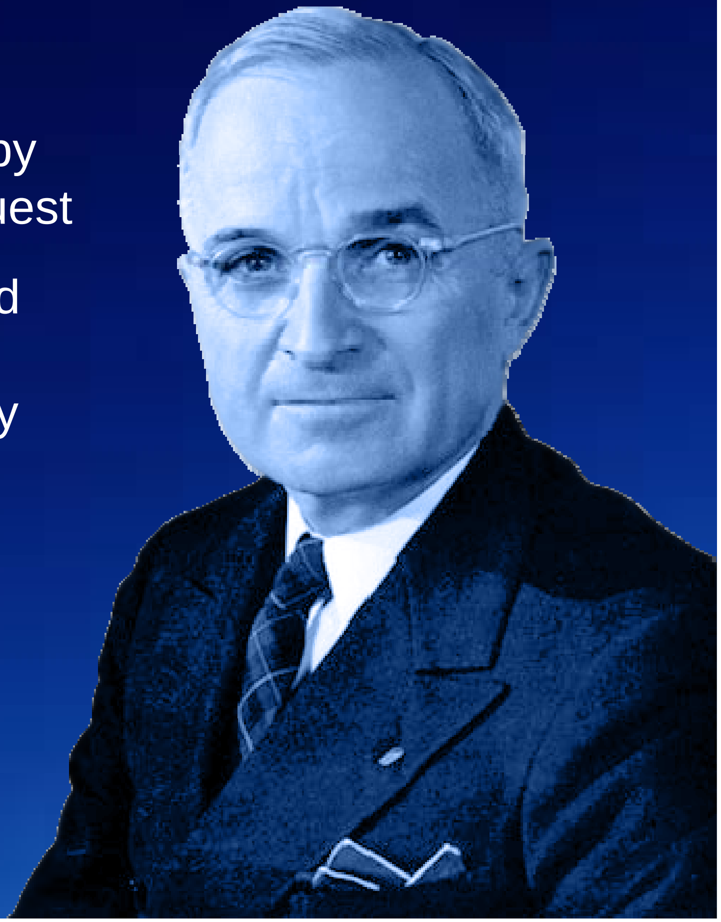
Overview

The National Petroleum Council (NPC)

Origins	Established in 1946 at the request of President Truman
Purpose	Advise the U.S. Secretary of Energy and Executive Branch by conducting studies at their request
Organization	Federally chartered, self-funded Advisory Committee; not an advocacy group; does not lobby



Overview

NPC Request From Energy Secretary Chu

Examine

opportunities to accelerate future prospects through 2050 for transportation fuels

Address

fuel demand, supply, infrastructure and technology

Consider

- Economic competitiveness
- Energy security
- Environment

Actions to stimulate the technological advances and market conditions needed to reduce greenhouse gas emissions in the U.S. transportation sector by 50 percent

Overview

Study Organization

National Petroleum Council

Committee on Future Transportation Fuels

Executive Committee Future Transportation Fuels

Chair
Clarence Cazalot, Jr. (Marathon)

Government Co-Chair
Daniel Poneman (DOE)

Vice Chair – Supply
John Watson (Chevron)

Vice Chair – Technology
John Deutch (MIT)

Vice Chair – Demand
James Owens (Caterpillar)

Secretary
Marshall Nichols (NPC)

Fuels Study Coordinating Subcommittee

Chair: Linda Capuano (*Marathon*)

Demand Task Group

Task Group Chair
Deanne Short *(Caterpillar)*

Supply and Infrastructure Task Group

Task Group Chair
Shariq Yosufzai (*Chevron)*

Technology Task Group

Task Group Chair
Stephen Brand *(ConocoPhillips)*

Overview
Varied Viewpoints From More Than 300 Participants

Hydrogen Subgroup

Chair

Anthony M. Boccanfuso	University of South Carolina

Assistant Chair

Puneet Verma	Chevron

Members

Nikunj Gupta	Shell Projects & Technology
Edward F. Kiczek	Air Products and Chemicals, Inc.
Todd Ramsden	National Renewable Energy Laboratory
Craig Scott	Toyota Motor Sales, U.S.A., Inc.
Ian Sutherland	General Motors Company
Matt I. Watkins	ExxonMobil Research & Engineering Company

Engaged other subject matter experts throughout the study period.

Study Approach

Consider accelerating the commercialization of alternative fuel-vehicle systems for 2050

1

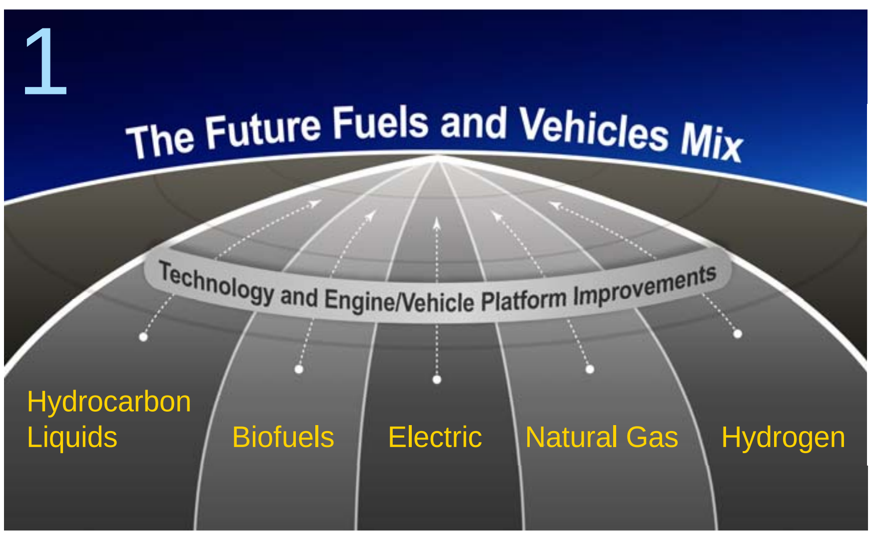
Analyze individual fuel and vehicle systems

2

Develop integrated portfolios with aggressive assumptions

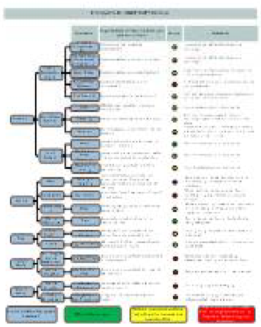
3

Create findings, recommendations and insights



Technology Assessment Methodology

1. Hurdle Charts



> 250 Technology and Non Technology Hurdles

2. Prioritisation Criteria

- Technology improvement needed to realize performance
- Technology improvement required to attain acceptable cost
- Technology improvement that would accelerate deployment
- Fuel dispensing infrastructure, how the pinchpoint supports infrastructure development
- How the pinchpoint can enable scaling to material volumes.

~30 Technology priorities

3. Critical Path

~20 Technology priorities

4a. Light Duty- GO/NO GO Analysis

Can the technology achieve wide scale material volumes if this technology hurdle is not resolved

11 Technology Priorities

4b. Medium/Heavy Duty cost/benefit

1 Technology Priority

Finding – Technology

12 Top Priority technology hurdles must be overcome

Identified 250 hurdles for the commercialization of all fuel/vehicle systems through a systematic process

Validated with top technology authorities

Top 12 were selected as the most important for achieving wide-scale commercialization

Focus Area	Twelve Priority Technologies
Light Duty Engines	Low-cost lightweighting (up to 30% weight reduction)
Biofuels	Hydrolysis
	Fermentation of C5 and C6 sugars
	Lignocellulose logistics and densification
	Production of higher value pyrolysis oil
	Biotechnology to increase food and biomass
Light-Duty Natural Gas	Leverage liquid ICE fuel economy technology
Light-Duty Electric	Lithium-ion battery energy density
	Lithium-ion battery degradation and longevity
Light-Duty Hydrogen	Compression and storage for dispensing
	Fuel cell degradation and durability
Medium/Heavy Duty Engines and Vehicles	Combustion optimization

Priority Technologies

Hurdles must be overcome for wide-scale commercialization of advanced fuel-vehicle systems by 2050

A broad portfolio of technology options provides the opportunity to benefit from potential disruptive innovations

1. Low cost lightweighting
   (up to 30 percent mass replacement)
2. Hydrolysis (reduction of volume enzymes and/or advances in chemical hydrolysis
3. Fermentation of C5/C6 sugars (develop microbes that can simultaneously ferment C5 and C6 sugars).
4. Lignocellulose logistics/densification (improve economics of transportation and long-term storage of localized biomass to increase scale of conversion plants)
5. Produce higher quality pyrolysis oil (improve bio-oil purity and stability to prevent poisoning hydrotreating catalysts)

Priority Technologies

6. Biotechnology to increase food/biomass (increase yield and productivity of land to meet both food and fuels needs
7. Lithium-ion battery energy density (increase stored energy per unit mass and/or volume
8. Lithium-ion degradation and longevity (increase both calendar life and cycle life)
9. Liquid ICE fuel economy technology (incorporate gasoline powertrain and platform technology in CNG light-duty vehicles for enhanced fuel economy.
10. Compression/storage for dispensing Reduce land, maintenance and capital requirements for hydrogen compression and storage
11. Fuel cell degradation and durability (increase both calendar life and cycle life
12. Combustion optimization Address four key areas: In-cylinder pressure and fuel injection, gas exchange, emerging CI technologies, and friction reduction

Finding Fuel Economy

- Fuel economy can be dramatically improved

  Lightweighting, rolling resistance, turbo charging, transmissions → continuous incremental improvements

  Up to 90% improvements in light duty fuel economy

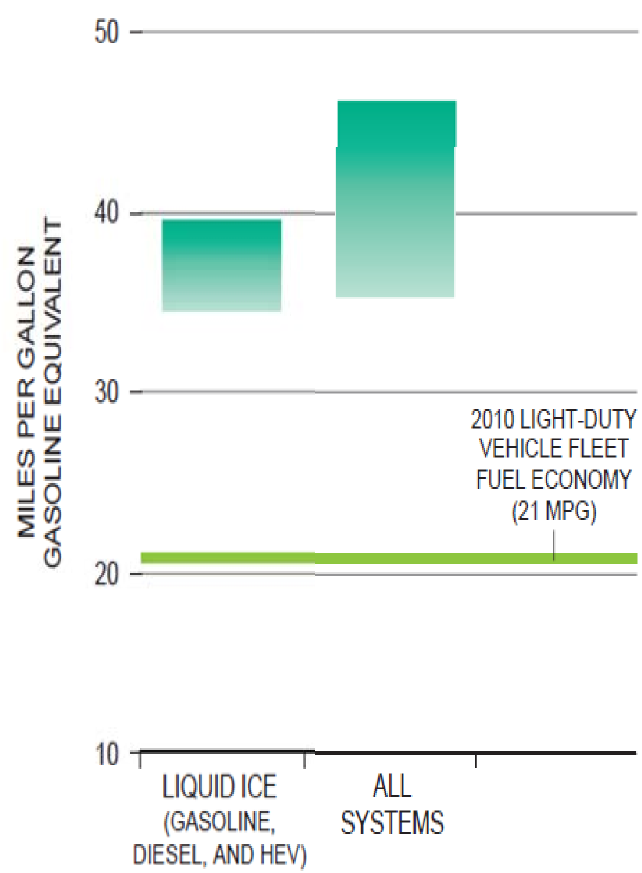
  Up to 100% improvement in heavy duty

- Internal combustion engines will continue to be dominant for decades to come

  Efficiency improvements and hybridization with liquid-fueled ICE's continue to challenge the economics of alternatives

  Many alternatives use ICE's (hybrids, plug-ins, natural gas)

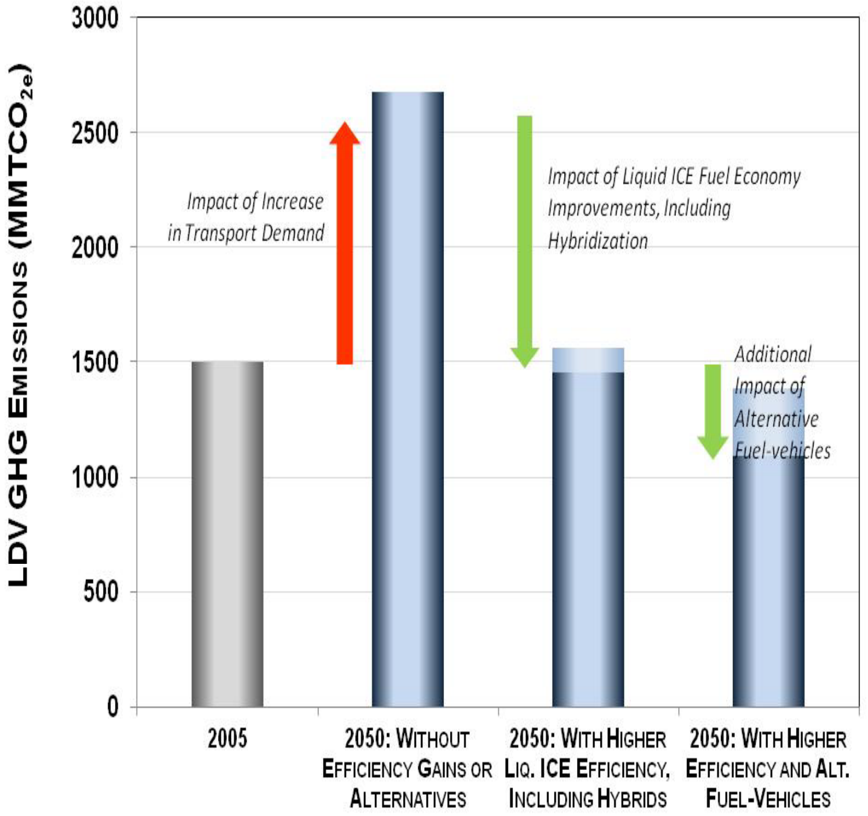
Range of Light-Duty Vehicle On-Road Fleet Fuel Economy in 2050



Finding - GHG

- Technology improvements will result in substantial reductions in GHG emissions on a per mile basis, however, these reductions will be offset by increased total miles traveled.
- GHG emissions per mile can improve by 40% or more, but increasing vehicle miles travelled would offset these gains.
- Reducing 2050 transportation sector emissions by half, relative to 2005 levels, would require additional strategies.

2050 Light Duty Fleet GHG Emissions



Finding - Infrastructure

Infrastructure challenges must be overcome for wide-scale commercialization

- Capital investments of $10s to $100s of billions are required for each new fuel option
- New infrastructure economics are challenged by low utilization
- Concurrent development of alternative fuel vehicles and infrastructure, such as leveraging existing infrastructure, corridor-deployment and multi-fuel vehicles

Fuel	Fuel Production (billion 2008$)	Dispensing (billion 2008$)
Compressed Natural Gas (CNG)	Not estimated	100-200
Hydrogen	30-90 (H2 from new Centralized Steam Methane Reforming)	275-430
Electricity	Not estimated	70-130
Advanced Biofuels	150-300	20-40 (includes distribution)
Liquefied Natural Gas (LNG)	40-60	10-20

Insights

Hydrocarbon liquids will continue to be a material portion in the future U.S. transportation system.

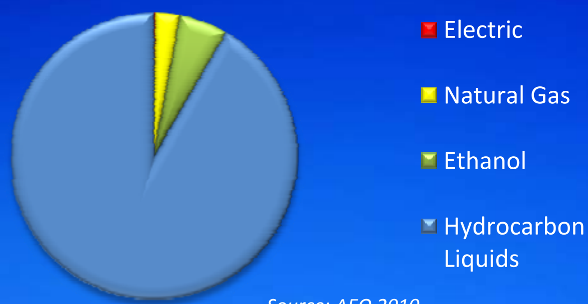
Internal combustion engines (ICE) will be a dominant technology for decades to come due to:

- Opportunities for continued, incremental fuel economy improvement
- Use of ICEs in alternatives such as hybrids, plug-in hybrids and natural gas engines

The biofuels industry cannot meet targets of the Renewable Fuels Standard 2 (RFS2).

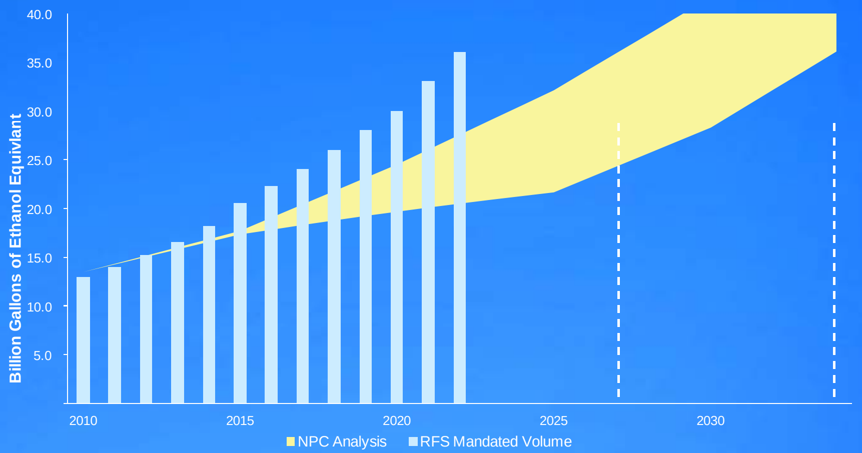
- Range of projections lag RFS2 by 5 to 10 years.

Transportation Energy Consumption by Source - 2035



Source: AEO 2010

Industry will be challenged to produce the biofuels volumes mandated under Renewable Fuels Standard 2 (RFS2)

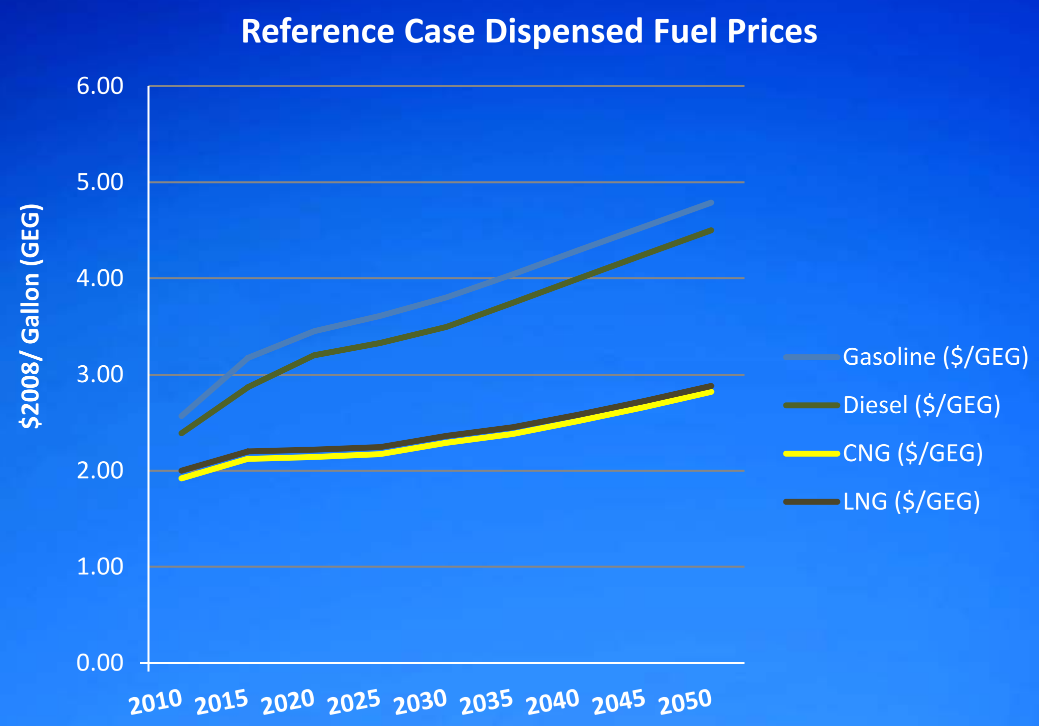


Insights

Natural gas vehicles have strong potential due to the fuel price differential.

Natural gas trucks can gain significant market share assuming:

- sustained natural gas price differential to oil per AEO 2010
- infrastructure and technology hurdles are overcome



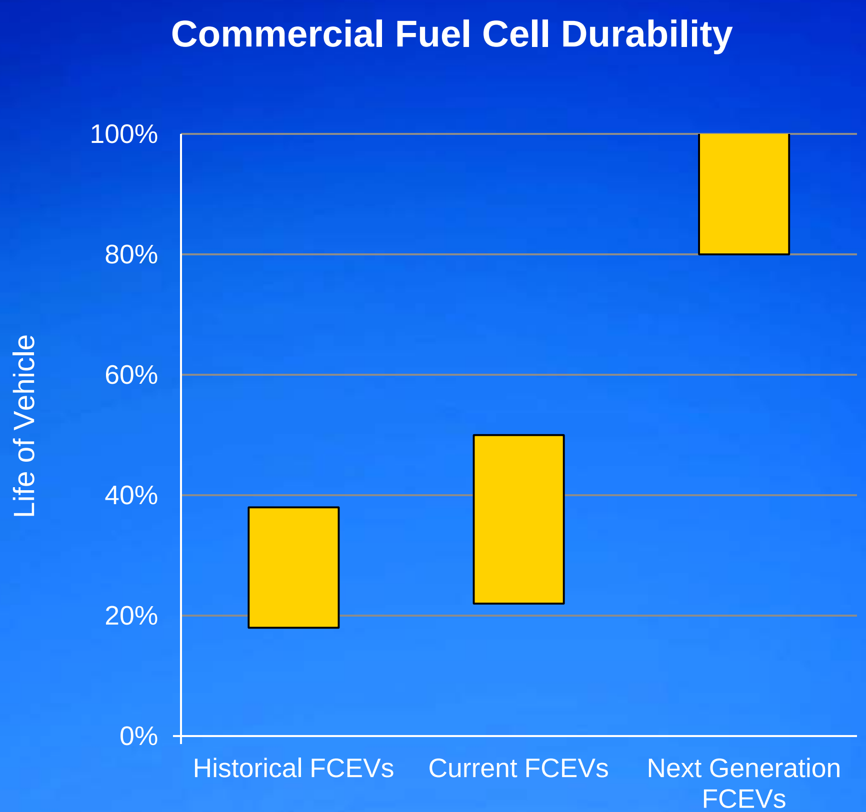
GEG: Gasoline Equivalent Gallon

Insights

Electric vehicles are challenged by battery issues such as battery cost, energy density, capacity degradation and longevity.

Hydrogen Fuel Cell vehicles are challenged by durability (life).

- Must be improved by a factor of two to be comparable to today's conventional vehicles



Based on vehicle operating life of 5000 hours/150,000 miles.
Data from DOE's Controlled Hydrogen Fleet and Infrastructure Demonstration and Project.

Hydrogen Technology Readiness

Fuel Cell Electric Vehicle

Technology Benefits	*Recent Achievements*	*Near Term Focus Areas*
☑ Vehicle efficiency	☑ Acceleration (stack power)	■ Durability & Degradation
☑ Zero tailpipe emissions	☑ Refueling time	■ Cost
☑ Low noise	☑ Interior space	
☑ Low vibration	☑ Sustained high power	
	☑ Freeze start	
	☑ Driving range	

Hydrogen Fueling Infrastructure

Technology Benefits	*Recent Achievements*	*Near Term Focus Areas*
☑ Domestic feedstock	☑ Distribution	■ Fuel cost
☑ Large-scale production	☑ Dispensing	■ Fueling network
☑ Low GHG emissions		■ On-site compression
		■ On-site storage

☐ Better than conventional ☐ Parity with conventional ■ Not at parity with conventional

Hydrogen Benefits & Challenges Summary

Benefits

- Compared to today's conventional light duty vehicles, GHG emissions can be reduced ~50% on a well to wheels basis by the deployment of FCEVs operating on hydrogen produced from natural gas.
- FCEV technology is applicable across all light duty vehicle segments.
- Existing hydrogen production capacity can be leveraged for early fueling infrastructure de ployment.
- As compared to other fuels, hydrogen dispensed fuel costs are less sensitive to changes in feedstock costs because capital infrastructure costs and taxes make up a greater proportion of the final fuel cost.

On-Going Challenges

- Fuel cell durability (life) improvements of 2X are needed to be comparable to today's conventional vehicles, based on publicly available fleet demonstration data.
- An early market value proposition for FCEVs is needed because the first generation(s) of commercial FCEVs are not expected to be cost-competitive with conventional vehicles.
- The economic viability for hydrogen fueling infrastructure is significantly dependent on scale of fueling capacity and utilization of installed fueling capacity.
- Technology advancements in compression and on-site-storage are needed and can provide reductions in capital costs, operating costs, and land requirements and can improve station reliability.

Overall Study Recommendations

1. Government should promote sustained funding and other resources – either by itself or in combination with industry – in pre-competitive aspects of the *12 Priority Technology areas* identified, as well as in areas that could lead to disruptive innovations

2. There is a great deal of uncertainty regarding which individual fuel-vehicle systems will overcome technology hurdles to become economically and environmentally attractive by 2050. Therefore, government policies should be technology neutral while market dynamics drive commercialization

3. The Federal Government should take a leadership role in convening state, local, private sector and public interest groups to design and advocate measures to streamline the permitting and regulatory processes in order to accelerate deployment of infrastructure

Overall Study Recommendations

4. Government should consider full lifecycle environmental impact and cost effectiveness across all sectors when evaluating GHG emission reduction options. It should also continue to advance the science behind the assessment methodologies and integrate lifecycle uncertainty into policy frameworks

5. Fuel, vehicle and technology providers should consider existing or new voluntary forums that include federal and state governments and other stakeholders, to address concurrent development of vehicles and infrastructure

Thank You