Advancing Technology for America’s Transportation Future
A National Petroleum Council Study

presented by:
Dr. Anthony Boccanfuso & Puneet Verma
## Overview

### The National Petroleum Council (NPC)

<table>
<thead>
<tr>
<th>Origins</th>
<th>Established in 1946 at the request of President Truman</th>
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<tbody>
<tr>
<td>Purpose</td>
<td>Advise the U.S. Secretary of Energy and Executive Branch by conducting studies at their request</td>
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<tr>
<td>Organization</td>
<td>Federally chartered, self-funded Advisory Committee; not an advocacy group; does not lobby</td>
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### Overview

**NPC Request From Energy Secretary Chu**

<table>
<thead>
<tr>
<th>Examine</th>
<th>Address</th>
<th>Consider</th>
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<tbody>
<tr>
<td>opportunities to accelerate future</td>
<td>fuel demand, supply, infrastructure and</td>
<td>- Economic competitiveness</td>
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<tr>
<td>prospects through 2050 for</td>
<td>technology</td>
<td>- Energy security</td>
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<tr>
<td>transportation fuels</td>
<td></td>
<td>- Environment</td>
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<td></td>
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<td>Actions to stimulate the technological advances and market conditions</td>
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<tr>
<td></td>
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<td>needed to reduce greenhouse gas emissions in the U.S.</td>
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<td></td>
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<td>transportation sector by 50 percent</td>
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# Overview

## Study Organization

### National Petroleum Council

#### Committee on Future Transportation Fuels

#### Executive Committee Future Transportation Fuels

<table>
<thead>
<tr>
<th>Chair</th>
<th>Government Co-Chair</th>
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<tbody>
<tr>
<td>Clarence Cazalot, Jr. (Marathon)</td>
<td>Daniel Poneman (DOE)</td>
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<tr>
<th>Vice Chair – Supply</th>
<th>Vice Chair – Technology</th>
<th>Vice Chair – Demand</th>
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<tbody>
<tr>
<td>John Watson (Chevron)</td>
<td>John Deutch (MIT)</td>
<td>James Owens (Caterpillar)</td>
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<th>Secretary</th>
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<td>Marshall Nichols (NPC)</td>
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### 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

The Future Fuels and Vehicles Mix

- Technology and Engine/Vehicle Platform Improvements
- Hydrocarbon Liquids
- Biofuels
- Electric
- Natural Gas
- Hydrogen

Developed integrated portfolios with aggressive assumptions

Economic competitiveness
Energy security
Environment

Oil Price:
- Lower Price
- Reference Price
- Higher Price

Technology Assumptions:
- Aggressive Technology
- Less Aggressive Technology
Technology Assessment Methodology

1. Hurdle Charts

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

3. Critical Path

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
   - 11 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

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

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<tbody>
<tr>
<td>Compressed Natural Gas (CNG)</td>
<td>Not estimated</td>
<td>100-200</td>
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<tr>
<td>Hydrogen</td>
<td>30-90 (H2 from new Centralized Steam Methane Reforming)</td>
<td>275-430</td>
</tr>
<tr>
<td>Electricity</td>
<td>Not estimated</td>
<td>70-130</td>
</tr>
<tr>
<td>Advanced Biofuels</td>
<td>150-300</td>
<td>20-40 (includes distribution)</td>
</tr>
<tr>
<td>Liquefied Natural Gas (LNG)</td>
<td>40-60</td>
<td>10-20</td>
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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.
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
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.

Commercial Fuel Cell Durability

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**
- ✓ Vehicle efficiency
- ✓ Zero tailpipe emissions
- ✓ Low noise
- ✓ Low vibration

**Recent Achievements**
- ✓ Acceleration (stack power)
- ✓ Refueling time
- ✓ Interior space
- ✓ Sustained high power
- ✓ Freeze start
- ✓ Driving range

**Near Term Focus Areas**
- □ Durability & Degradation
- □ Cost

**Hydrogen Fueling Infrastructure**

**Technology Benefits**
- ✓ Domestic feedstock
- ✓ Large-scale production
- ✓ Low GHG emissions

**Recent Achievements**
- ✓ Distribution
- ✓ Dispensing

**Near Term Focus Areas**
- □ Fuel cost
- □ Fueling network
- □ On-site compression
- □ On-site storage
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 deployment.
- 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