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SUMMARY REPORT

Natural Gas and Hydrogen
INFRASTRUCTURE OPPORTUNITIES
WORKSHOP

October 18–19, 2011
Argonne National Laboratory | Argonne, IL

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Bill Liss (Gas Technology Institute),
Brian Bonner (Air Products and Chemicals, Inc.), and
Matt Fronk (Matt Fronk & Associates)

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Natural Gas and Hydrogen Infrastructure Opportunities Workshop

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EXECUTIVE SUMMARY

Introduction

The overall objective of the Workshop was to identify opportunities for accelerating the use of both natural gas (NG) and hydrogen (H_2) as motor fuels and in stationary power applications. Specific objectives of the Workshop were to:

1. Convene industry and other stakeholders to share current status/state-of-the-art of NG and H_2 infrastructure.

2. Identify key challenges (including non-technical challenges, such as permitting, installation, codes, and standards) preventing or delaying the widespread deployment of NG and H_2 infrastructure. Identify synergies between NG and H_2 fuels.

3. Identify and prioritize opportunities for addressing the challenges identified above, and determine roles and opportunities for both the government and industry stakeholders.

The Workshop was attended by approximately 50 participants, with representation from natural gas and hydrogen producers and suppliers, vehicle manufacturers, alternative vehicle agencies, fuel cell developers, academia, national laboratories, and government agencies. The Workshop agenda is given in Appendix A, and a list of the Workshop attendees is given in Appendix B.

Plenary speakers and panel discussions summarized the current status of the NG and H_2 infrastructure, technology for their use in transportation and stationary applications, and some of the major challenges and opportunities to more widespread use of these fuels. Two break-out sessions of three groups each addressed focus questions on: (1) infrastructure development needs; (2) deployment synergies; (3) natural gas and fuel cell vehicles (NGVs, FCVs), specialty vehicles, and heavy-duty trucks; (4) CHP (combined heat and power), CHHP (combined hydrogen, heat, and power), and synergistic approaches; and (5) alternative uses of natural gas.

The results of the discussions at the Workshop are summarized below. The descriptions represent the output of the discussions among the Workshop participants rather than the views or recommendations of the DOE or of specific individuals or industries.

Current Status/State-of-the-Art for Natural Gas and Hydrogen Infrastructure

The following key points were highlighted in the plenary talks.

- The current NG infrastructure includes more than 300,000 miles of transmission and 2,000,000 miles of distribution pipelines.

- Switching internal combustion engine (ICE) fuel from gasoline to compressed natural gas (CNG) can reduce greenhouse gas (GHG) emissions (g-CO_2 equivalent/mile) by ~21%. Converting NG to H_2 for FCVs can yield an additional ~25% reduction in GHG emissions. If the central station reforming of NG to H_2 is also accompanied with carbon capture and sequestration, the use of H_2 FCVs can lead to nearly 100% reduction in GHG emissions, compared to conventional vehicles.

- Vehicle technology for NGVs does not require any breakthrough developments. The technology exists for operating ICEs on CNG or liquefied natural gas (LNG). Current ICEs will need to be modified for use with NG, however, which would add to the initial cost of the NGV. Simply adding NGVs at the rate of growth and scrap replacement would require several decades to achieve significant penetration of NGVs into the U.S. fleet of light-duty and heavy-duty vehicles.

- The 2.6 million Class 8 long-haul trucks in the U.S. fleet consumed 9.4% of the total petroleum used in 2010, an amount that is comparable to the amount of oil the United States imports from Saudi Arabia.

- NGVs already have a viable market niche in medium- and heavy-duty vehicles, but the cost of NGVs remains high. Just the NG fuel conversion package for General Motors' cargo vans costs $15,000, in addition to the cost of the standard vehicle.

- There are three major pathways for the use of NG in transportation:

1. CNG ▶ NGV hybrid: 28% efficiency, 250-mile range;
2. NG ▶ H_2 ▶ FCV: 36% efficiency, 400-mile range; and
3. NG ▶ Electricity ▶ BEV (battery electric vehicle): 24% efficiency, 100-mile range.

- A major opportunity for the increased use of NG in transportation is presented by the large price difference between NG ($12/million BTU) and gasoline/diesel ($22/million BTU)[1]; this difference is projected to grow in the future, with NG at $13/million BTU and gasoline/diesel at $28/million BTU by 2025 (in constant 2009 dollars).

- The U.S. automobile manufacturers (original equipment manufacturers [OEMs]) plan to offer gasoline vehicle conversion to NG fuel through their dealers starting in 2012, which is expected to lower conversion/certification costs.[2]

- Of the NG and gasoline light-duty vehicles available in the market today, the Honda Civic CNG vehicle has a fuel economy of 28 miles per gallon of gasoline equivalent and annual emissions of 5.6 tons of CO_2, compared to 50 miles per gallon and 3.8 tons of CO_2 for the Toyota Prius Hybrid vehicle, and 41 miles per gallon and 4.6 tons of CO_2 for the Honda Civic Hybrid vehicle. Note, however, that the Honda Civic CNG vehicle is not a hybrid vehicle.

- Light-duty gasoline hybrid vehicle sales peaked in 2008 at 3%–4% of new car sales, and that fraction has not grown since, in spite of a near doubling of the number of hybrid vehicle models available for sale since 2008.

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1 The commodity price of natural gas in mid January 2012 was less than $3.00/million BTU. The $12/million BTU price of natural gas indicated here includes estimated motor vehicle fuel taxes and estimated dispensing costs. The $22/million BTU price for gasoline represents the weighted average price for all grades, and it includes Federal, State, and local taxes. The diesel fuel price is for on-road use, and it includes Federal and State taxes, but it excludes county and local taxes.

2 On February 1, 2012, Navistar, Inc., the third-largest seller of heavy-duty trucks in the United States, announced that they will begin offering NG-fueled engines across their line of medium- and heavy-duty trucks this year. Navistar also announced a partnership with Clean Energy Fuels Corp. to add 70 NG fueling stations at Pilot-Flying J Travel Centers in 33 states by the end of 2012. Navistar will also offer an incentive program to help offset the additional cost of the vehicles, including a guarantee that fuel prices will remain below those of diesel fuel for 5 years (Chicago Tribune, Thursday, February 2, 2012).

Addressing Key Challenges for Increased Use of Natural Gas and Hydrogen Fuels

The following actions were suggested as necessary to address the key obstacles to increased use of NG and H_2 as motor fuels and in stationary applications.

- Resolve the chicken-and-egg dilemma between the availability of vehicles and the availability of NG/H_2 fuels, by establishing partnerships between vehicle manufacturers, fuel providers, the government (both in the United States and globally), and other stakeholders.

- Develop long-term incentives for the use of NG/H_2 (and perhaps disincentives for gasoline/diesel vehicles).

- Develop improved, lower cost components and processes (such as lower-cost home-fueling and better compressor and dispensing equipment) by exploiting the many technology and hardware synergies between the two fuels.

- Reduce costs of, and procedural barriers to, setting up NG and H_2 fueling stations.

- Reduce costs of, and procedural barriers to, NGV emissions certification.

- Harmonize U.S. and international codes and standards. For example, at present, European NGVs cannot be imported because they do not meet U.S. certification regulations.

- Develop technologies for improved on-board storage of the fuels, where the current technologies limit driving range.

- Develop enhanced materials that are compatible with both NG and H_2, and reduce the balance-of-plant costs by exploiting synergies between the two fuels.

- Promote the deployment of CHP/CHHP systems and NGV/FCV refueling stations at the neighborhood scale to expand NG uses in stationary applications.

Roles and Opportunities for Government and Industry Stakeholders

Workshop participants identified potential roles and opportunities for government and industry, respectively, in the following key areas.

Infrastructure Development

- Establish long-term (>10 years) strategic plans and incentives for NG and H_2 fuels:
  - Institute tax and investment credits;
  - Develop uniform codes and standards;
  - Establish corporate average fuel economy (CAFE) and zero emission vehicle (ZEV) mandates;
  - Involve States as active participants; and
  - Develop a national plan rollout, similar to those in Germany and Japan.

- Establish disincentives for oil-derived fuels for vehicles:
  - Tax carbon use or GHG emissions;
  - Maintain minimum (high) gasoline/diesel prices (perhaps through taxes); and
  - Use disincentive tax revenues to fund NG/H_2 infrastructure growth.

- Reduce cost to OEMs of meeting safety and emissions standards:
  - Establish tradable CAFE credits;
  - Develop standardized, pre-certified components;
  - Use Global Technical Regulation as a baseline in the United States; and
  - Harmonize qualification requirements globally.

Synergies between Natural Gas and Hydrogen

- Make NG and H_2 part of a comprehensive strategy for transportation fuels:
  - Define a vision/strategy;
  - Develop a commercialization plan; and
  - Identify applications and end-users that exemplify the significant advantages of using these gaseous fuels.

- Promote on-site H_2 from NG, using CHP/CHHP, for early build-out of H_2 infrastructure:
  - Inventory current technology options and re-evaluate for adapting NG technology to H_2 applications;
  - Research small-scale reforming for on-site H_2 production; and
  - Ramp up production volumes of cars and fuel processors to reduce unit costs.

Priorities for Gaseous Fuel Vehicles (NGVs and FCVs)

- Develop additional vehicle models that use CNG- and LNG-fueled ICEs to cover a wide spectrum of vehicle platforms:
  - Define targets for different categories of engines;
  - Increase number of NG refueling stations for Class 8 trucks; and
  - Ease market entry for the new vehicles.
- Conduct technology research and development:
  - Fuel metering, storage tanks, fueling stations;
  - Low-cost carbon fiber;
  - Conformable and higher capacity storage tanks for H_2 and NG; and
  - Standardized dispensing hardware and process to reduce costs and improve the fueling experience.

Summary Highlights of the Breakout Group Discussions

The breakout sessions addressed specific questions but solicited general input, as well. Facilitators provided note cards and prioritized the identified key issues and suggested actions (by voting) in five areas. The following summaries capture the main points, while more detailed/raw comments are given in Appendix C.

Infrastructure Development

There is a need for policies to provide long-term (>10 years) incentives for NG and H_2 fuels, while imposing disincentives for the use of gasoline and diesel fuel in vehicles. Development of low-cost, widely deployable fueling technologies (including home fueling), compressors, and storage tank advancements is needed. Creating demand for these fuels is the best strategy for expanding infrastructure. Harmonization of codes and standards and education of the code officials are necessary for general acceptance. The chicken-and-egg dilemma can be addressed through partnerships between fuel providers, vehicle manufacturers, and the government (via deployment incentives for both vehicles and infrastructure, and research and development funding).

Deployment Synergies between Natural Gas and Hydrogen

It is necessary to develop a comprehensive strategy encompassing both fuels, across a multitude of transportation and stationary applications, with supporting funding. There are synergies in H_2 and H_2-NG blends, both of which are produced from NG. They have similar storage and regulatory concerns, as well. It may be necessary to build clusters of refueling centers to support a critical mass of vehicles.

Natural Gas and Hydrogen Vehicles

Vehicle technology, especially for NGVs, does not require any breakthrough developments. However, having a wider array of engine options than is currently available would help to expand the deployment of NGVs and the infrastructure to support them. Current emissions regulations constrain the deployment of heavy-duty NGVs. In addition, to expand NGV and FCV deployment we need to improve the NG and H_2 refueling network, especially along the major commercial corridors. Technical development needs include advanced and reliable metering for fuel dispensers, and on-board storage tanks with higher capacities.

Combined Heat and Power and Combined Hydrogen, Heat, and Power Synergistic Approaches

The use of CHP and CHHP at the neighborhood scale, and at other distributed locations that can also serve as refueling centers, is a very promising pathway. The cost and durability of such units present two significant technical barriers, however. These systems can be promoted through collaborative ventures with utilities, and they would benefit if given the same status as renewable energy systems in Federal energy policy.

Alternative Uses of Natural Gas

Faster expansion of NG use can be facilitated by setting up consuming applications, such as refueling centers for trucks and machinery, near the wellheads and by using NG-fueled turbines to buffer intermittent wind power. H_2 can be blended with NG to increase the efficiency of ICEs, while fuel cell systems can be used for lighting and power for special applications. H_2 can also be used by utilities for energy storage for variable or intermittent renewable energy. Use of NG and H_2 can be promoted through demonstrations by the aircraft industry (flight and ground), and at community-scale refueling centers.

General Themes

There is a strong need for a consistent, long-term energy policy, including incentives—such as tax credits, subsidies, and regulations—for NG and H_2 fuels and their uses in transportation and stationary applications. Lacking such assurances for at least 10 years, it would be difficult to attract industry or venture capital resources to build up the needed NG and H_2 infrastructure.

There is a need for a vision of the future, and plans and processes needed to realize that vision. Collaboration between government and industry is needed to achieve this. Examples of such collaboration can be seen in Germany (OEMs, oil and energy companies, government, and NOW GmbH) and Japan (OEMs, oil and gas suppliers), where large numbers of fueling stations and FCVs are to be deployed starting in 2015.

Another example is the proposed East Coast/National Hydrogen Infrastructure Development Plan, a public/private partnership of OEMs, H_2 suppliers and associated industry, government, and academia; the proposed roll-out is to begin in 2015, leading to 50,000 cars and 100 fueling stations in New York State by 2020.

It is also necessary to conduct analyses to convince policymakers, to advance fuel storage technologies, and for the DOE to develop a roadmap to promote the use of NG in medium- and heavy-duty vehicle segments, with subsequent expansion to the light-duty vehicle marketplace.

Next Steps and Path Forward

Potential next steps were identified in research and development, codes and regulations, financing concepts, business and community leadership, and building on past successes.

Research and Development

Research is needed to develop low-cost, conformable, lower pressure (sorbent-based) on-board CNG tanks, low-cost tanks and systems for off-board storage at the fueling stations, and low-cost, efficient compressors for both NG and H_2 fuels.

Codes and Regulations

Codes and regulations need to be harmonized across the United States and globally, including legislation to level the playing field among the different technology options; the current varying codes and regulations across the United States tend to inhibit the growth of standardized elements of the infrastructure. Also needed are activities with a large multiplier effect, such as educating/training fleet maintenance operators, code officials, fire marshals, and other safety personnel, with the involvement of State and local governments. For example, South Carolina is promoting statewide uniform permitting for H_2 and fuel cells at the local level.

Financing Concepts

The investment community needs to become involved to get more financing ideas. Existing infrastructure incentives need to be publicized. The DOE should issue an RFI (request for information) on how best to facilitate the development of financial tools, such as infrastructure bonds or franchise zones, where organizations could bid for installing H_2 stations, similar to what was done for off-shore wind power installations. For these and other incentives, such as tax credits, timing is very important; if they are not provided at the right time, they will not be effective.

Business and Community Leadership

There is a lack of involvement by business and community leaders in developing NG and H_2 infrastructure, but this involvement is necessary in planning for the infrastructure build-out. Several States have already taken initiatives in this area, including California, New York, Connecticut, and South Carolina. The Federal government should work with the officials of those States, senior management/CEOs of NG and H_2 suppliers, OEMs, and other stakeholders (such as vendors to the NG and H_2 industries). A plan developed jointly by all involved parties should spell out the reality of NG and H_2 vehicles being marketed, when, where, and in what numbers, to identify the needed elements of the infrastructure buildup.

Building on Past Successes

The DOE needs to publicize past success stories in NG and H_2, in particular, instances when the DOE has been a catalyst for demonstrations that resulted in companies buying more of the technology because they could readily see a viable business case. For example, the DOE FCT Program R&D has led to 310 patents that have fostered the development of more than 30 commercial and 63 emerging technologies. South Carolina is another example of a success story to publicize. The DOE can quantify the benefits of the funding provided under ARRA (American Recovery and Reinvestment Act) and existing tax credits to show how the taxpayer has benefited.

Post Script

After the Workshop, the participants were asked to provide feedback via a short Internet survey. The survey questions and the responses (from ~20% of the attendees) are given below.

1. What were the top three most valuable outcomes for you at the Workshop?
   - Review of status of NG infrastructure and NGVs, understanding the challenges, brainstorming solutions, and getting a vision of future trends.
   - Identification of critical needs in (1) certification and education of code officials, and (2) tank issues for NG, not just for H_2.
   - Confirmation of the DOE's strong interest in developing NG and H_2 infrastructure and use in transportation and stationary applications.

2. What were the top three remaining items you would like to see addressed?
   - Bringing together NG and H_2 industry, OEMs, research and development institutions, and the government for the planning and execution of the infrastructure and use, as done in Germany and Japan.
   - Gain better understanding of OEM LNG heavy-duty vehicle development and light-duty vehicle conversion to CNG, and the cost hurdles associated with emissions certification.
   - The gas utilities stand to be big winners from the widespread deployment of NGVs and FCVs, but they were not represented at the Workshop.

3. Any other comments or suggestions?
   - Need follow-up workshops to bring together stakeholders and maintain momentum.
   - More focused future meetings. Major NG infrastructure and NG power generation at the MW scale are both mature technologies. Need to focus on where the challenges are in using NG and H_2 for vehicles and distributed CHP.
   - Future workshops should be at an AGA convention or similar meeting where gas utilities can attend, be informed, and participate, with little additional cost.

Miscellaneous Ratings (% of respondents)

	Excellent	Good	Fair	Poor
Workshop Structure and Content	70	20	10	0
Plenary Presentations	60	40	0	0
Panel discussions	80	20	0	0
Breakout Group Discussions	60	20	20	0
Meeting Arrangements	60	40	0	0

SUMMARY OF PLENARY PRESENTATIONS

Workshop Goals, Objectives, and Desired Outcomes – Steve Chalk (DOE)

(See Appendix D for the presentation slides)

The overall objective of the Workshop was to help accelerate the use of both NG and H_2 for motor fuels and stationary power applications. As part of the process to achieve this objective, we need to identify and prioritize the key technical and non-technical challenges that are inhibiting the widespread deployment of NG and H_2 infrastructure and the development of motor vehicles and distributed combined heat and power systems as the end-use applications. We also need to determine the respective roles of industry (NG industry and vehicle manufacturers) and government in bringing about the desired growth in the production, distribution, and use of NG and H_2 fuels.

Natural gas is a domestic resource with very large energy security benefits. The infrastructure currently includes 300,000 miles of transmission and 2 million miles of distribution pipelines in place. There are nearly 1000 NG vehicle fueling stations, about half of which are available to the general public. In addition to its use as a motor fuel, tri-generation (i.e., combined hydrogen, heat, and power generation) offers a potentially significant opportunity for the growth of the NG infrastructure.

There are currently about 2.6 million long-haul Class 8 trucks in the United States, which consumed 9.4% of the total oil consumed in 2010. Switching this entire fleet of heavy-duty trucks to LNG would eliminate an amount of petroleum that is comparable to the amount the United States imports annually from Saudi Arabia. Although such a switch is technically feasible, there would be an initial added cost of about $40,000/truck, in addition to the infrastructure costs. The advantages of switching to LNG would be substantially lower fuel costs, with the needed fuel being completely domestic. However, a significant challenge for implementing the switch to LNG (and CNG for medium- and light-duty vehicles) is the need for 1,000–5,000 new NG fueling stations along the major U.S. transportation networks (i.e., major Interstate and U.S. highways), which would require significant private industry investment or new financing mechanisms. In addition, the $40,000 cost difference between an NG-fueled truck and a conventional diesel-fueled truck needs to be reduced by engineering research and development and volume production.

For FCVs fueled with H_2 generated by distributed NG reforming, GREET lifecycle analyses show the potential for a more than 50% reduction in GHG emissions compared to current vehicles, as well as an almost complete elimination of petroleum use in light-duty vehicles. Compared to the current annual U.S. NG consumption of 22.2 tcf (trillion cubic feet), the impact of adding 1 million FCVs on the annual U.S. NG use would be about 0.035 tcf (i.e., <0.2%). The production of H_2 from NG decouples carbon from end use; it allows carbon emissions to be managed at the point of fuel production rather than at the vehicles' tail pipes. At high volumes of production, the cost of hydrogen per gallon gasoline equivalent (gge) is projected to be:

- $3.00 to $4.00 for distributed NG reforming, with NG at $4.50 to $10/million BTU (January 2012 commodity NG price is less than $3.00/million BTU);
- $4.60 to $5.70 for electrolysis and reforming of pyrolysis oil;
- $2.70 for centralized production from renewables (at the plant gate); and
- $5.00 or less for photovoltaic (PV) electrolysis, if SunShot targets are met (i.e., $1/watt for PV cells/modules).

U.S. Natural Gas Markets and Perspectives – Bill Liss (GTI)

(See Appendix E for the presentation slides)

The major NG industry segments are exploration, production, transmission, storage, and distribution. The current U.S. NG infrastructure includes 305,000 miles of transmission pipeline, 2 million miles of distribution pipelines, and 400 storage fields. Industry investments run to $6–10 billion/year in interstate pipelines, and $12 billion (in 2010) in the distribution infrastructure. The major consumers of NG are 500 electric power generation plants (7.4 tcf), 2,000 industrial plants (6.6 tcf), 5 million commercial businesses (3.2 tcf), and 63 million homes (5.0 tcf).

The recent big story is a robust and expanding NG supply, with substantial NG supply additions (>100 times current annual consumption) in the past 5 years in many different regions of the lower 48 States.

At present, the major growth in NG demand is for power generation (to replace older coal-fired plants), from ~7 tcf in 2011 to ~9 tcf by 2020. While interest in NG for vehicles is growing sharply, the direct use is very small, only ~0.04 tcf (combined CNG and LNG). The core NGV markets are in the medium- and heavy-duty vehicle segments, where the interest is being driven by the large fuel price difference between NG and gasoline/diesel fuels. Use of NG in light-duty vehicles, perhaps with home fueling, is a longer term prospect.

The main challenges to increasing the use of NG for transportation are the relatively high initial vehicle cost, insufficient on-board storage capacities, and an inadequate fueling infrastructure.

Synergies in Natural Gas and Hydrogen Fuels – Brian Bonner (APCI)

(See Appendix F for the presentation slides)

Compared to the NG annual consumption of over 22 tcf, the consumption of H_2 is a little over 3 tcf/year, the bulk of which is in petroleum refining (67%) and the manufacture of chemicals and petrochemicals (31%). A strong driver for the use of NG in transportation (as CNG, LNG, gas-to-liquid fuels, or reformed to H_2) is the comparatively low price of NG. This price is projected to remain steady or grow slowly, but still be one-half to one-third the price of electricity, gasoline, or diesel on an equivalent BTU basis.

H_2 is currently derived primarily from NG. The next step in H_2 feedstock evolution is expected to be large-scale renewable H_2 from biomass, which could supply 395 million H_2 FCVs (i.e., more than the entire U.S. light-duty vehicle fleet). The ultimate step of obtaining H_2 from renewable electricity (solar, wind, geothermal) would be regional and relatively long term, although it has the potential to fuel the entire U.S. vehicle fleet. Scale, affordability, and footprint are the issues with renewable H_2 production via electrolysis.

A second driver for the use of NG and H_2 in transportation is the reduction in GHG emissions. The emissions of CO_2 from gasoline-fueled vehicles are 410–540 grams/mile, while those from a NG-fueled vehicle would be 320 grams/mile and from a H_2-fueled FCV would be 250 grams/mile.

NG and H_2 both promote energy independence, and both are environment-friendly. Although the two gaseous fuels have many similarities, the current codes and standards make it difficult for one fueling station to dispense both fuels.

Finally, to promote market pull and acceptance of these fuels, we need a broad spectrum of NGVs and FCVs in the marketplace to develop and commercialize the technologies. This may be facilitated by the formation of partnerships among the fuel suppliers, vehicle manufacturers, and the government.

NGV and FCV Light Duty Transportation Perspectives – Matt Fronk (Matt Fronk and Associates, LLC)

(See Appendix G for the presentation slides)

The corporate average fuel economy (CAFE) standard for LDVs is set to increase to 54.5 miles per gallon (mpg) by the 2025 model year. This standard will be difficult to meet with current automotive technologies. Just switching fuels from gasoline (or diesel) to NG will not be sufficient, either. Meeting the 2025 CAFE standard will call for a portfolio of technologies, rather than a single approach, to meet the diverse needs of the marketplace.

There are three predominant energy carriers for use on-board vehicles: liquid fuels, such as gasoline and diesel; gaseous fuels, such as NG and H_2; and batteries (electricity). Each energy carrier or a particular combination thereof is most applicable to specific market segments and applications. CNG vehicles, for which the basic technology already exists, can save the consumer up to $2/gge (for gasoline at $4/gal) while meeting the requirements of medium- and heavy-duty market segments. Electric vehicles can serve the small to medium vehicle segment for relatively short travel distances. Hybrid, plug-in hybrid, and fuel cell vehicles can cover the small to large vehicle segments requiring long travel distances.

While more research and development is needed for on-board storage of NG and H_2, proven technology for fuelling stations is already available. Development and implementation of the fueling infrastructure, however, will require a national plan generated by a collaborative effort by Federal and State governments, automobile manufacturers, fuel suppliers, and other industry stakeholders. Examples of such plans may be found in Germany and Japan. On a smaller scale, New York State has a draft plan to install 100 H_2 stations by 2020, 70 in cities and 30 along major highways, with a State investment of $50 million over six years (from 2015 to 2020) to meet the requirements of a projected FCV fleet that would grow from 1,500 cars in 2015 to 50,000 cars by 2020. At present, no new H_2 fueling stations are being built in New York, in spite of a $200,000 tax incentive for such stations, because they will not be needed until significant numbers of FCVs are on the roads in the State. It has not yet been determined who will own these stations.

SUMMARY OF PANEL DISCUSSIONS

Fuel Supply and Infrastructure: Markets and Barriers

Panelists
Roger Marmaro (Hythane Company)
Mike McGowan (Linde North America)
Matt Most (Encana Natural Gas)
Brian Weeks (Gas Technology Institute)

Moderator **Bill Liss (Gas Technology Institute)**

This panel focused on the issues, markets, and barriers to the growth of NG and H_2 fuel supply and infrastructure. While all panelists offered preliminary remarks, Matt Most also showed a set of slides highlighting the value proposition for NG (i.e., its environmental, economic, societal, and energy security benefits), the opportunities for using NG for transportation, and the elements to the path to viability (infrastructure, incentives, policies, costs, and OEM involvement); these slides are given in Appendix H. The salient points made in this panel discussion are categorized and summarized below.

Opportunity

Increasing the use of NG for transportation, either directly in NGVs or indirectly as H_2 in FCVs, offers very significant benefits in environmental, economic, societal, and energy security areas. The potential for daily NG use in transportation is 61.6 bcf (billion cubic feet), 23.3 bcf of which would represent displacement of oil from OPEC (Organization of Petroleum Exporting Countries). The largest opportunity lies in using NG for light-duty vehicles (42.4 bcf). The most commercially ready use is in medium- and heavy-duty vehicles, which have the potential to use 14 bcf, with an additional 4.2 bcf use in marine, rail, and other transportation applications.

Uncertainty concerning incentives for CNG and LNG (and NGVs) has a significant negative effect on the NG value proposition, however. Uncertainty in funding and long-term policy inhibits growth in infrastructure and end use. This is not the case in Germany, for example, where industry, government, and other stakeholders have mutually agreed on definitive endpoints, and then developed a strategy for how to get there (the needed number of stations, size of stations, and locations), with assured funding over 10 years.

H_2 and NG markets are synergistic, and NG-H_2 blended fuels offer the positive aspects of H_2 and the storage capability and energy content of NG for the use of such blends in ICE vehicles. As an example of these synergies, the 300 refuse trucks currently operating on LNG could be readily converted to operate on CNG, H_2, or a blend of the two with little change in the engine hardware. On the other hand, blending NG with H_2 would limit the use of the fuel to ICEs, since FCVs require pure H_2.

Challenges and Barriers

Key technology challenges to the growth of NG in transportation are capital cost, tank design limitations, and vehicle range. The incremental cost of converting to NG fuel is caused largely by emissions certification for the conversion. The current limited size of NGV and FCV fleets is also an impediment to fueling infrastructure development. It is not a chicken-or-egg (infrastructure-or-vehicles) issue, however; both will need to develop simultaneously.

For developing the infrastructure, current regulations are cumbersome. The authorities are not always familiar with the new technology, and permitting and safety issues are not addressed uniformly. Clear, feasible, and integrated regulations are needed for both H_2 and NG, as well as for blended fuels. To take advantage of current uses of NG for transportation (e.g., refuse trucks), there are technology and regulatory barriers: capital cost of switching to NG fuel is high ($15,000 for a light-duty vehicle and up to $40,000 for a heavy-duty vehicle), which is partly due to the low volumes of NGV conversion or manufacture. Regarding regulatory hurdles, although NGVs are in more common use in Europe, the European NGVs cannot be imported for use in the United States because they do not meet U.S. safety and emissions regulations. In addition, there is inconsistent treatment of NGVs for CAFE in light-duty versus heavy-duty vehicles. The differences between California, U.S., and international standards are hurdles that must be overcome by harmonization of global safety and emissions standards.

Fueling stations need to meet projected demand minimums before a commercially feasible site can be developed. Gasoline marketers look for sales of 7,000–10,000 gal/day, or start with 3,000–4,000 gal/day, at least, with a clear pathway for reaching the larger volumes. The demonstration stations installed at present are too small in terms of daily dispensing volumes to be commercially practical. There are no significant technology barriers to building fueling stations, but it is not economical to build many "replaceable" stations that are small to begin with and then give way to larger stations as the demand increases. Infrastructure costs would be prohibitive without an assured, sufficient demand for 10–15 years. In addition, at present the applicable codes and standards, some defined as legacy or holdovers from past use, limit the amount of H_2 (and NG) that can be stored on-site; these codes must be updated to allow the installation of large, commercially sustainable, fueling stations.

A challenge in making investments for both NG and H_2 infrastructure is that the fuel supply industry may be unwilling to make investments in a market where it cannot reasonably project the fuels' demand scenario. The lack of a clear and consistent energy policy for 5–10 years or longer has a strong negative effect on fueling infrastructure development.

The high cost of tariffs for moving gases through pipelines was also mentioned as a potential impediment to the use of existing and planned NG pipelines for transporting H_2 and blended fuels.

Actions/Strategies Needed to Increase Deployment of NG and H_2 Infrastructure and Use

It is clear that to increase NG use in transportation, we need to enhance the infrastructure, institute incentives and policy drivers, and greatly increase the number of OEM vehicles, while decreasing vehicle costs. Incentives, policies, and emissions standards for NGVs must be such that they "level the playing field." The costs of on-board storage tanks must be decreased, while their storage capacities must be increased.

Actions and strategies suggested for vehicles and infrastructure included the following:

- Develop lower cost, smaller, conformable storage tanks, possibly using sorbents such as spent corncobs for NG.
- Institute an "X Prize" for developing novel technology, such as home fueling for NGVs and FCVs.
- Set a desired goal along the lines of the ZEV mandate in California and what has been done in Germany and Japan. An example of such a goal would be that a certain minimum fraction of all new vehicles sold will operate on NG, H_2, or NG-H_2 blended fuels by a certain date. Technology diversity could hurt growth, however, if the choices are split in too many directions.
- Develop standardized, pre-approved components for conversions, to reduce conversion costs. It was mentioned that U.S. OEMs will offer conversions to NG through their dealers in 2012; this should lower conversion costs.
- Issue infrastructure bonds to fund installations (but a mechanism will be needed to repay the bonds).
- State and Federally regulated transmission and distribution companies can be required to raise money to pay for the needed capital investments. This would require an industry consensus, but similar actions have been implemented in the past.
- Review the Natural Gas Act—it has incentives on fuel, infrastructure, and vehicles. The currently low price of NG is a huge driver, but, if the price of oil drops, additional incentives or government intervention may be needed.
- Set up a government fund to build stations in remote locations that might not be profitable initially, but would be necessary to complete the fueling network.
- Tax imported fuels more than domestic fuels and clean energy fuels, and use this tax revenue to help fund infrastructure (people talk green, but often are not willing to pay for green).
- Provide long-term assurance of infrastructure value and use.

Transportation and Stationary Applications

Panelists	**Dan Hennessy (Delphi)**
	Zakiul Kabir (Clear Edge Power)
	Bob Wimmer (Toyota)
Moderator	**Matt Fronk (Matt Fronk and Associates LLC)**

This panel addressed the applications and end-use side of growing the NG and H_2 markets and infrastructure. Panelist Bob Wimmer showed two slides that summarized the major pathways for the use of NG in transportation and a comparison of the fuel economies and GHG emissions of an NGV and two gasoline hybrid vehicles that are currently available in the market; these slides are given in Appendix I. The main points made in this panel discussion are categorized and summarized below.

Factors Impeding the Growth of NGVs and FCVs

There are essentially three pathways for the use of NG in transportation, each leading to a very different onboard "engine" technology:

1. NG ▶ CNG ▶ ICE-hybrid NGV: 28% efficiency, 250-mile range;
2. NG ▶ H_2 ▶ FCV: 36% efficiency, 400-mile range; and
3. NG ▶ Electricity ▶ BEV: 24% efficiency, 100-mile range.

For Pathway 1, along with the relatively high initial costs of conversion and lack of adequate retail infrastructure, the operating costs of NGVs (even at the current low prices for commodity NG) are not low enough to generate much consumer interest. For example, hybrid vehicle sales peaked in 2008 at 3–4% of all cars sold, and this market share of new vehicle sales has been flat since then, even with a near doubling of available hybrid vehicle models since 2008. Hybrid vehicle buyers are also expected to be the first NGV and FCV buyers (i.e., there is likely to be little net increase in the NGV/FCV/hybrid vehicle market share). In addition, vehicle manufacturers are not emphasizing NGVs much, although that might be changing. Further, dual fuel systems are expensive (if used to overcome driving range issues).

There is a great deal of interest in Pathway 2, with the first step of generating H_2 by reforming NG being conducted at the fueling station or at a central location, but significant growth of NG use would depend on a significant growth in FCV use. Similarly, Pathway 3 offers opportunities for growth in NG use and infrastructure, but in this option the controlling factors will be the fraction of electricity generated by NG power plants and the rate of introduction of battery electric vehicles (BEVs). A variation of Pathway 3 is the use of plug-in hybrid electric vehicles (PHEVs) with an NG or other ICE on-board.

There is a lack of understanding of NG and fuel cell technology. Early adopters of these technologies like them, but safety officials (e.g., fire marshals) are skeptical; this skepticism needs to be overcome by educating them about these technologies. These products should be introduced not just as new technology, but as new products that add value for the consumer.

While early adopters are necessary for the introduction of new technologies into the marketplace, the real question is how to get past the early adopters to the mainstream consumer. At the very least, the new products must have the same cost (real and perceived) as the conventional vehicles; while the early adopters are typically not concerned about payback, the general consumer's choice is affected by the costs of the technology, both initial and lifetime.

Factors Impeding the Growth of CHP and CHHP Systems

The high initial cost of CHP systems, in particular micro-CHP systems, is a major impediment to increased use of stationary NG-fueled CHP and CHHP systems. To overcome the initial cost hurdle, better financing options are needed. At present, supporters with deep pockets (e.g., the energy industry or the venture capital community) are not engaged in financing NG and H_2 infrastructure. This would be encouraged if the government supports such activity (e.g., by tax incentives); otherwise, private investment would not be forthcoming. One option would be to put the cost of a distributed generation unit in the rate basis to amortize its cost and lower the cost to the consumer. Categorizing the electricity generated by fuel cell systems as renewable energy would increase interest from power companies to deploy the technology nationwide; currently, only nine States consider electrical energy from fuel cells to be "renewable energy" for purposes of achieving their renewable energy goals.

Recognition is needed from the gas companies that these systems are mutually beneficial for the gas and fuel cell industries. Stationary equipment OEMs need access to customers, while gas companies, who already have access to customers, can make money; facilitating this partnership would be useful to both. For example, in Japan, fuel cell companies are linked with energy companies in developing and installing residential CHP systems.

The durability and the projected reliability of these systems still need to be improved. A related issue is the need to "standardize" the allowable levels of impurities in NG, which currently vary in the gas from different sources.

Infrastructure Needs

In addition to predictability about the number and location of NG and H_2 stations, the durability and reliability of the stations must be improved; they must maintain a high degree of availability by reducing downtime for maintenance or other factors. The fueling experience has to be consistent and positive. For the truck market, the fueling infrastructure needs to ensure that the fuel will be available for the life of the vehicle (6–7 years), on the routes the truck will travel, and that there will be a consistent cost advantage, on a cents per mile basis, over the life of the vehicle. In addition, they will need to assure consistency of gas quality and uniformity of dispensing/fueling equipment and procedures.

Innovative Strategies

Panelists	**Gus Block (Nuvera Fuel Cells)**
	Marc Klein (Clean Energy Fuels)
	Gary Stottler (General Motors)
	Frank Wolak (Fuel Cell Energy)
Moderator	**Steve Chalk (DOE)**

The focus of this panel was on identifying innovative strategies in technical, financial, and marketing areas. Panelist Gus Block showed one slide (see Appendix J) of a fuel cell power and hydrogen generator that can generate electricity at $0.12/kWh along with 250 kg/day of ultra-high purity, 800-bar H_2 at a cost of less than $6/kg. In addition, panelist Marc Klein showed a short video clip of a Chicago NGV taxicab.[1] The results of the panel discussions are summarized below.

Technical

There are two major points to consider:

To meet the new CAFE standard by 2025, some light-duty vehicles that get 60–70 mpg or more will be needed; current technologies will not get us there.

DOE should provide techno-economic analyses and transparent, credible information about current and developing technologies that businesses can trust and that reduces their (and their investors') risk.

Financing

Developing adequate, long-term financing is a critical part of success in commercializing any new technology. For example, government (DOE) could provide the money needed to help the taxi industry upgrade its vehicles to alternative fuel and higher mpgge vehicles. The first grant of this type was provided by DOE to New York City cabs, where 100% of the cost of conversion to CNG was covered by the grants. However, significant amounts of Federal money are not likely to become available for this purpose, at least in the short term. In addition, the DOE loan guarantee system is not set up for early systems for small loans (<$20 million).

There is a need to address how NG and H_2 can become economically viable as transportation fuels, and in particular, how this can be made economically workable at low market volumes. Individual companies may not be able to do this alone, but teams of OEMs, fuel providers, and other stakeholders could do this successfully.

Other potential options for financing the growth of infrastructure are PACE bonds (Property Assessed Clean Energy bonds), Energy Improvement Districts (EIDs), and "Clean Energy Funds" or "Clean Energy Banks," as set up in Connecticut and South Carolina. Such funds can supply the last bit of money needed by a project, and they can allow a variety of projects to be put together and implemented. It may be possible for government bodies to issue infrastructure bonds, but mechanisms will have to be developed to repay the borrowed amounts.

The NG and H_2 industries could also learn from the solar industry experience. Solar energy was initially perceived to be too expensive. With Federal incentives that covered 30% of the initial costs, New Jersey used revenues from electric utility bills to buy solar equipment. New Jersey is now the second-largest State in solar installations, and the cost of solar energy is headed towards grid parity with conventional power production.

Marketing

When trying to implement a new technology, the first question to ask is, "Who is the customer, and how can the new technology best meet the customer's needs?" To do this, in addition to basic benefits, the systems (vehicles, CHP) need to have clear benefits other than "environmental friendliness" to capture the attention of potential customers. If possible, the systems should provide multiple benefits (e.g., use of renewable waste gas for heat, electricity, and H_2), which could attract a number of different organizations that would then want to see the systems being adopted. Thus, success in marketing means moving from "projects" to "products."

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1 Available at: http://www.youtube.com/user/cityofchicagotv#p/u/7/ke8dU8G-VmU.

The government could help establish the market by requiring, for example, GSA to purchase increasing numbers of NGVs and FCVs when acquiring new vehicles for government fleets. This would create ready markets for the corresponding fueling stations. It would be useful to conduct workshops for fleet maintenance managers, since they influence the decisions on the vehicles to be acquired.

Another approach is to create a shared "Auto Park" where OEMs could provide cars and fueling, so that customers can try out different alternative fuel vehicles. It would allow the technology to be put in front of the masses.

For example, Clean Energy partnered with GTI to upgrade their O'Hare Airport CNG dispenser so that taxi vehicles could use it and pay with their normal credit cards; now taxi companies want to order more CNG taxis. Clean Energy is also installing a CNG station for the biggest taxi operator in Queens, New York. In West Haven, Connecticut, a demonstration wheelchair-accessible CNG vehicle with 290-mile range brought together advocates for the disabled and for clean transportation to seek deployment of additional vehicles. Other options include working with Walmart and other big-box stores as potential mass retailers of NG and H_2 as motor fuels, once there are significant numbers of NGVs and FCVs on the roads.

HIGHLIGHTS OF BREAKOUT GROUP DISCUSSIONS

Infrastructure Development; Regulatory, Safety, and Environmental Issues; and Research and Development Needs

(Breakout Groups 1A and 1B)

Breakout Groups 1A and 1B addressed the issues of infrastructure development, regulatory and environmental issues, and research and development needs.

Infrastructure Development

Develop pipeline and other materials that are compatible with both NG and H_2, as well as with mixtures of the two fuels.

- Standardize designs and increase manufacturing volumes of fueling stations and components; for example, some companies make thousands of gasoline pumps per year.
- Improve the quality of the equipment so that it is reliable and effective.
- Make efforts to collocate gaseous fuels to avoid duplication of work.
- Develop home fueling technology to drive the market.
- Make gas more cost-effective to help get vehicles to market.

Regulatory, Safety, and Environmental Issues

- Provide sustained incentive and regulatory platforms, which may require congressional action (e.g., CAFE).
- Reduce regulatory barriers for vehicle conversion.
- Duplicate models that have been successful at the State level (California, Hawaii, New York, Connecticut).
- Support analyses and data collection (DOE); issue RFIs for broad input.
- Institute a carbon tax or similar policies at the State/Federal level.
- Require busy gasoline stations to have at least one NG dispenser.
- Harmonize codes and standards at the level of the highest standards.
- Introduce Federal incentives for station owners and State regulators.
- Facilitate the certification of vehicles by developing proactive regulations at the Federal (EPA) and State levels.
- Train and educate safety officials and their governing bodies.
- Encourage development of "market pull" by conducting educational programs for the general public.
- Address public perception of safety to convince people that H_2 is predictable and controllable.

Research and Development

- Recognize that the United States is not lagging in either NG or H_2 technologies.
- Conduct research and development on component and system hardware, such as storage tanks, valves, compressors, and fuel dispensers, to lower costs and improve durability and reliability.
- Encourage standardization in hardware designs.
- Conduct cost sensitivity analyses on where gas cleanup is best accomplished (i.e., before/after conversion to H_2).

- Increase manufacturing volumes and improve manufacturing processes to reduce component costs.
- Advance the NG storage tank technology by a combination of research and development, scale, innovation, and government intervention.

Deployment Synergies

(Breakout Group 1C)

Breakout Group 1C addressed the issues of developing collaborations to make use of existing or potential synergies between NG and H_2 fuels.

Collaborative Activities

- Develop a vision, commercialization plan, and comprehensive strategy to move forward, using a collaboration of OEMs, DOE, policymakers, and fuel providers (independent gas companies).
- Develop a clear plan for the growth of commercial NG and H_2 technologies for transportation and stationary uses.
- Develop innovative ways to finance the commercial applications of both NG and H_2.
- Find "champions" to promote these new technologies to businesses, government, and end-users.
- Ramp up production to reduce costs—OEMs, industry.

Synergies in NG and H_2 Infrastructure

- Once the demand for H_2 grows to a stable, reasonable volume, re-evaluate the use of the existing NG infrastructure with on-site reforming as an alternative to developing a parallel H_2 delivery infrastructure.
- Re-evaluate on-site reforming—industry and DOE—as a complete package for a clean, high-pressure supply of H_2, including the technology's readiness level and the optimum sizes for deployment under various scenarios.
- Exploit similarities in storage technologies for H_2 and NG to lower costs of often identical or nearly identical components.
- Improve compression technology (reduce costs, improve durability).

Regulatory Synergies

- Involve the U.S. Department of Transportation to ensure better regulations; current tank regulations are overly burdensome.
- Develop coordinated standards among relevant agencies.
- Expand scope of current H_2 work at the National Renewable Energy Laboratory to include NG, on both vehicle and infrastructure sides.
- Develop incentives, and eliminate barriers and disincentives, for renewable sources of NG to help pull it into the market (e.g., injecting renewable NG into pipelines is currently prohibited in California) to provide both energy security and environmental benefits.

NGVs, FCVs, Specialty Vehicles, and Heavy-Duty Trucks

(Breakout Group 2A)

Breakout Group 2A considered potential issues in the transportation use of NG and H_2. The discussions suggested the following potential activities:

- Develop a better and wider range of CNG powertrains (vehicle manufacturers and engine suppliers, especially heavy duty engines and vehicles) to promote market growth.
- Develop ground-up designs to improve efficiency of CNG engines (vs. retrofits) through DOE-sponsored research and development.
- Develop reliable, low-cost flow meters that dispense H_2 with accuracy required by U.S. Department of Commerce regulations ($\pm$1.5% of meter reading).
- Conduct research and development to increase on-board storage capacity and raise energy density (e.g., enhance properties of carbon fiber).
- Extend financial incentives for long-term support (e.g., tax credits).
- Identify and develop dependable secondary/tertiary markets for Class-8 trucks and other potential early market NGVs to improve lifecycle costs.

CHP, CHHP, and Synergistic Approaches

(Breakout Group 2B)

Breakout Group 2B discussed the research and development needs, implementation strategies, and synergies in the use of NG and H_2 for stationary power generation combined with waste heat utilization and hydrogen production.

- Conduct research and development for order-of-magnitude improvement in materials' properties.
- Improve performance of balance-of-plant (BOP) components (for diverse constituents in fuel inputs).
- Seek policy parity for NG and H_2 with renewable fuels.
- Develop partnerships between manufacturers and fuel providers to accelerate market adoption.
- Analyze where there are H_2 applications that could have added benefits of CHHP, beyond just CHP (and vice versa).
- Develop standardized components for ease of certification for CHP and CHHP.

Alternative Uses for Natural Gas and Hydrogen

(Breakout Group 2C)

Breakout Group 2C discussed potential alternative uses for NG and H_2 that would spur demand and emphasize the need for growth in the supply infrastructure for the two fuels.

- Use H_2 as an energy storage medium to support the power grid (for valley fills and grid stability).
- Develop neighborhood energy and power management systems and require that new residential and commercial developments install (1) H_2 and NG dispensers, and (2) fuel cells for backup power.
- Simplify the permitting process for neighborhood energy and power management systems.
- Promote the use of H_2 fuel cells for primary power, auxiliary power, and in ground support equipment by developing case studies of prototype applications.
- Use H_2 and NG to power locomotives or tugs in rail yards.
- Blend H_2 in NG to improve the efficiency of ICEs (will need to establish standards and limits for H_2 in such blends).
- Develop H_2 fuel cell–based systems for electric power in mines and other enclosed spaces.
- Develop H_2 fuel cell–based systems for portable and field lighting in off-grid locations and other applications, such as concert venues and road repairs.

ABBREVIATIONS, ACRONYMS, AND FORMULAS

BEV	battery electric vehicle
BNL	Brookhaven National Laboratory
CaFCP	California Fuel Cell Partnership
CAFE	corporate average fuel economy (mpg of gasoline or gasoline equivalent)
CHHP	combined hydrogen, heat, and power (system)
CHP	combined heat and power (system)
CNG	compressed natural gas
CO_2	carbon dioxide
DHS	Department of Homeland Security
DOC	U.S. Department of Commerce
DOE	U.S. Department of Energy
DOE/EE	U.S. Department of Energy, Energy Efficiency and Renewable Energy
DOE/FCT	U.S. Department of Energy, Fuel Cell Technologies Program
DOE/FE	U.S. Department of Energy, Fossil Energy
DOE/VT	U.S. Department of Energy, Vehicle Technologies Program
DOT	U.S. Department of Transportation
EID	Energy Improvement District
EPA	U.S. Environmental Protection Agency
FCV	fuel cell vehicle
GHG	greenhouse gases
GM	General Motors
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Transportation (a software package developed at Argonne National Laboratory)
GSA	General Services Administration
GTI	Gas Technology Institute
H_2	hydrogen
ICE	internal combustion engine
LDV	light-duty vehicle
LEED	Leadership in Energy and Environmental Design
LNG	liquefied natural gas
mpgge	miles per gallon gasoline equivalent
NETL	National Energy Technology Laboratory
NASA	National Aeronautics and Space Administration
NG	natural gas
NGV	natural gas vehicle
NOW Gmbh	Nationale Organisation Wasserstoff-und Brennstoffzellentechnologie (Germany)
NREL	National Renewable Energy Laboratory
OEM	original equipment manufacturer (most often, an automobile manufacturer)
ORNL	Oak Ridge National Laboratory
PACE	Property Assessed Clean Energy (bonds)
PHEV	plug-in hybrid electric vehicle
RFI	request for information
SNL	Sandia National Laboratory
TRL	Technology Readiness Level
ZEV	zero emission vehicle

APPENDICES

Appendix A	Workshop Agenda
Appendix B	Workshop Attendee List
Appendix C	Notecard and Storyboard Details from the Breakout Sessions
Appendix D	Presentation Slides: Workshop Goals, Objectives, and Desired Outcomes (Steve Chalk, DOE)
Appendix E	Presentation Slides: U. S. Natural Gas Markets and Perspectives (Bill Liss, GTI)
Appendix F	Presentation Slides: Synergies in Natural Gas and Hydrogen Fuels (Brian Bonner, APCI)
Appendix G	Presentation Slides: Natural Gas and Fuel Cell Vehicle Light-Duty Transportation Perspectives (Matt Fronk, Matt Fronk & Associates, LLC)
Appendix H	Presentation Slides: Natural Gas and Hydrogen Infrastructure Opportunities: Markets and Barriers to Growth (Matt Most, Encana Natural Gas)
Appendix I	Presentation Slides: Natural Gas Pathways and Fuel Economy Guide Comparison (Bob Wimmer, Toyota)
Appendix J	Presentation Slide: Hydrogen Generator Appliance (Gus Block, Nuvera Fuel Cells)

Natural Gas and Hydrogen Infrastructure Opportunities Workshop

Building 200 Auditorium • Chemical Sciences and Engineering Division (CSE)

Argonne National Laboratory •9700 S Cass Avenue, Lemont, IL 60439

October 18–19, 2011

Agenda

Workshop Objectives:

- Convene industry and other stakeholders to share current status/state-of-the art for natural gas and hydrogen infrastructure.
- Identify key challenges (both technical and non-technical, such as permitting, installation, codes and standards) preventing or delaying the widespread deployment of natural gas and hydrogen infrastructure. Identify synergies between natural gas and hydrogen fuels.
- Identify and prioritize opportunities to address the challenges reported above, and determine roles and opportunities for both government and industry stakeholders.

Tuesday, October 18, 2011

9:00–10:00 AM **Registration and Continental Breakfast**

10:00–10:15 AM **Welcome**

- **Dr. Peter Littlewood**, Argonne Associate Laboratory Director for Physical Sciences and Engineering

10:15–10:30 AM **Workshop Goals, Objectives, and Desired Outcomes**

- **Steve Chalk,** Deputy Assistant Secretary, Energy Efficiency and Renewable Energy, U. S. Department of Energy (DOE)

10:30–11:00 AM **Natural Gas Markets and Perspectives**

- **Bill Liss**, Gas Technology Institute

11:00–12:00 PM **Panel Discussion #1: Fuel Supply & Infrastructure: Markets and Barriers**

*(Moderator: **Bill Liss**, Gas Technology Institute)*

*Panel Members: **Roger Marmaro**, Hythane Company,* **Mike McGowan,** Linde North America, ***Matt Most**, Encana Natural Gas, **Brian Weeks**, Gas Technology Institute*

- Natural Gas and Hydrogen Markets – Barriers to Infrastructure Growth (Technical, Regulatory, Other)

12:00–12:30 PM **Working Lunch (box lunches provided)**

12:30–2:30 PM **Breakout Session #1: Market Potential and Barriers**

- 1A: Infrastructure Development, Regulatory & Environmental Issues, R&D needs
- 1B: Infrastructure Development, Regulatory & Environmental Issues, R&D needs
- 1C: Deployment Synergies

2:30–2:45 PM **Break**

2:45–3:30 PM **Summary Reports from Breakout Group Discussions**

3:30–4:00 PM **Synergies in Natural Gas and Hydrogen Fuels**

- **Brian Bonner**, Air Products and Chemicals, Inc.

4:00–4:30 PM **Moderated General Discussion on the Day's Topics**

(Moderator: **Fred Joseck**, DOE)

5:00 PM **Adjourn**

Natural Gas and Hydrogen Infrastructure Opportunities Workshop

Building 200 Auditorium • Chemical Sciences and Engineering Division (CSE)

Argonne National Laboratory •9700 S Cass Avenue, Lemont, IL 60439

October 18–19, 2011

Agenda

(Continued)

Wednesday, October 19

8:00–8:30 AM **Check-in and Continental Breakfast**

8:30–9:00 AM **NGV and FCV Transportation Perspectives**

- **Matt Fronk**, Matt Fronk and Associates, LLC

9:00–10:00 AM **Panel Discussion #2: Fuel Use: Transportation and Stationary Applications**

*(Moderator: **Matt Fronk**, Matt Fronk & Associates)*

*Panel Members: **Dan Hennessy,** Delphi, **Zaki Kabir**, Clear Edge Power, **Bob Wimmer**, Toyota*

- NGVs (light- and heavy-duty vehicles)
- FCVs, CHP, and Fuel Providers

10:00–10:15 AM **Break**

10:15–12:15 PM **Breakout Session #2: Transportation and Stationary Applications**

- 2A: NGVs, FCVs, Specialty Vehicles and Heavy-Duty Trucks
- 2B: CHP, CHHP, and Synergistic Approaches
- 2C: Alternative Uses for Natural Gas and Hydrogen

12:15–12:45 PM **Working Lunch (box lunches provided)**

12:45–1:30 PM **Summary Reports from Breakout Group Discussions**

1:30–2:30 PM **Panel Discussion #3: Innovative Strategies**

*(Moderator: **Steve Chalk**, DOE)*

*Panel Members: **Gus Block**, Nuvera Fuel Cells, **Marc Klein**, Clean Energy Fuels, **Gary Stottler**, GM, **Frank Wolak**, Fuel Cell Energy*

- Innovative Approaches to Accelerate Deployment, including Policies, Financial Incentives, Innovative Business Case Strategies

2:30–3:00 PM **Moderated General Discussion: Suggested Next Steps**

*(Moderator: **Sunita Satyapal**, DOE)*

3:00–3:30 PM **Wrap-Up: Steve Chalk, DOE**

3:30 PM **Adjourn**

Workshop Attendee List

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1A – Infrastructure Development Needs

FOCUS QUESTION 1: What is needed for widespread deployment of natural gas and hydrogen fueling infrastructure for motor fuels or stationary power applications?

Tech Barrier/ R&D Needs	Regulatory Issues	Strategies/ Approaches	Policy	Education/ Training
• Better, cost-effective, reliable hydrogen compressors • New NG pipeline materials of construction that are compatible for co-carrying H_2 or for conveying NG and H_2 separately in the same line • Home refueling unit that is inexpensive and durable (light-duty vehicle requirement) • Engineering and tooling required for high-volume (1,000–5,000 unit) production of compression and dispensing units • A CNG and H_2 fuel cell hybrid car • A “happy medium” on vehicle storage pressure (e.g., storage materials, lower pressure) • Purify NG before H_2 production to make the process less complex (e.g., odorant removal) • Continued support of H_2 storage R&D • Ways to capture/re-use LNG boil-off from vehicle tanks	• Reduce cost for OEMs to meet safety (DOT) and emission (EPA) certification requirements on low-volume units • Reduce cost of distributed NG-to-H_2 production and purification • Implement incentives or progressive rate policy to allow gas utilities to invest in NG and H_2 infrastructure • Work toward global harmonization of components and system qualification requirements and procedures (e.g., for Type-IV tanks) • Work with authorities having jurisdiction (AHJs) to adopt codes and standards for H_2 use in parking, service facilities, and tunnels	• Collocate NG and H_2 dispensing (and other fuels) at each station to spread costs • Use distributed generation to facilitate FCV refueling in the near term – Electrolysis – Co-generation – Recovery and recycling • Establish political leadership that creates clear regulatory rules to support goals • Develop standardized hydrogen fueling station layouts and designs (storage, compression, dispensers, safety systems) for urban, suburban, and rural deployment • Explore strategies for laying H_2 pipelines along with new NG pipelines • Develop ways to capitalize on the secondary use market (i.e., what to do with vehicles after initial use?) • Identify and promote another near-term, high-volume market for H_2	• Provide a sustained (~10 year) incentive platform for NG and H_2 fuels – Fuel tax credit – Investment tax credit • Develop “”alternative fuel franchise zones” that provide early station investors and early movers an advantage • Mandate that large corporations (i.e., Fortune 500) adopt alternative fuels in their light-duty vehicle fleets and among users to incite market demand • Implement a $10/barrel tax on imported oil and use that money to develop alternative fuel infrastructure • End “chicken-and-egg” dilemma by pulling together vehicle and infrastructure providers and government funding and tax incentives in key markets, to plan deployment (similar to CaFCP and Hawaii) • Provide a means for customer choice/consumer	• Develop and provide harmonized education/training for AHJs in areas where stations are planned (or where fuel is dispensed publicly) • Provide first-responder training for AHJs

Tech Barrier/ R&D Needs	Regulatory Issues	Strategies/ Approaches	Policy	Education/ Training
• Lower cost of loading 700-bar H_2 on fuel cell vehicles – Compressor vs. high-pressure storage – Added soft cost		(after material handling equipment; focused on polymer electrolyte fuel cells) • Leverage H_2 and NG in renewable energy storage applications to help drive down costs • Build toward light-duty vehicle applications from sustainable markets – H_2: material handling equipment – NG: heavy-duty vehicles • Natural gas infrastructure is building out; can the H_2 industry put H_2 pipelines with new NG pipelines? • Start with NG-H_2 blends and move to pure H_2 as a deployment strategy • Use H_2-fueled internal combustion engine vehicle as a transition vehicle • Build on what already exists, so technology is “backwards compatible”	preference input into policy decisions • Provide policy parity between renewable power production and renewable NG or H_2	

1A – Infrastructure Development Needs

FOCUS QUESTION 2: What can be done to address or achieve the top priorities?

Top Priorities	What? (Actions)	Who? (How)
• Sustained (10 year) incentive platform for NGV and H_2 fuels – Fuel tax credit – Investment tax credit	• Requires congressional action • Examine what codes and standards need to be in place to enable widespread adoption • Implement a sustained incentive program for H_2modeled on the Natural Gas Act • Establish a sliding scale of tax credits (over time) for fuel providers • Find ways for incentives provided to OEMs to pass through as lower costs for product consumers • Use CAFE and ZEV as models for regulations that drive technology • Get States involved as means of economic development	• Industry groups/associations • States, economic development agencies, etc. • DOE: Supporting analyses, support for harmonized codes and standards
• Reduce cost for vehicle OEMs to meet safety (DOT) and emission (EPA) certification on small-volume units	• Provide tradable CAFE credits (e.g., 6.1 CAFE multiplier) • Work on developing pre-certified components for H_2 and NG use • Use the Global Technical Regulations as a baseline for regulations in the United States • Work toward global harmonization of component/system qualification requirements	• Industry groups/associations • DOE: Solicitation for low-cost certified designs (for pre-certified components or standardized station designs)
• Better, cost-effective, reliable H_2 compressors	• Develop engineering and tooling as if to make high volumes (1,000–5,000 units) • Conduct R&D on cryogenic H_2 compressors	• DOE: (1) Solicitation around design of high-volume manufacturable compressors, and (2) R&D
• Develop new NG pipeline materials of construction that are compatible for co-carrying H_2 or for conveying NG and H_2 separately in the same line	• Continue R&D on pipeline materials • Explore opportunities for laying H_2 pipeline with new NG pipeline – Also explore ways to recoup this investment in the near term	• DOE
• Collocate NG and H_2 (and other fuels) at each station to spread costs	• Work toward standardized station designs	• DOE: (1) Support R&D and (2) issue request for Information

Top Priorities	What? (Actions)	Who? (How)
• Identify and exploit opportunities to reduce costs of distributed H_2 production for FCV refueling in the near term – Purification of NG before H_2 production – Electrolysis – Co-generation – Recovery and recycling	• Conduct analyses to determine if there is a cost advantage to purifying NG before H_2 production (e.g., to remove ordorants)	• DOE
• Develop "alternative fuel franchise zones" that provide early station investors and early movers an advantage	• Modify PACE or EID laws or programs to advance municipal investment	x

1A – Infrastructure Development Needs

Breakout Group Participant List

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1B – Infrastructure Development Needs

FOCUS QUESTION 1: What is needed for widespread deployment of natural gas and hydrogen fueling infrastructure for motor fuels or stationary power applications?

Tech Barrier/ R&D Needs	Regulatory Issues	Strategies/ Approach	Policy	Education/ Training

• Develop home-fueling technologies with low costs for CNG and H_2
• Lower-cost components for fueling stations
• NGV storage tank advancement
  ○ Low compression
  ○ Max capacity
  ○ Tank shape
• R&D to expedite cost reduction for proven technologies (high TRL)
• H_2/CNG compatible materials R&D
• Lighter-weight LNG tanks for vehicles (heavy-duty NG/Trans)
• Increase demand by introducing NG-consuming technologies such as FC CHP systems
	• Harmonization of codes and standards from a fuel perspective and globally
	  ○ Facilitate certification of vehicles
	• A common “transport” of gaseous fuels will stimulate the technology rollout
	• Distribution pipelines are needed to overcome the storage and size barriers
		• Vehicles with fuel demand; market strategy to create demand for vehicles
		• Sustainable and substantial orders to go to mass production
		Need a strategic plan to put in X# of stations across United States that are available for both commercial and consumer use; avoid limitation of closed/private facilities
		  ○ Need public access
		• Acceptance from Federal, local, and State levels. To what level (?), role (?) (CA is a driver)
			• Government could provide disincentives for oil-fueled vehicles (sustained and substantial). Sustained high oil prices or high cost of oil for consumers
			• For NG transportation, long-term regulatory incentive environments. If tax credits expire, it’s hard to invest
			  ○ Longer term/more stable investment and fuel incentives (tax credits, loans, etc.)
			• National policy on energy and GHG emissions
			• Rational common denominator for alternative fuels
			• Jobs/economic development
			  ○ Emissions reduction
			  ○ Energy security
			  ○ Max benefit/$ incentive
			• Need to expand incentives for NGVs so bi-fuel vehicles get the same incentives as dedicated-fuel vehicles
			• Heavy-duty NG/transportation subsidy for LNG-fueling development along trucking corridors
			• Get rid of cost share or make cost share a function of company size. Promote high-TRL technologies focused on cost reduction to get technologies to market
			• CAFE/GHG credits for NGVs
			  ○ Bi-fuel vehicles should get the same treatment as dedicated-fuel vehicles
				• Education of local code officials (more so for H_2 than NG)
				• Public concern about compressed fuel safety, especially H_2
				• Increase availability of maintenance/repair expertise for vehicles and CHP
				• Consumer education and marketing to grassroots consumers

1B – Infrastructure Development Needs

FOCUS QUESTION 2: What can be done to address or achieve the top priorities?

Top Priorities	What? (Actions)	Who? (How)
• Government could provide disincentives for oil-fueled vehicles (sustained and substantial). Sustained high oil prices or high cost of oil for consumers	• Tax GHG emissions; national policy on energy • Sustained and substantial carbon tax policy approach • Vary gas tax to keep gas price at $x/gal. Use revenue to incentivize technology • Provide disincentives, level playing field at pump, high import tariff, revenue-neutral tax structure, put money back into infrastructure	• State • Federal

• Develop home-fueling technologies with low costs for CNG and H_2	• Cost-share reform—get companies to do it; provide on an as-needed basis
	• Regulations to support permitting—pre-approval processes
	  ○ Harmonize codes/standards
		• R&D
		  – Industry
		  – Government

• Vehicles with fuel demand; market strategy to create demand for vehicles	• For NG transportation: cost-effective vehicle availability
	  ○ Regulation and scale; OEMs have technology overseas—make it easy to bring it here (sell in China, too)
	• For light duty: a good, reasonably priced bi-fuel CNG/gasoline mid-size sedan certified to U.S. environmental and safety standards (Fiat/Chrysler?)
	• Need to expand incentives for NGVs so bi-fuel vehicles get the same incentives as dedicated-fuel vehicles
	• CAFE/GHG credits for NGVs
	  ○ Bi-fuels should get same as dedicated-fuel
	• Public access to filling stations
	• Convenience
	  ○ Need to know where they are (build GPS-enabled database [25 for LA])
	  ○ Capacity: cluster, long haul along corridors
	• Harmonize codes and standards
	• For stations with more than "X#" gallons sales per month, require to put in NG and H_2 pumps
		• Station owners
		• State regulators
		• Federal incentives

• Education of local code officials (more so for H_2 than NG)	• More education • Strategy to get it out, such as a fireman's ball and education	• Industry

Top Priorities	What? (Actions)	Who? (How)
• National policy on energy and GHG emissions		
• For NG transportation, long-term regulatory incentive environments. If tax credits expire, it's hard to invest ○ Longer-term/more stable investment and fuel incentives (tax credits, loans, etc.)	• Clean and cost-effective fuels • Clean energy policy	• Voters
• Harmonization of codes and standards from a fuels perspective and globally ○ Facilitate certification of vehicles	• Proactively address regulations • Remove regulatory barriers • Somehow reduce costs	• Federal—EPA • States
• Lower-cost components for fueling stations	• R&D manufacturing • Scale (needed orders) • Innovation	• Industry—manufacturers • Government—materials • GTI—R&D
• NGV storage tank advancement ○ Low compression ○ Max capacity ○ Tank shape	• R&D manufacturing • Scale (needed orders) • Innovation	• Industry—manufacturing • GTI—R&D • Government—materials
• Public concern about compressed fuel safety, especially H_2	• Public education	• Government—education

1B – Infrastructure Development Needs

Breakout Group Participant List

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1C – Deployment Synergies

FOCUS QUESTION 1: What synergies exist between natural gas and hydrogen that could facilitate or accelerate the deployment of natural gas and hydrogen fueling infrastructure for motor fuels or stationary power applications?

Barriers to Synergies	Economies of Scale	Piggyback Opportunities	Technology Synergies	Other Synergies

• Both NG and H_2 need to fit into a total strategy to be effectively implemented for transportation
  ◦ There is no clear commercial execution plan
  ◦ There is a lack of leadership (vision and strategy)
  ◦ Funding is unlikely for both H_2 and NG infrastructure development
• Odorants are not acceptable for fuel cell uses
• Competing technologies dilute initial markets
• Footprint in fuel cell vehicle “priority areas,” such as Los Angeles, is an inhibiting factor (underground tanks versus above-ground tanks)
• NGVs tend to be in interstate highways or rural areas; FCVs tend to be in cities
• Inequality of demand: uncertainty about who will take the cost of the lower demand infrastructure
	• Use same pipeline materials for NG and H_2 (need R&D to ensure it is okay). For example, high-density polyethylene has some H_2 diffusion, but is it enough to prevent us from using it?	• Will need build out to occur in clusters to support critical mass of vehicles and geographical areas
		• NG and H_2 use similar building codes for station construction and vehicle standards; SAE should follow this example
		• NG right-of-way is a valuable transportation asset that facilitates use of pipelines for H_2 transport
		• Opportunity to leverage market acceptance of NG, followed by CNG, and H_2 onboard storage
		• Distribution of H_2 in low percentage in existing NG pipelines
			• On-site H_2 generation from NG enables the use of existing NG infrastructure for H_2 and H_2/NG blends. Utilize CHP fuel cell systems to initiate H_2 infrastructure for early deployment
			• Similar storage
			  ◦ Current solutions
			  ◦ Problems and areas to improve
			• NG for medium- and heavy-duty trucks will require refueling along interstates. Locate small steam methane reforming at refueling sites along the same routes
			• For gaseous fuels, compression, storage, and dispensing are similar and require similar components. Both systems utilize high-pressure components. By using high-pressure NG, in a CNG configuration, costs and pressure can be reduced for H_2, thus helping to reduce the end costs
				• Regulatory synergies could be developed (both are flammable, gaseous fuels)
				• NG and H_2 share conventional and renewable sources
				• Non-energy, high-value uses if H_2 can help “subsidize” fuel use for on-site generation
				• Develop regulations for fuels all together, including blends

1C – Deployment Synergies

FOCUS QUESTION 2: What can be done to address the top priorities and who should be involved?

Priorities	What can be done?	Who should be involved?
Both NG and H_2 need to fit into a total strategy to be effectively implemented for transportation	• Define vision • Develop commercialization plan • Find champion	• Collaboration between DOE (lead), industry, and academia
On-site H_2 generation from NG enables the use of existing NG infrastructure for H_2 and H_2/NG blends. Utilize CHP fuel cell systems to initiate H_2 infrastructure for early deployment	• Reevaluate the technology (right size and how to integrate it) • Research small-scale reforming	• DOE with industry input
	• Ramp-up production of cars and fuel processors to reduce costs	• Industry (OEMs)
Similar storage (current solutions, problems, and areas to improve)	• Improve compression • Find a better way to store, such as low pressure and high density	• DOE • DOT • Industry
NG and H_2 share conventional and renewable sources	• Incentivize use of renewables	• Policymakers (local and Federal)
	• Enable the use of biogas by allowing pipeline injection	• Policymakers

Regulatory synergies could be developed (both are flammable, gaseous fuels)	• Develop regulatory synergies, standards	• Standards development organizations:
		  • National Institute of Standards and Technology
		  • International Standards Organization
		  • ASTM International
		  • Society of Manufacturing Engineers
		  • International Code Council
		  • National Fire Protection Association
		  • SAE International

	• Establish liaison between codes and standards for H_2 and NG	• DOE (for example, NREL has been involved in discussions of standards for H_2. These discussions could include NG as well)

1C – Deployment Synergies

Breakout Group Participant List

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2A – NCVs, FCVs, Specialty Vehicles, and Heavy-Duty Trucks

FOCUS QUESTION 1: What is needed to make NG and H2 viable fuels for a broad spectrum of vehicle platforms?

Class 7 and 8	Technical Barriers/ R&D Needs	Regulatory Issues	Strategies/ Approach	Policy	Education/ Training

• Better/wider CNG engine availability
  ○ LNG
  ○ No CNG Class 8 and 7
• More engine platforms (manufacturers) users loyal to brand
• Engine efficiency not optimized for NG
• For Class 8 trucks: fuel tank capacity (range)
	• Flow meters for H_2 to sell H_2
	  ○ ±2.5% is accuracy in type evaluation
	• Storage
	  ○ Higher energy density, both CNG and LNG
	  ○ Decrease tank size
	• Simplicity for fuels
	  ○ Easy to use (no hazmat)
	  ○ Twice the range
	  ○ Lower emissions
	  ○ Lower costs
	• Light duty requires home refueling to have any chance for success for CNG (not H_2)
	• Certified H_2 and CNG bus engine(s)
	• Onboard LNG storage needs to improve (tank integrity; heat loss)
		• Truck emission regulations may drive use of NG
		• Better understanding of emissions (supply and vehicle)
		• Perform quantitative analysis of regulatory barriers (certification, etc.)
		  ○ CNG and H_2
		  ○ Then focus on technology solutions
			• Fueling stations for Class 8 and light duty
			  ○ Interstate highway fueling infrastructure
			  ○ Need for capital for LNG (not technical)
			• A dependable secondary market for older Class 8 LNG trucks—i.e., 2–5 year old (max)
			• Start small number of commercial corridors with dedicated fueling. Also, some shorter routes (500–1,000 miles)
			• Education on alternative fuel advantage and capabilities
				• Taxes/fees on traditional fuels
				  ○ Port, State, Federal
				  ○ Easier entry to market
				  ○ Certification
				• National energy policy and initial government incentives to purchase vehicles
				• High gasoline/oil prices/volatility (e.g., China, carbon tax)
				• $7,500 tax credit on LDV; incentive to bring renewable H_2 to parity with NG H_2
				• Vehicle purchase or retrofit Incentives	

2A – NCVs, FCVs, Specialty Vehicles, and Heavy-Duty Trucks

FOCUS QUESTION 2: What can be done to address or achieve top priorities?

Top Priorities	What? (Actions)	Who? (How)
• Better/wider CNG engine availability ○ LNG ○ No CNG Class 8 and 7 • More engine platforms (manufacturers) users loyal to brand • Engine efficiency not optimized for NG	• DOE solicitation for engines • Target options in categories not available • Easier entry to market ○ Certification	• Congress • DOE • CARB • EPA
• Taxes/fees on traditional fuels ○ Port, State, Federal ○ Easier entry to market ○ Certification • High gasoline/oil prices/volatility (e.g. China, carbon tax) • $7,500 tax credit on LDV; incentive to bring renewable H_2 to parity with NG H_2	• Congress and State policies to make fuels more attractive	• Congress • Utility commissions • Industry • H_2 and NG stakeholders
• Flow meters for H_2 to sell H_2 ○ $\pm$2.5% is accuracy in type evaluation	• DOE solicitation to help meet regulations on performance • Can it be done • How to be cost effective	• DOE • Scientific equipment and meter manufacturers
• Fueling stations for Class 8 and light duty ○ Interstate highway fueling infrastructure ○ Need for capital for LNG (not technical)	• Identify where to put stations • Build out	• DOE • Industry • DHS national security • Congress
• National energy policy and initial government incentives to purchase vehicles • Vehicle purchase or retrofit incentives	• Permanent and consistent policy	• Congress • Industry
• For Class 8 trucks, expand fuel tank capacity (range) • Storage ○ Higher energy density, both CNG and LNG ○ Decrease tank size	• $5/lb carbon fiber T700 ○ Decrease cost of carbon fiber to lower cost of tank ○ Applies to NG and H_2	• DOE

Top Priorities	What? (Actions)	Who? (How)
• Onboard LNG storage needs to improve (tank integrity; heat loss)		
• A dependable secondary market for older Class 8 LNG trucks—i.e., 2–5 year old (max)	• Publicize opportunity to importer/exporter. Some countries have prohibitive import taxes	• CalStart

2A – NCVs, FCVs, Specialty Vehicles, and Heavy-Duty Trucks

Breakout Group Participant List

Name	Organization
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2B – CHP, CHHP Synergistic Approaches

FOCUS QUESTION 1: What is needed to increase the use of hydrogen fuel cells or natural gas turbines for combined heat and power or combined hydrogen, heat, and power?

Enabling Synergies	Market Drivers/ Policies	Strategies Approach	Regulatory Issues	Technology Barriers / R&D Needs
• CHHP integration at neighborhood-scale (planned unit developments or gated communities). Siting CHHP facilities near H_2 station (such as warehouse facilities) • Further enhancement of materials and materials compatibilities for a reduced balance-of-plant: – Compressors are unreliable. Different designs or better materials may be needed for CNG and fuel cells – Lower-cost components for high-pressure H_2 and NG systems • CHHP enables vehicle fuel for either home or commercial use (adds value) • Business case for CHHP (e.g., for office buildings [heat] and fleet [H_2]). Recognition of H_2 storage compared with batteries for grid backup • H_2 storage/H_2 fuel cell—distributed generation for grid	• Reduce customers' energy bills • Increase "coolness" factor of product (e.g., "the i-cell") • Provide backup power and energy security • Make customers feel good about their decision to choose a CHP system • Economics of all CHP systems are marginal. Monetize benefits of fuel cell systems • Market pull for stationary fuel cells (consumer awareness and utility acceptance) • Extend State Renewable Portfolio Standards to NG • Establish Renewable Portfolio Standards on national level • ARPA-E or DOE R&D effort/focus to advance technology performance from 2011 levels to new industry-suggested benchmarks	• Recognition of fuel cell/H_2 CHP or CHHP as having equal status to renewables in Federal energy goals • Partnership (perhaps mandated) between fuel cell manufacturers and utilities. Government package for residential customers • More fair treatment of CHP and CHHP systems by the Leadership in Energy and Environmental Design (LEED) • Identify gaps for technology (e.g., through DOE's RFIs) • Strategy for broader deployment: – Achieve cost and durability goals – Develop financial goals (rate base, preferential NG pricing, power purchase agreements) • Local education of technologies outside the states that are major players (i.e., California and New York)	• Listing/certification of H_2 fuel cell CHP systems/ components—evaluate status. Facilitate testing for certification • Tax GHG emissions and reward renewables • Identify the inconsistencies in regulations that prevent national/global fuel cell penetration • Allow cost recovery by electric or NG industries for adoption of grid-enhancing H_2 fuel CHP or CHHP	• Reduce the cost of bipolar plate and membrane electrode assembly by one order of magnitude. Also, achieve low-cost stack durability of 100,000 hours • Performance degradation – External (e.g., fuel quality) – Internal (e.g., membrane/electrode interface issues) • Gas quality: Need cost-effective cleanup system • Identify impact of economies of scale and learning by doing • System integration/optimization of heat/electricity for CHP in different applications and in different geographical areas

Enabling Synergies	Market Drivers/ Policies	Strategies Approach	Regulatory Issues	Technology Barriers / R&D Needs
stability • NG/H_2 blends for microturbines (investigate NO_x reduction sweet point such as with internal combustion engines?) • High-value alternative uses, such as use of CHP for residential swimming pool heating				

2B – CHP, CHHP Synergistic Approaches

FOCUS QUESTION 2: What can be done to address the top priorities and who should be involved?

Priorities	What can be done?	Who should be involved?
• Recognition of fuel cell/H_2 CHP or CHHP as having equal status to renewable in federal energy goals	• Recognize fuel cell/H_2 CHP or CHHP as having equal status to renewable in Federal energy goals	• Federal government • State governments • Trade associations
• Reduce the cost of bipolar plate and membrane electrode assembly by one order of magnitude. Also, achieve low-cost stack durability of 100,000 hours	• Reduce the cost of bipolar plate by one order of magnitude • Reduce the cost of membrane electrode assembly by one order of magnitude • Achieve low-cost stack durability of 100,000 hours	• DOE (RFI and funding) • Suppliers • OEMs
• Further enhancement of materials and material compatibility for a reduced balance of plant: – Compressors are unreliable. Different designs or better materials may be needed for CNG and fuel cells – Lower-cost components for high-pressure H_2 and NG systems	• Identify areas that need the most progress	• DOE • Suppliers • OEMs
• CHHP integration at neighborhood-scale (planned unit development or gated community). Siting CHHP facilities near H_2 station (such as warehouse facilities)	• Determine the most economical scale—cost per unit of output (review existing analyses and determine if they are still valid) • Identify prime candidate users (Federal facility, post office, etc.) • Extend existing body of CHP analyses to include CHHP	• DOE
	• Establish a stationary consortium	• Utilities • OEMs • States (New York State Energy Research and Development Authority, California Energy Commission, and equivalents)
• Partnership between fuel cell manufacturers and utilities	• Get partners together	• Public utility commissions • DOE • Industry (NG, electric, fuel cell, home builders)

2B – CHP, CHHP Synergistic Approaches

Breakout Group Participant List

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Dave Stinton	Oak Ridge National Laboratory
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Scott Weil	U.S. Department of Energy
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2C – Alternative Uses for Natural Gas and Hydrogen

FOCUS QUESTION 1: What are potentially significant uses of NG and H_2 that could spur growth in demand and development of supply infrastructure?

NG	Hythane	H_2	H_2 and/or NG
• Use LNG at the well head to fuel trucks and machinery • Use of NG-fueled turbines to buffer intermittent wind power will be a growth market • Could CNG replace propane for outdoor lighting? – Trucks operating on LNG—same source provides CNG	• Use Hythane in gas turbines for mid-size to large stationary peaking – Use surplus H_2 used as a supply (for NO_x control)	• Use H_2 as a means of balancing NG energy content to increase the efficiency of gas engines • Use H_2 fuel cells for lighting and electric power in mines and enclosed spaces or for silent lighting and electric power in studios, concert venues, or other applications • Utility-scale energy storage for intermittent renewable energy (as alternative to compressed air storage) • Grid stabilization (frequency response) with H_2 generated as a byproduct • Develop and support recovery, recycling, and reuse of H_2 from industrial processes – Heating value – Power generation – Recycling – Distributed refueling • Use electrolyzers to produce on-site H_2 fuel and enroll them in utility load shedding programs • Racing—H_2 fuel cell race cars at NASCAR/Indy • Use H_2 fuel cell in personal electronics • Use H_2 fuel cell for uninterruptible power systems • Use H_2 fuel cell APUs onboard refrigerated trucks—low noise for morning deliveries • Use H_2 as the working fluid for	• Demonstrate use of H_2 or NG as fuels in the aircraft industry – For primary flight power, ground support equipment, and auxiliary power • Implement a policy that requires new residential or commercial developments to install a community-scale CNG or H_2 dispenser • Use of NG or H_2 to operate trains, locomotives, etc. – Or tugs in train yards • Foster use of H_2 fuel cells for neighborhood backup or emergency power where solar is the primary energy source • Promote versatility and usability of H_2-powered fuel cells at tailgate parties • Use of rail or barges to transport NG or H_2 from new production sources • Use of NG and/or H_2 for cathodic protection of pipelines

NG	Hythane	H_2	H_2 and/or NG
		refrigeration Wind → H_2 and H_2 → ammonia (on-site at farm for on-farm use) • H_2 + CO_2 → fuel (for standard resources) • Use H_2 for energy storage, combined with a reversible fuel cell to lower capital cost • Use H_2 as the working fluid for solar Stirling engines	

2C – Alternative Uses for Natural Gas and Hydrogen

FOCUS QUESTION 2: What can be done to address or achieve the top priorities?

Top Priorities	What? (Actions)	Who? (How)
• Grid stabilization (frequency response) with H_2 generated as a byproduct – Utility-scale energy storage for intermittent renewable (as alternative to compressed air storage)	• Conduct R&D on H_2-fueled gas turbines – Better link the H_2 R&D community with the National Energy Technology Laboratory's ongoing R&D activities • Conduct R&D on geological storage • Conduct R&D on reversible fuel cells	• DOE
• Foster use of H_2 fuel cells for neighborhood backup or emergency power where solar energy is the primary energy source – Implement a policy that requires new residential or commercial developments to install a community-scale CNG or H_2 dispenser	• Conduct R&D to lower the cost of dispensing technology • Simplify permitting requirements • Work with power control authorities to develop and implement neighborhood power management strategies	• DOE (R&D) • Local government • Power authorities (e.g., GTI, EPRI)
• Demonstrate use of H_2 or NG as fuels in the aircraft industry – For primary flight power, ground support equipment, and auxiliary power	• Develop and publish case studies of existing demonstrations in ground support equipment • Partner with NASA for onboard uses • Conduct R&D for onboard use of H_2 and fuel cells	• Federal Aviation Administration • Equipment integrators
• Use of NG or H_2 to operate trains, locomotives, etc. – Or tugs in train yards	• Conduct demonstrations and publish case studies • Conduct and publish an analysis of the business case	• DOT • Rail companies and associates
• Use H_2 as a means of balancing NG energy content to increase the efficiency of gas engines	• Now: it is possible to carry 5%–10% H_2 in NG lines and most end uses would benefit • Work with GTI or others to establish a standard H_2 quantity range	• GTI • DOE
• Use LNG at the well head to fuel trucks and machinery – We are doing this now but it is not advertised	• Publish case studies of existing uses and benefits	x
• Use emission-free H_2 fuel cells for lighting	• Conduct demonstrations and publish case	• DOE

Top Priorities	What? (Actions)	Who? (How)
and electric power in mines and enclosed spaces or for silent lighting and electric power in studios, concert venues, or other applications	studies • Evaluate H_2 storage options and capabilities for these power demands – Solve the size mismatch problem • Develop codes and standards for mining applications	• Department of Defense • Equipment suppliers • Regulators

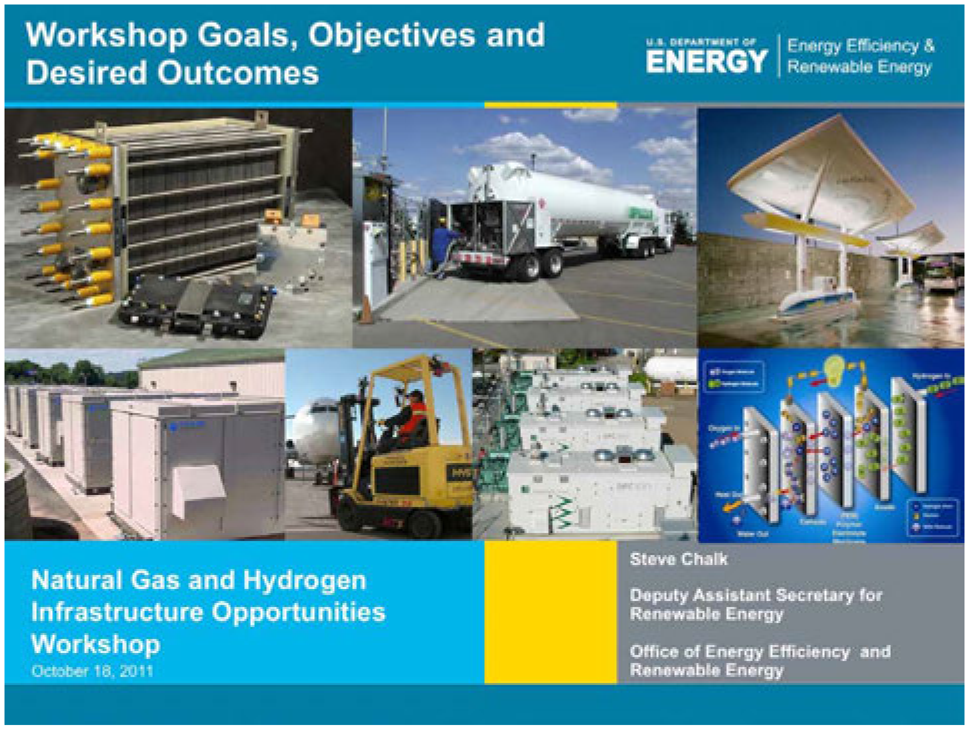
2C – Alternative Uses for Natural Gas and Hydrogen

Breakout Group Participant List

Name	Organization
Everett Anderson	Proton Onsite
Jim Black	National Energy Technology Laboratory
Gus Block	Nuvera
Glenn Eisman	H2Pump LLC
Chinbay Fan	Gas Technology Institute
Rick Farmer	U.S. Department of Energy, Fuel Cell Technology Program
Jay Keller	Sandia National Laboratories
Romesh Kumar	Argonne National Laboratory
Bill Liss	Gas Technology Institute
Roger Marmaro	Hythane Company
Mike McGowan	Linde
Mark Ruth	National Renewable Energy Laboratory
Nancy Selman	Avalence, LLC
Patty Strabbing	Chrysler
Jim Wegrzyn	Brookhaven National Laboratory
Shawna McQueen (Facilitator)	**Energetics Incorporated**
Stephanie Byham (Scribe)	**SRA International**

Presentation Slides: Workshop Goals, Objectives, and Desired Outcomes

Steve Chalk, DOE



Objective, Goals, Desired Outcomes

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Overall Objective:

- Accelerate the use of both natural gas and hydrogen for motor fuels and stationary power applications

Goals:

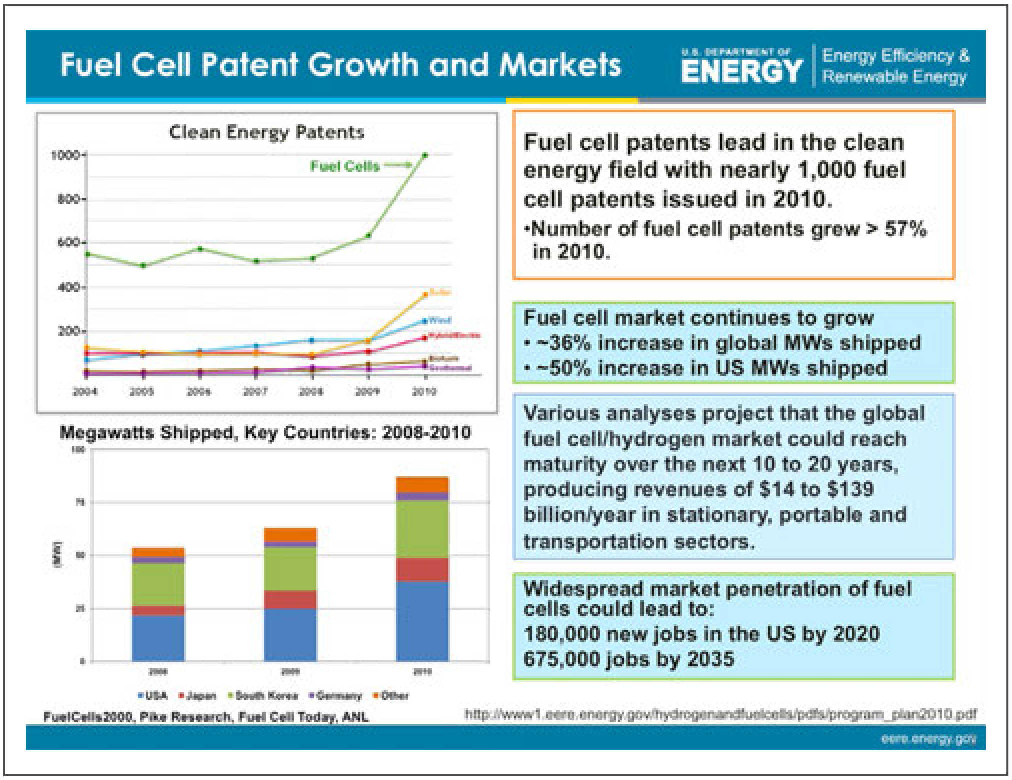
- Identify key technical and non-technical challenges which prevent or delay the widespread deployment of natural gas and H_2 infrastructure

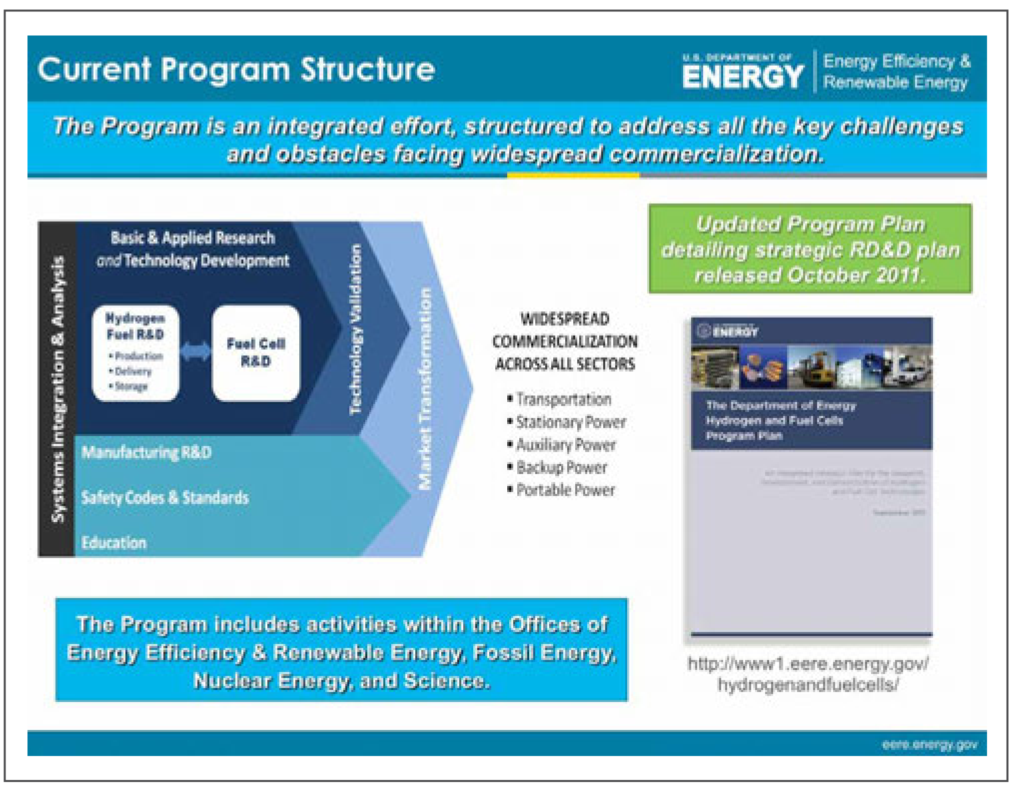
Desired Outcomes:

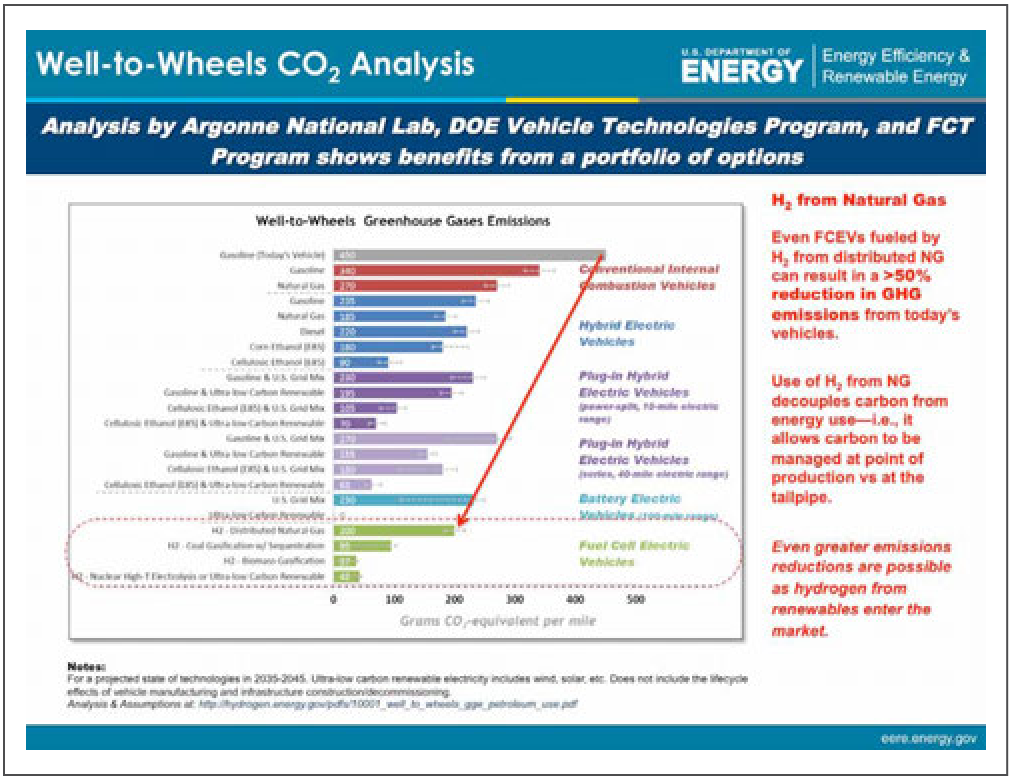
- Identify and prioritize opportunities to address the key challenges and synergies between natural gas and H_2
- Determine roles and opportunities for government and industry stakeholders

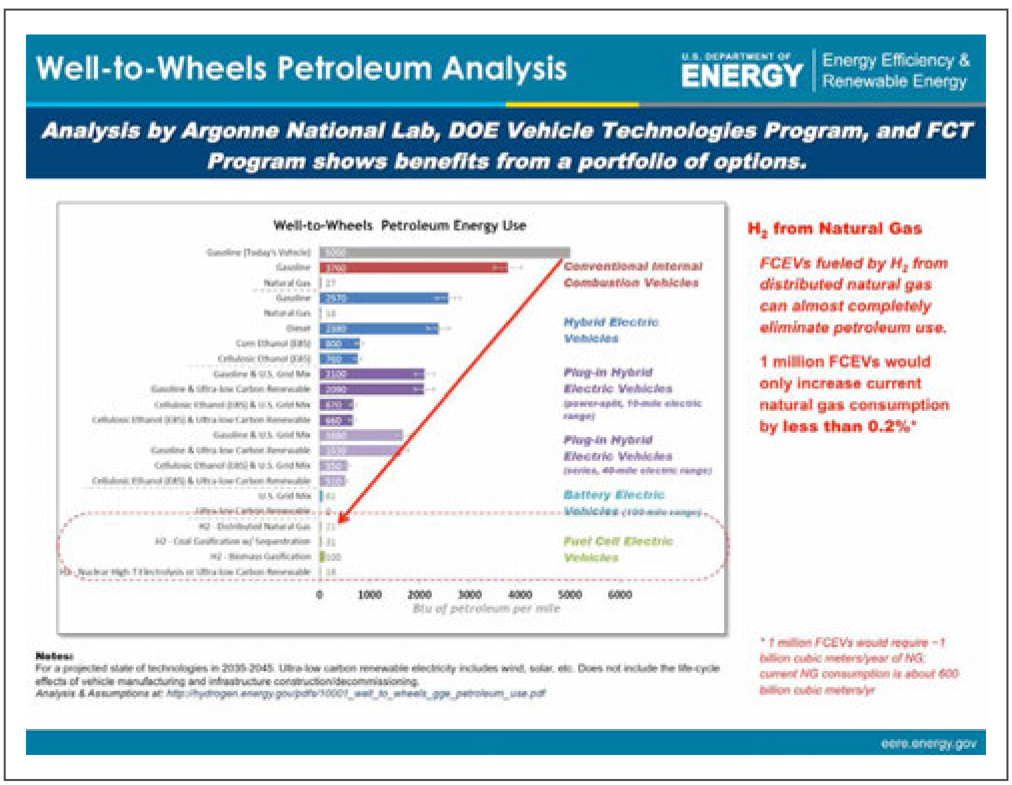
Source: US DOE 10/2010- draft Program Plan
Includes basic science through the Office of Science and applied RD&D through EERE, FE, NE

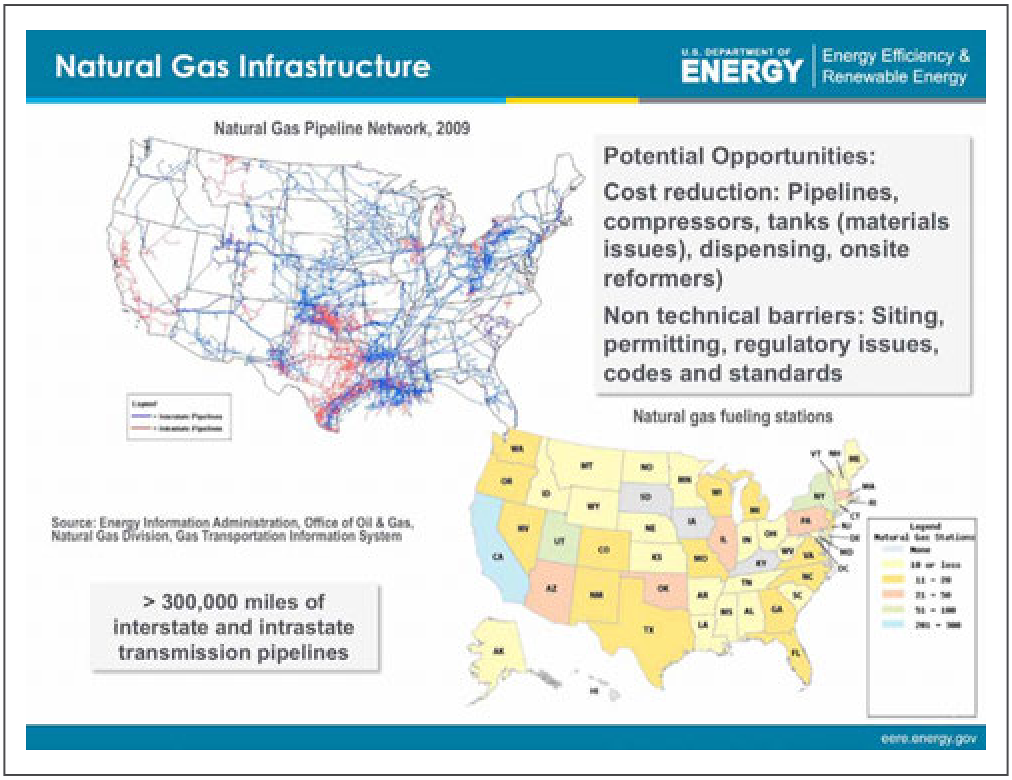
eere.energy.gov

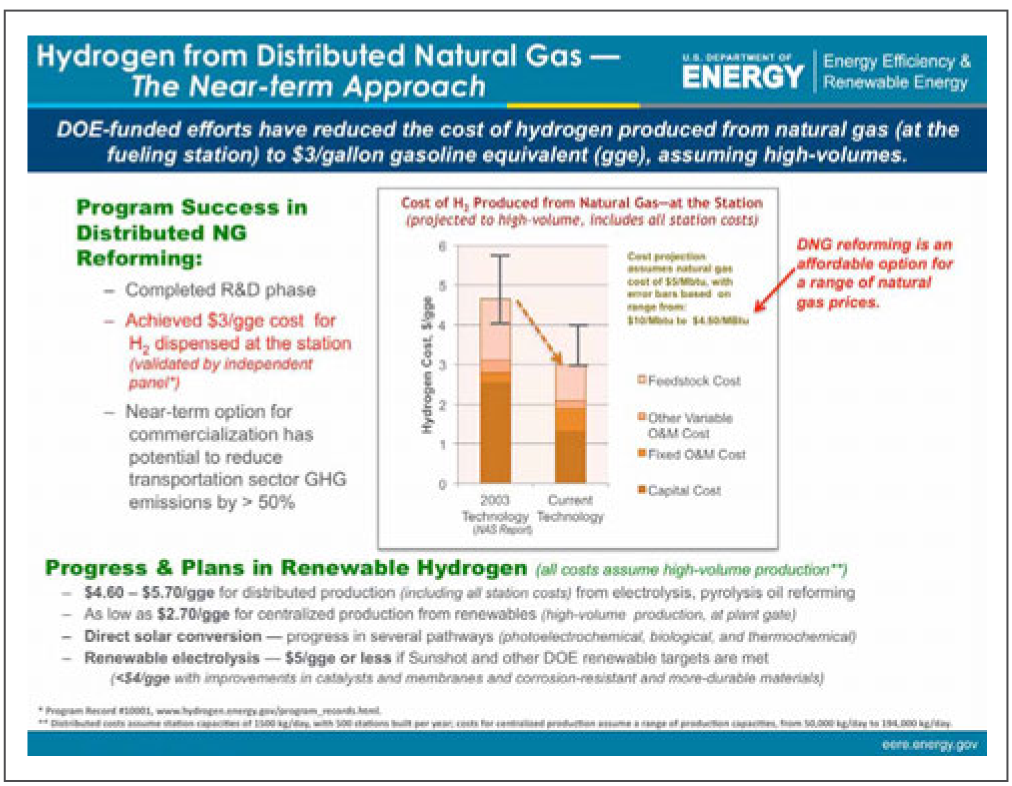

Fuel Cell Patent Growth and Markets
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
Clean Energy Patents
Fuel Cells
1000
800
600
400
200
2004
2005
2006
2007
2008
2009
2010
Fuel cell patents lead in the clean energy field with nearly 1,000 fuel cell patents issued in 2010.
•Number of fuel cell patents grew > 57% in 2010.
Fuel cell market continues to grow
• ~36% increase in global MWs shipped
• ~50% increase in US MWs shipped
Megawatts Shipped, Key Countries: 2008-2010
Various analyses project that the global fuel cell/hydrogen market could reach maturity over the next 10 to 20 years, producing revenues of $14 to $139 billion/year in stationary, portable and transportation sectors.
Widespread market penetration of fuel cells could lead to:
180,000 new jobs in the US by 2020
675,000 jobs by 2035
USA
Japan
South Korea
Germany
Other
FuelCells2000, Pike Research, Fuel Cell Today, ANL
http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/program_plan2010.pdf
eere.energy.gov


Current Program Structure
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
The Program is an integrated effort, structured to address all the key challenges and obstacles facing widespread commercialization.
Systems Integration & Analysis
Basic & Applied Research and Technology Development
Hydrogen Fuel R&D
• Production
• Delivery
• Storage
Fuel Cell R&D
Technology Validation
Market Transformation
Manufacturing R&D
Safety Codes & Standards
Education
WIDESPREAD COMMERCIALIZATION ACROSS ALL SECTORS
• Transportation
• Stationary Power
• Auxiliary Power
• Backup Power
• Portable Power
Updated Program Plan detailing strategic RD&D plan released October 2011.
The Department of Energy Hydrogen and Fuel Cells Program Plan
The Program includes activities within the Offices of Energy Efficiency & Renewable Energy, Fossil Energy, Nuclear Energy, and Science.
http://www1.eere.energy.gov/hydrogenandfuelcells/
eere.energy.gov


Well-to-Wheels CO2 Analysis
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
Analysis by Argonne National Lab, DOE Vehicle Technologies Program, and FCT Program shows benefits from a portfolio of options
Well-to-Wheels Greenhouse Gases Emissions
Conventional Internal Combustion Vehicles
Hybrid Electric Vehicles
Plug-in Hybrid Electric Vehicles (power-split, 10-mile electric range)
Plug-in Hybrid Electric Vehicles (series, 40-mile electric range)
Battery Electric Vehicles (100-mile range)
Fuel Cell Electric Vehicles
0
100
200
300
400
500
Grams CO2-equivalent per mile
H2 from Natural Gas
Even FCEVs fueled by H2 from distributed NG can result in a >50% reduction in GHG emissions from today's vehicles.
Use of H2 from NG decouples carbon from energy use—i.e., it allows carbon to be managed at point of production vs at the tailpipe.
Even greater emissions reductions are possible as hydrogen from renewables enter the market.
Notes:
For a projected state of technologies in 2035-2045. Ultra-low carbon renewable electricity includes wind, solar, etc. Does not include the lifecycle effects of vehicle manufacturing and infrastructure construction/decommissioning.
Analysis & Assumptions at: http://hydrogen.energy.gov/pdfs/10001_well_to_wheels_gge_petroleum_use.pdf
eere.energy.gov


Well-to-Wheels Petroleum Analysis
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
Analysis by Argonne National Lab, DOE Vehicle Technologies Program, and FCT Program shows benefits from a portfolio of options.
Well-to-Wheels Petroleum Energy Use
Conventional Internal Combustion Vehicles
Hybrid Electric Vehicles
Plug-in Hybrid Electric Vehicles (power-split, 10-mile electric range)
Plug-in Hybrid Electric Vehicles (series, 40-mile electric range)
Battery Electric Vehicles (100-mile range)
Fuel Cell Electric Vehicles
0
1000
2000
3000
4000
5000
6000
Btu of petroleum per mile
H2 from Natural Gas
FCEVs fueled by H2 from distributed natural gas can almost completely eliminate petroleum use.
1 million FCEVs would only increase current natural gas consumption by less than 0.2%*
* 1 million FCEVs would require ~1 billion cubic meters/year of NG; current NG consumption is about 600 billion cubic meters/yr
Notes:
For a projected state of technologies in 2035-2045. Ultra-low carbon renewable electricity includes wind, solar, etc. Does not include the life-cycle effects of vehicle manufacturing and infrastructure construction/decommissioning.
Analysis & Assumptions at: http://hydrogen.energy.gov/pdfs/10001_well_to_wheels_gge_petroleum_use.pdf
eere.energy.gov


Natural Gas Infrastructure
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
Natural Gas Pipeline Network, 2009
Potential Opportunities:
Cost reduction: Pipelines, compressors, tanks (materials issues), dispensing, onsite reformers)
Non technical barriers: Siting, permitting, regulatory issues, codes and standards
Natural gas fueling stations
Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System
> 300,000 miles of interstate and intrastate transmission pipelines
eere.energy.gov


Hydrogen from Distributed Natural Gas — The Near-term Approach
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
DOE-funded efforts have reduced the cost of hydrogen produced from natural gas (at the fueling station) to $3/gallon gasoline equivalent (gge), assuming high-volumes.
Program Success in Distributed NG Reforming:
– Completed R&D phase
– Achieved $3/gge cost for H2 dispensed at the station (validated by independent panel*)
– Near-term option for commercialization has potential to reduce transportation sector GHG emissions by > 50%
Cost of H2 Produced from Natural Gas—at the Station (projected to high-volume, includes all station costs)
Hydrogen Cost, $/gge
0
1
2
3
4
5
6
2003 Technology (NAS Report)
Current Technology
Feedstock Cost
Other Variable O&M Cost
Fixed O&M Cost
Capital Cost
DNG reforming is an affordable option for a range of natural gas prices.
Progress & Plans in Renewable Hydrogen (all costs assume high-volume production**)
– $4.60 – $5.70/gge for distributed production (including all station costs) from electrolysis, pyrolysis oil reforming
– As low as $2.70/gge for centralized production from renewables (high-volume production, at plant gate)
– Direct solar conversion — progress in several pathways (photoelectrochemical, biological, and thermochemical)
– Renewable electrolysis — $5/gge or less if Sunshot and other DOE renewable targets are met (<$4/gge with improvements in catalysts and membranes and corrosion-resistant and more-durable materials)
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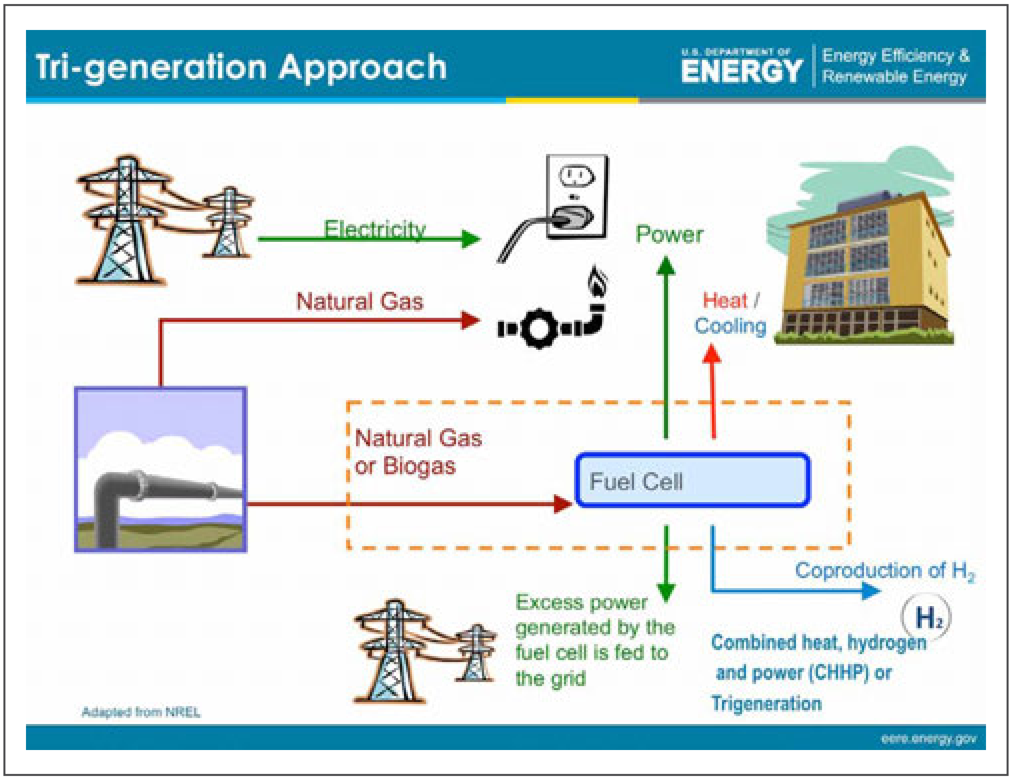
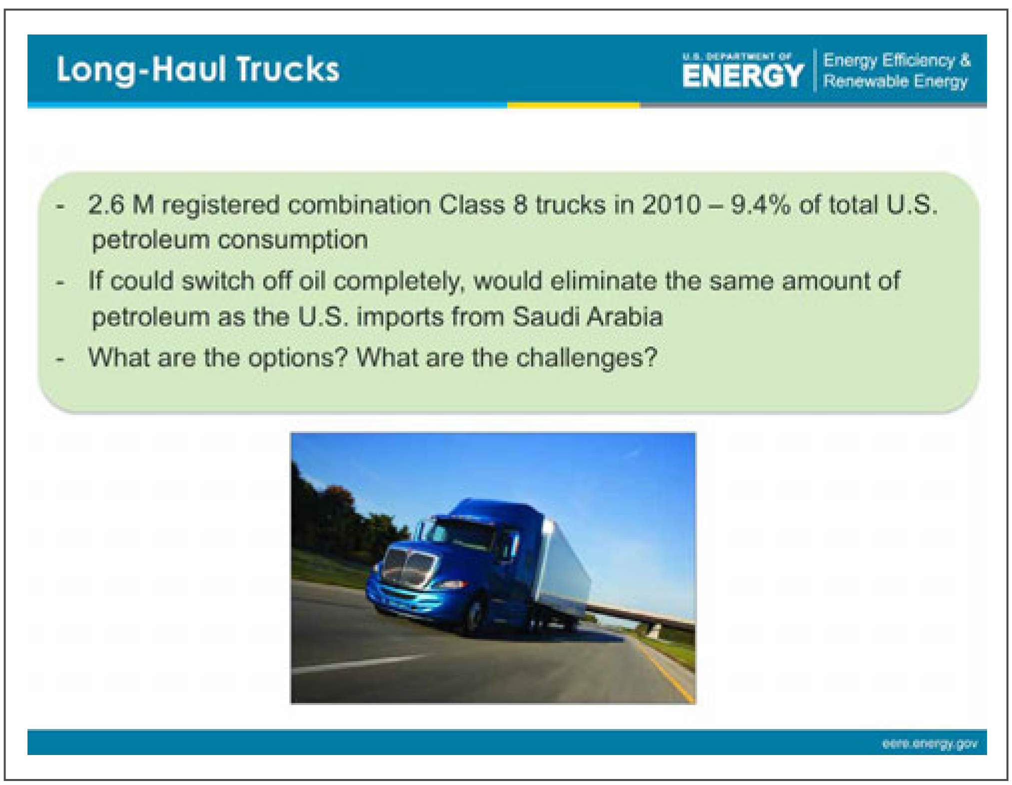

Tri-generation Approach
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
Electricity
Natural Gas
Power
Heat / Cooling
Natural Gas or Biogas
Fuel Cell
Coproduction of H_2
H_2
Excess power generated by the fuel cell is fed to the grid
Combined heat, hydrogen and power (CHHP) or Trigeneration
Adapted from NREL
eere.energy.gov


Long-Haul Trucks
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
- 2.6 M registered combination Class 8 trucks in 2010 – 9.4% of total U.S. petroleum consumption
- If could switch off oil completely, would eliminate the same amount of petroleum as the U.S. imports from Saudi Arabia
- What are the options? What are the challenges?
eere.energy.gov

Potential Options

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

	Diesel with Improved Efficiency	Liquefied Natural Gas	Drop-In Biofuels	Electrification
Cost	Vehicle minimal, but fuel prices rising and unpredictable	Vehicle cost is higher, but fuel costs low and more consistent	Vehicle minimal, but fuel not currently at cost	Vehicle cost extremely high; no practical payback period
Energy security	Imported fuel; could reduce demand but not eliminate	Domestic; could completely fulfill need	Domestic could fulfill some need, but aviation may have higher demand	Domestic; will be in-demand for light-duty
Feasibility	High	High	Medium	Low

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Challenges and Responses

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Infrastructure build-out: 1,000-5,000 new stations
  - Private industry investing
  - Potential unique financing mechanisms
- Uncertainty of change
  - UPS Recovery Act pilot project
- Secondary market
  - Recovery Act projects in multiple applications
- Vehicle cost differential
  - Potential for further R&D

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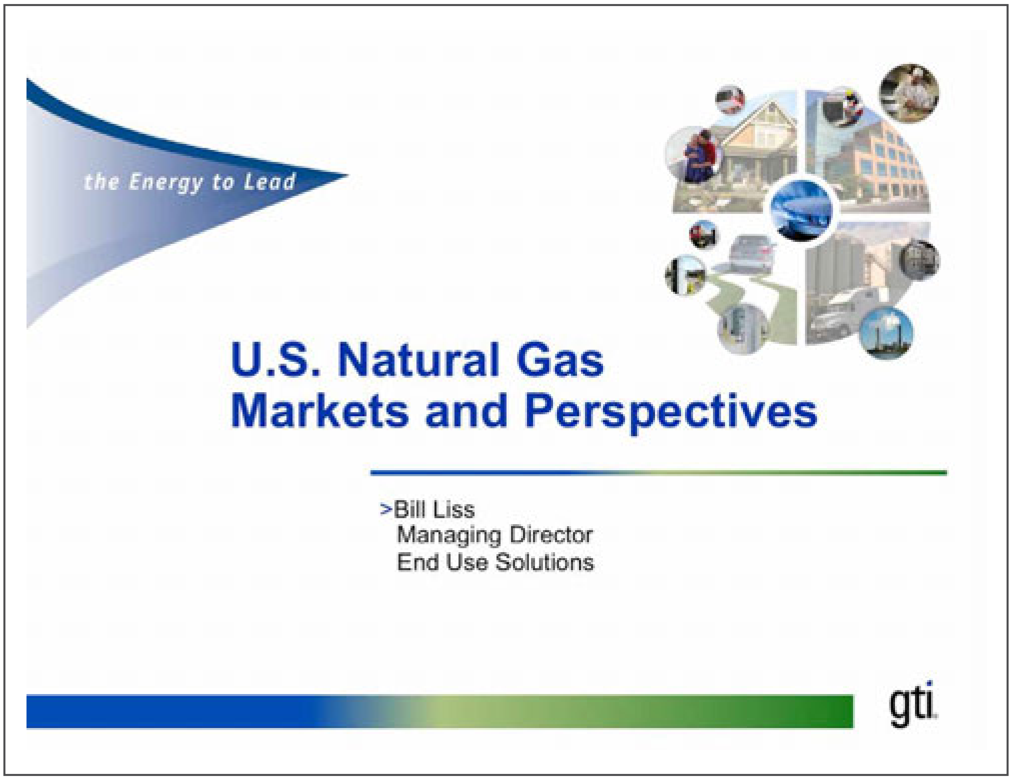
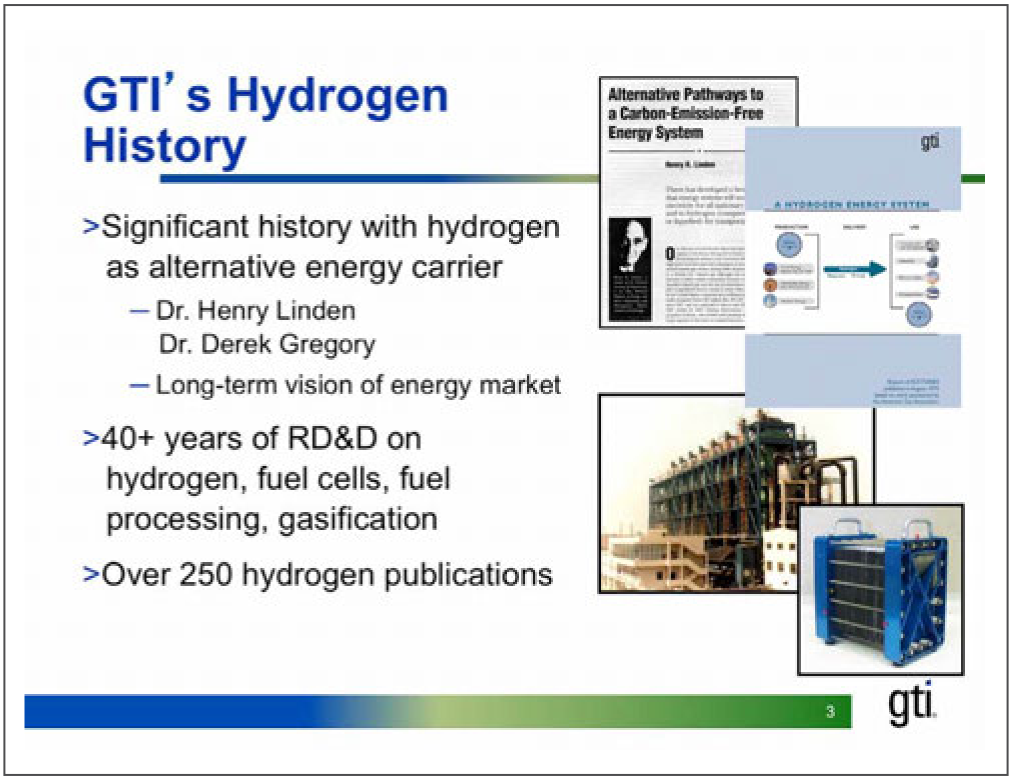
Natural Gas Vehicle Technology Forum
– 2011 Meeting
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
NGVTF
• Identify barriers to increased NGV market penetration
– Held annually
– Primarily focused on medium- and heavy-duty vehicles and associated infrastructure
• Government/industry stakeholder discussion forum
– Technology development and deployment barriers for NGVs
– Impact of energy economics on technology development
– New standards development
– Ongoing projects: status updates from DOE/CEC/SCAQMD
October 25-26, 2011
San Francisco, CA
www.eere.energy.gov/cleancities/natural_gas_forum_meeting_oct11.html
eere.energy.gov

Presentation Slides: U.S. Natural Gas Markets and Perspectives

Bill Liss, GTI




GTI's Hydrogen History
>Significant history with hydrogen as alternative energy carrier
– Dr. Henry Linden
Dr. Derek Gregory
– Long-term vision of energy market
>40+ years of RD&D on hydrogen, fuel cells, fuel processing, gasification
>Over 250 hydrogen publications
Alternative Pathways to a Carbon-Emission-Free Energy System
A HYDROGEN ENERGY SYSTEM
3
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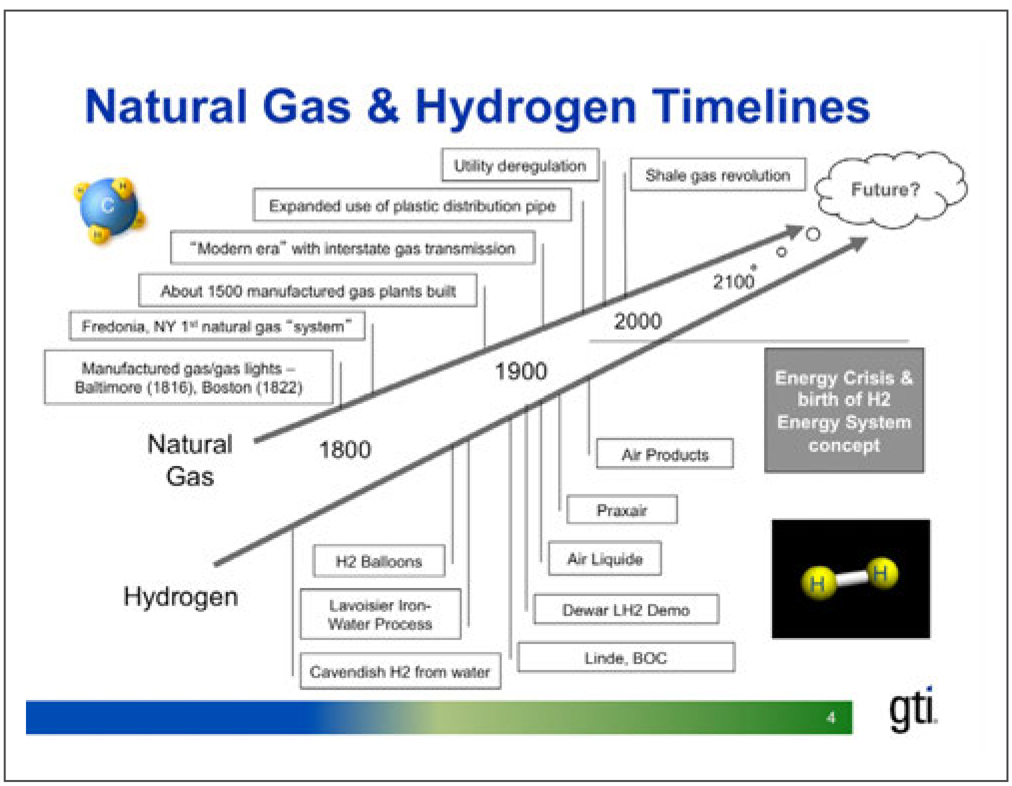
Natural Gas & Hydrogen Timelines
Utility deregulation
Shale gas revolution
Future?
Expanded use of plastic distribution pipe
"Modern era" with interstate gas transmission
About 1500 manufactured gas plants built
Fredonia, NY 1st natural gas "system"
Manufactured gas/gas lights – Baltimore (1816), Boston (1822)
Natural Gas
1800
1900
2000
2100
Energy Crisis & birth of H2 Energy System concept
Air Products
Praxair
Air Liquide
Dewar LH2 Demo
Linde, BOC
H2 Balloons
Lavoisier Iron-Water Process
Cavendish H2 from water
Hydrogen
4
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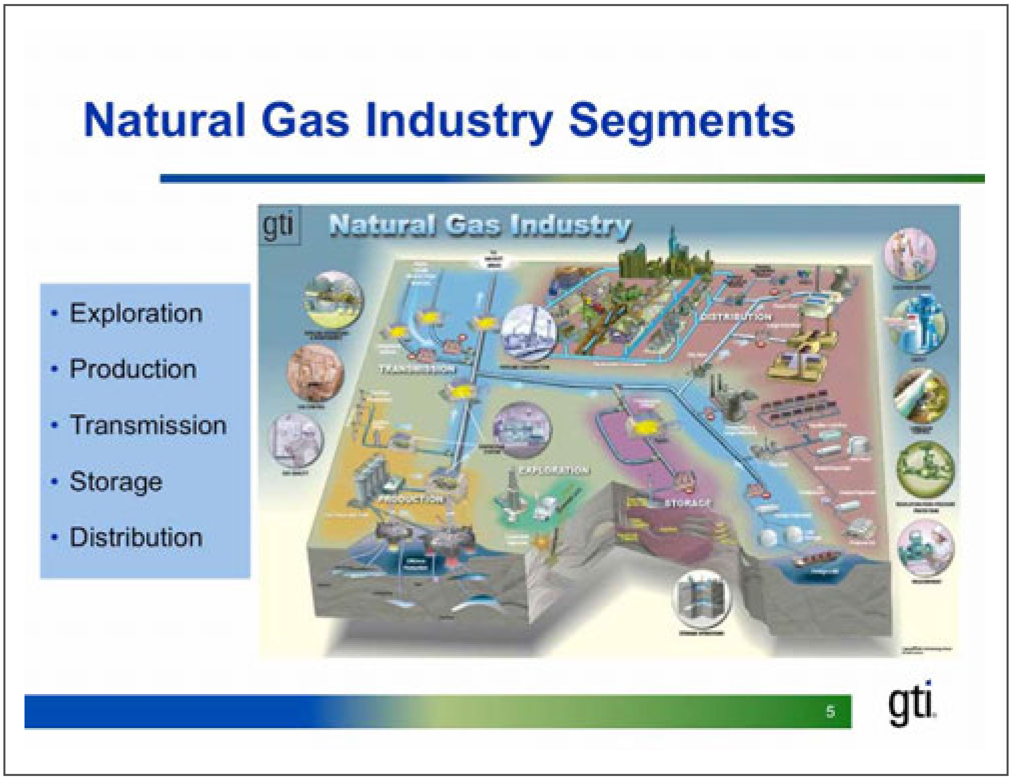
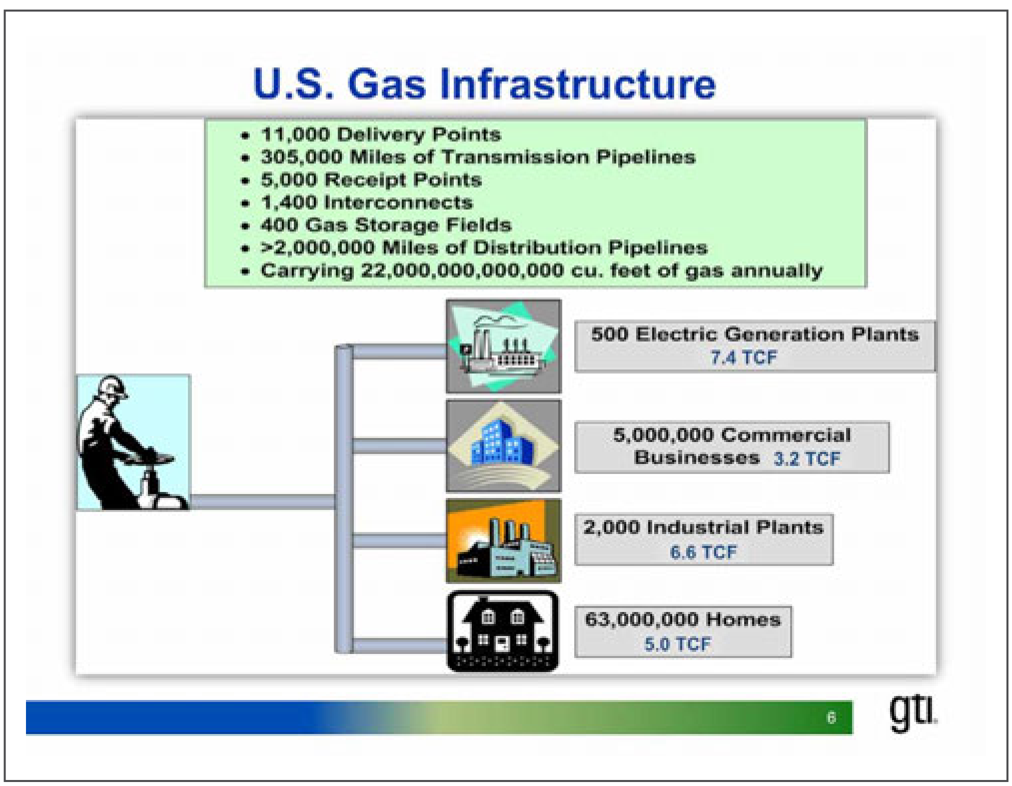

Natural Gas Industry Segments
• Exploration
• Production
• Transmission
• Storage
• Distribution
gti
Natural Gas Industry
5
gti


U.S. Gas Infrastructure
• 11,000 Delivery Points
• 305,000 Miles of Transmission Pipelines
• 5,000 Receipt Points
• 1,400 Interconnects
• 400 Gas Storage Fields
• >2,000,000 Miles of Distribution Pipelines
• Carrying 22,000,000,000,000 cu. feet of gas annually
500 Electric Generation Plants 7.4 TCF
5,000,000 Commercial Businesses 3.2 TCF
2,000 Industrial Plants 6.6 TCF
63,000,000 Homes 5.0 TCF
6
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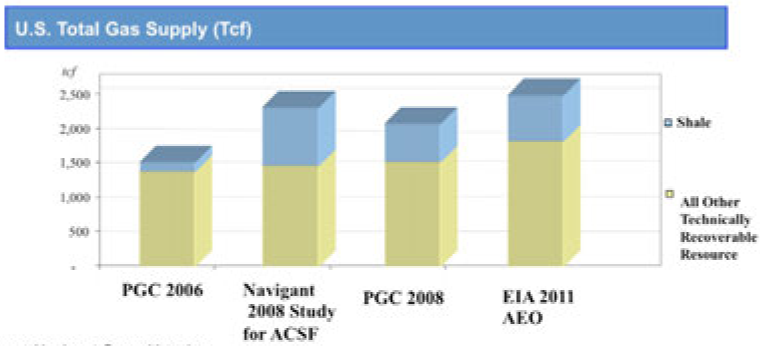
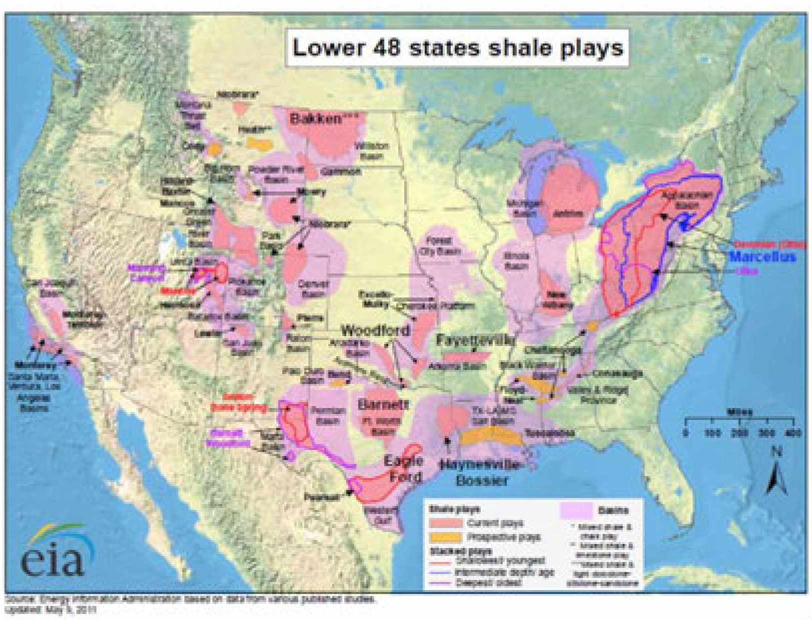
Today's Big Story: Robust and Expanding Gas Supply Estimates

>Substantial natural gas supply additions in past five years (over 100x annual consumption)

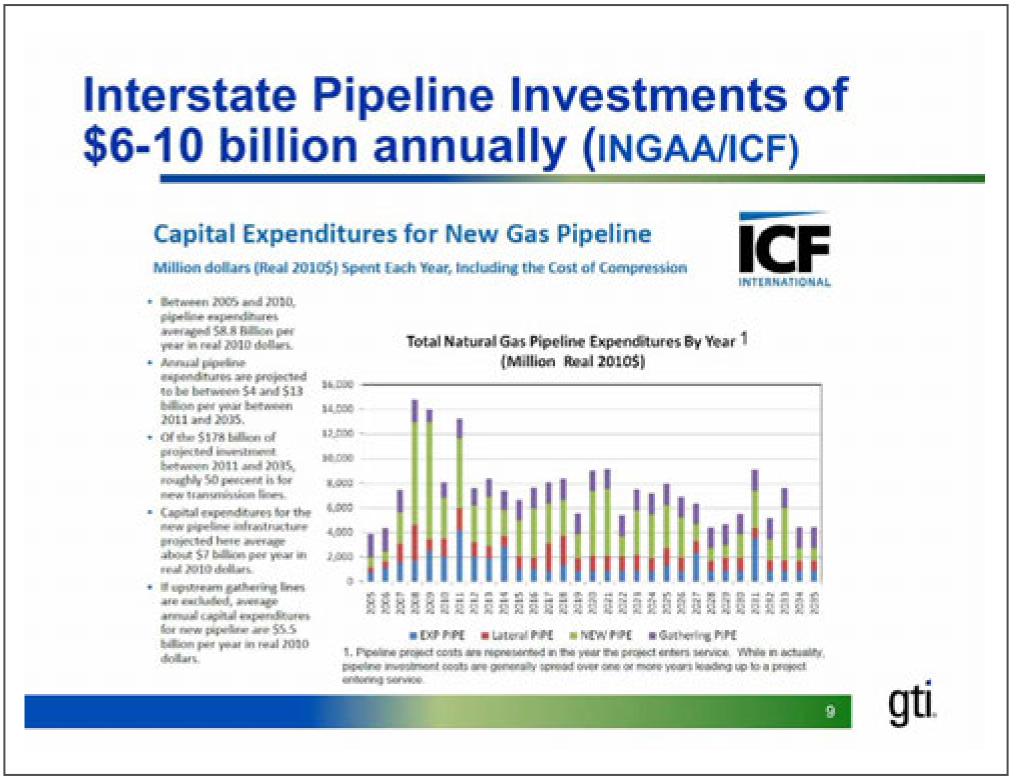


Source: Navigant Consulting, Inc.

7 gti



8 gti


Interstate Pipeline Investments of $6-10 billion annually (INGAA/ICF)
Capital Expenditures for New Gas Pipeline
Million dollars (Real 2010$) Spent Each Year, Including the Cost of Compression
ICF INTERNATIONAL
• Between 2005 and 2010, pipeline expenditures averaged $8.8 Billion per year in real 2010 dollars.
• Annual pipeline expenditures are projected to be between $4 and $13 billion per year between 2011 and 2035.
• Of the $178 billion of projected investment between 2011 and 2035, roughly 50 percent is for new transmission lines.
• Capital expenditures for the new pipeline infrastructure projected here average about $7 billion per year in real 2010 dollars.
• If upstream gathering lines are excluded, average annual capital expenditures for new pipeline are $5.5 billion per year in real 2010 dollars.
Total Natural Gas Pipeline Expenditures By Year 1
(Million Real 2010$)
EXP PIPE
Lateral PIPE
NEW PIPE
Gathering PIPE
1. Pipeline project costs are represented in the year the project enters service. While in actuality, pipeline investment costs are generally spread over one or more years leading up to a project entering service.
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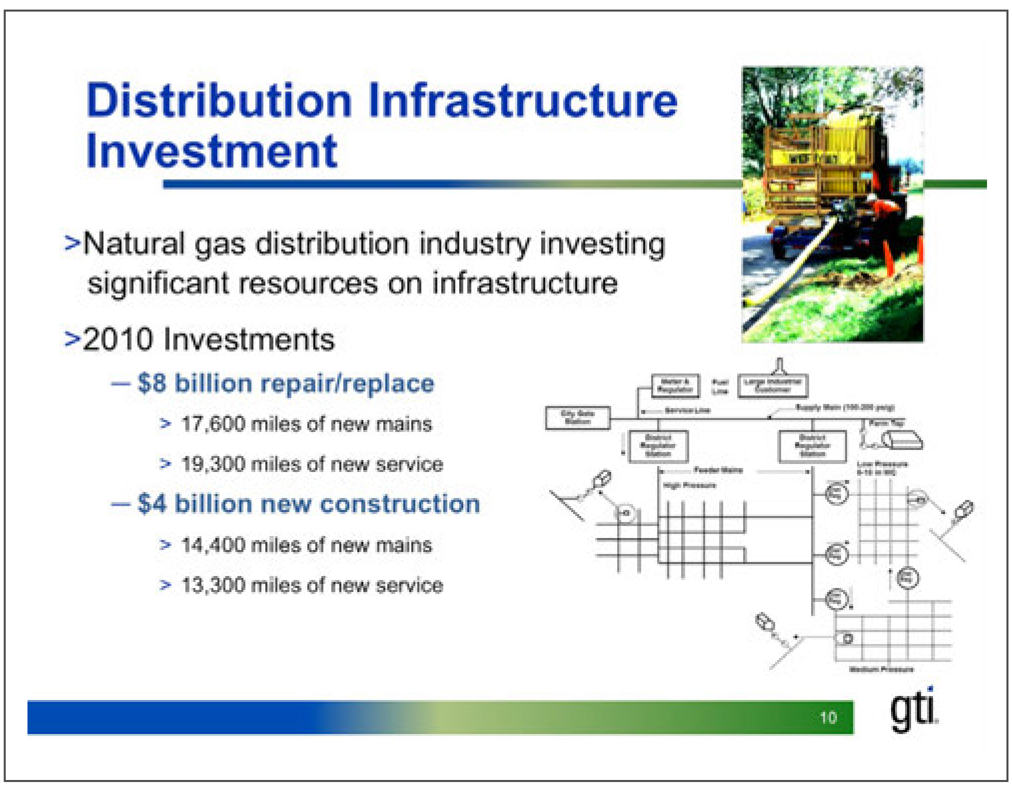
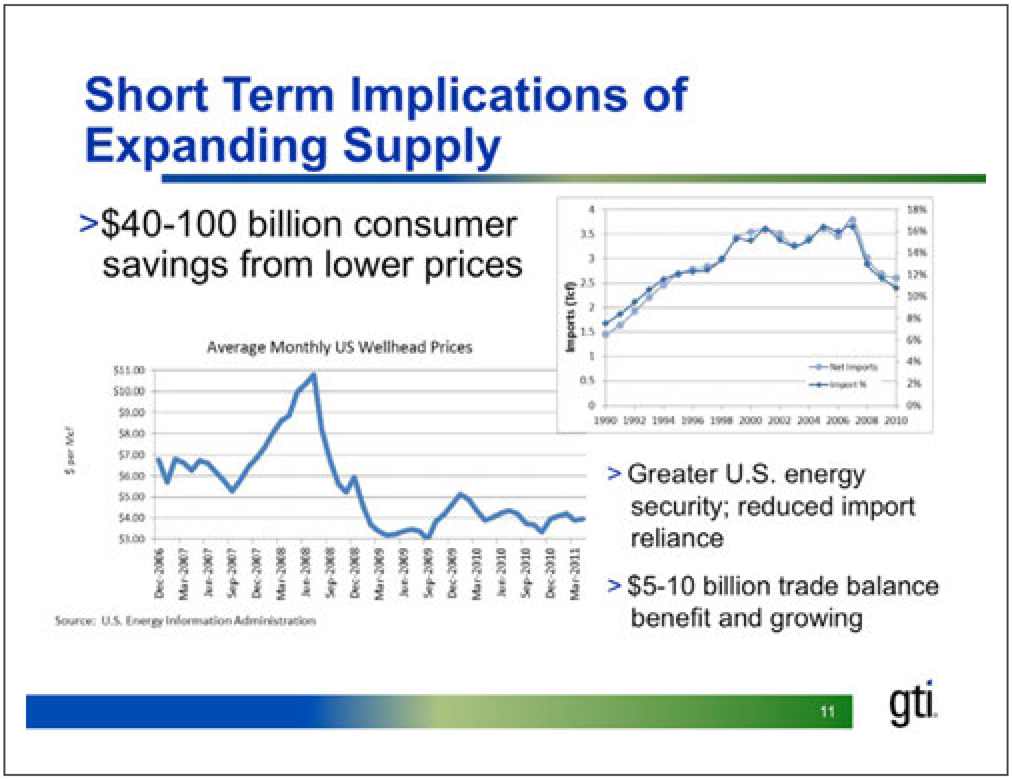
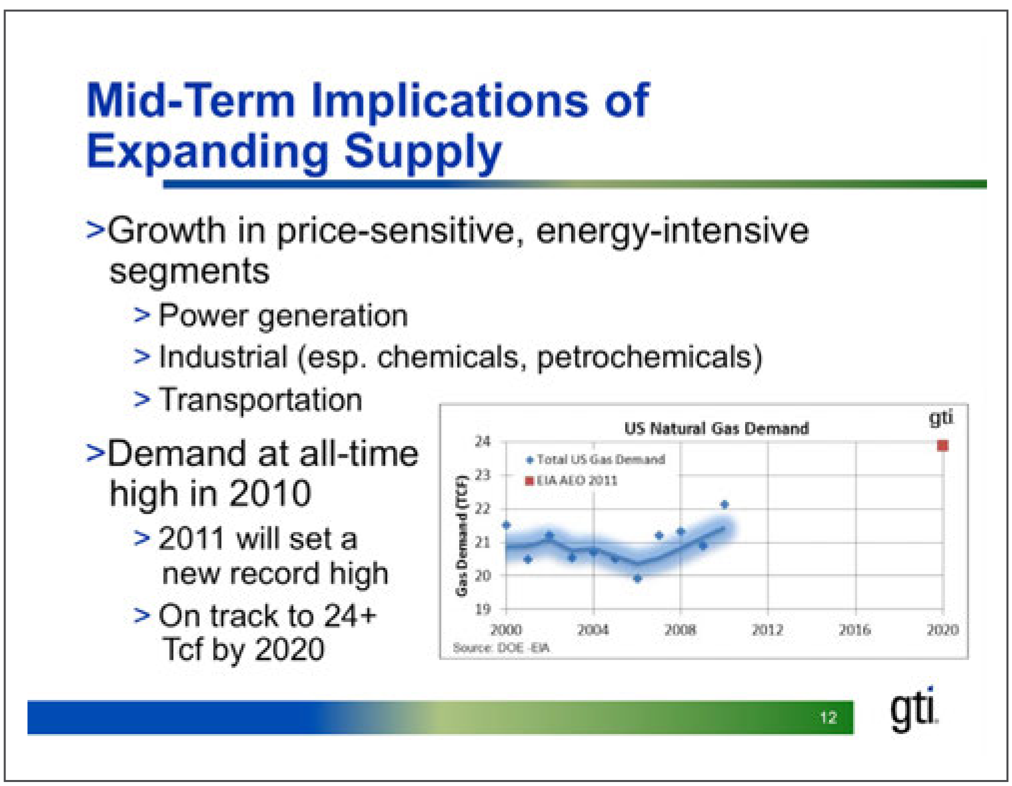
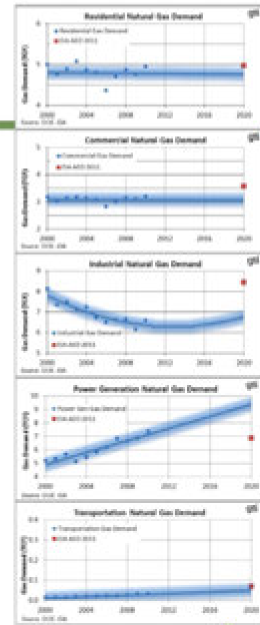

Distribution Infrastructure Investment
>Natural gas distribution industry investing significant resources on infrastructure
>2010 Investments
– $8 billion repair/replace
> 17,600 miles of new mains
> 19,300 miles of new service
– $4 billion new construction
> 14,400 miles of new mains
> 13,300 miles of new service
10
gti


Short Term Implications of Expanding Supply
>$40-100 billion consumer savings from lower prices
Average Monthly US Wellhead Prices
$ per Mcf
Source: U.S. Energy Information Administration
Imports (Tcf)
Net Imports
Import %
>Greater U.S. energy security; reduced import reliance
>$5-10 billion trade balance benefit and growing
11
gti


Mid-Term Implications of Expanding Supply
>Growth in price-sensitive, energy-intensive segments
>Power generation
>Industrial (esp. chemicals, petrochemicals)
>Transportation
>Demand at all-time high in 2010
>2011 will set a new record high
>On track to 24+ Tcf by 2020
US Natural Gas Demand
Total US Gas Demand
EIA AEO 2011
Gas Demand (TCF)
Source: DOE -EIA
12
gti

Natural Gas Demand Outlook

- >Growth led by expanding use in power generation
  - –Displace older coal power plants
- >Industrial sector rebound
  - –Onshoring; improved logistics and reduced shipping costs
- >NGV interest growing sharply
  - –Price differential to gasoline/diesel
- >Stable residential/commercial use
  - –Smart, efficient use; source energy policies

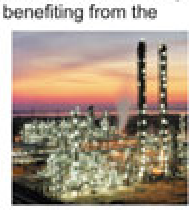


13 gti

New Announcements for Multiple Major Projects and Expanded Use

Power, petrochemicals, manufacturing: major plans

Natural Gas Boom Helps Petrochemical Industry
The petrochemical industry is benefiting from the recent boom in U.S. natural gas supplies, which has lowered feedstock costs. "Capital investment is now being reconsidered," said Kevin Swift, chief economist with the American Chemistry Council.



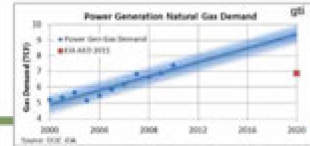
Natural Gas Taking America's Electric Power Sector by Storm
Currently, natural gas-fired generators constitute 39% of America's total electric generation capacity. Natural gas is a newer player-- 65% of America's natural gas-fired capacity has been added since 1980.

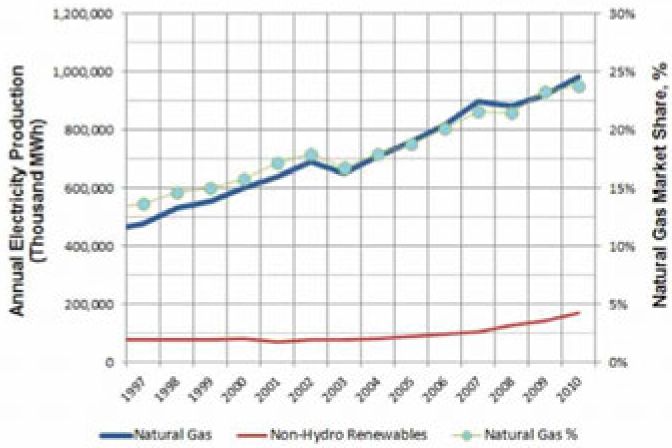
Nucor's Natural Gas Direct Reduced Iron plant
Over the next several years, Nucor Steel will be building what could be one of the most significant industrial projects in Louisiana history. The first phase, a 2.5 million tons-per-year iron-making facility, will convert natural gas and iron ore pellets into direct reduced iron for Nucor's steel mills

14 gti

Power Generation

Moving To 9 Tcf Annual Demand





15 gti

Natural Gas Opportunities to Reduce Liquid Fuel Dependence

- Natural gas poised to gain market from liquid fuels
  - High fuel oil, diesel, gasoline prices
  - Residential/commercial heating oil: over 1 Tcf incremental gas market
  - Transportation: 1 Tcf with high displacement scenario
- Offset U.S. demand for imports
- Improve energy security and balance of trade (about $25-35 billion)

Res/Com Market Displacement Potential	Current Annual Fuel Oil Sales, million gallons	Natural Gas Equivalent Potential (Tcf)
Residential	4,600	0.63
Commercial	3,000	0.4
	7,600	**1.03**

Transportation Displacement Scenarios	Diesel Gallons, millions	Gasoline Gallons, millions	Natural Gas Equivalent Potential Tcf
Low	940	570	0.11
Medium	2,800	1,640	0.32
High	9,400	2,610	**1.06**

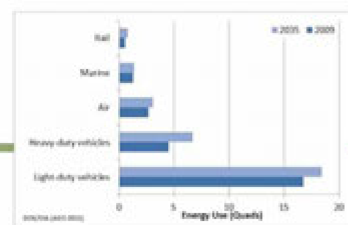
16 gti

Transportation Sector and Natural Gas

- Natural gas use for vehicles is multi-faceted
  - Direct, indirect
  - About 1.3 Tcf (mostly indirect "industrial sector" fuels production)
- Direct: NGVs
  - CNG, LNG (about 40 bcf)
- Indirect
  - Hydrogen for petroleum refining
  - Ethanol, biofuel production
- New paths:
  - H2 vehicles, GTL, PHEV power

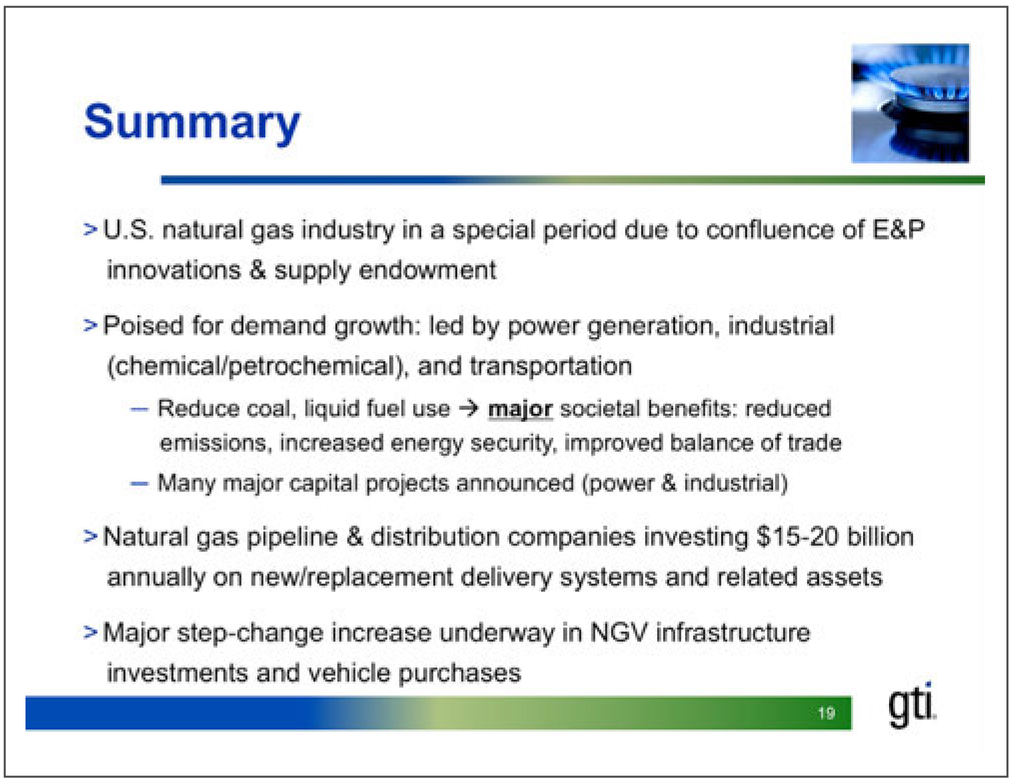
17 gti

Natural Gas Vehicles



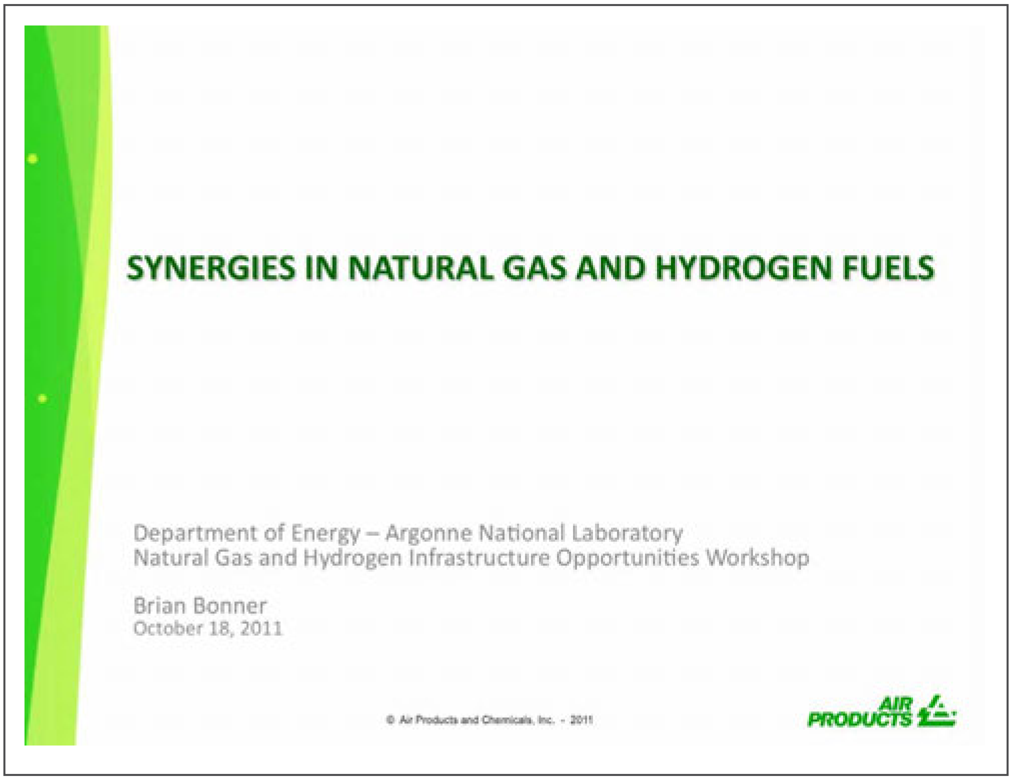
- Strong market interest, driven by fuel price differential
  - Medium and heavy-duty fleet vehicles are core market
  - Off-road opportunities (e.g., marine)
  - Light duty (and home fueling) is long-term goal
- Main challenges: cost reduction for vehicles, infrastructure
  - Growth & volume will move market towards improved pricing over next five years

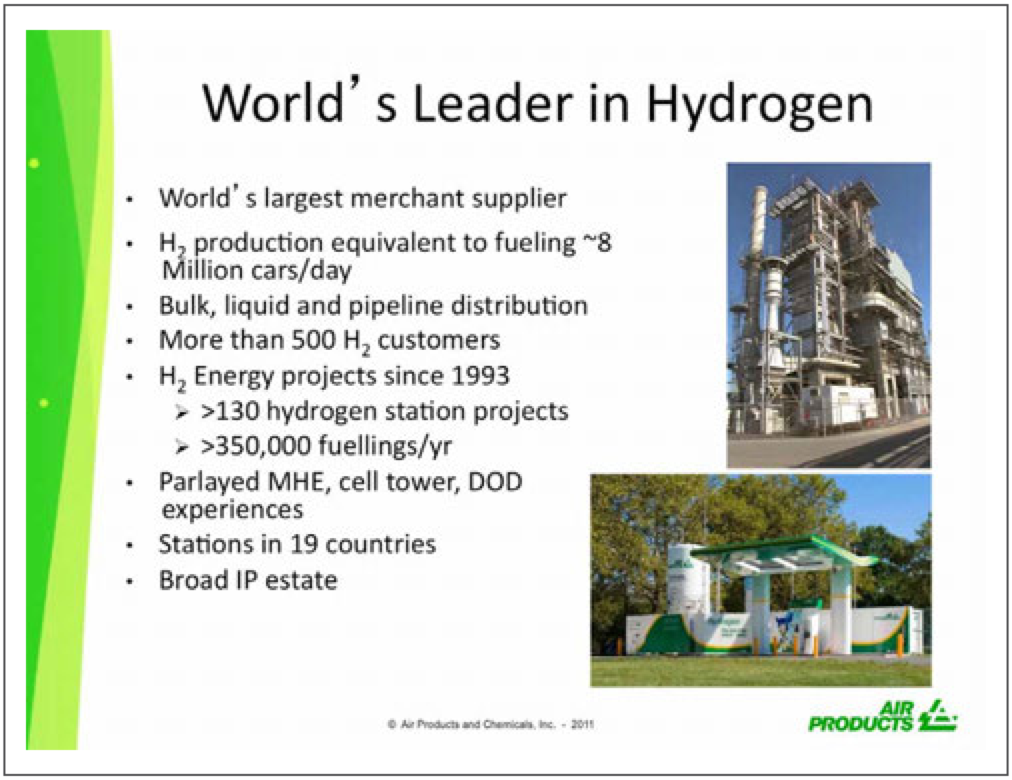
18 gti


Summary
> U.S. natural gas industry in a special period due to confluence of E&P innovations & supply endowment
> Poised for demand growth: led by power generation, industrial (chemical/petrochemical), and transportation
– Reduce coal, liquid fuel use → major societal benefits: reduced emissions, increased energy security, improved balance of trade
– Many major capital projects announced (power & industrial)
> Natural gas pipeline & distribution companies investing $15-20 billion annually on new/replacement delivery systems and related assets
> Major step-change increase underway in NGV infrastructure investments and vehicle purchases
19
gti

Presentation Slides: Synergies in Natural Gas and Hydrogen Fuels

Brian Bonner, Air Products and Chemicals, Inc.




World's Leader in Hydrogen
• World's largest merchant supplier
• H_2 production equivalent to fueling ~8 Million cars/day
• Bulk, liquid and pipeline distribution
• More than 500 H_2 customers
• H_2 Energy projects since 1993
➢ >130 hydrogen station projects
➢ >350,000 fuellings/yr
• Parlayed MHE, cell tower, DOD experiences
• Stations in 19 countries
• Broad IP estate
© Air Products and Chemicals, Inc. - 2011
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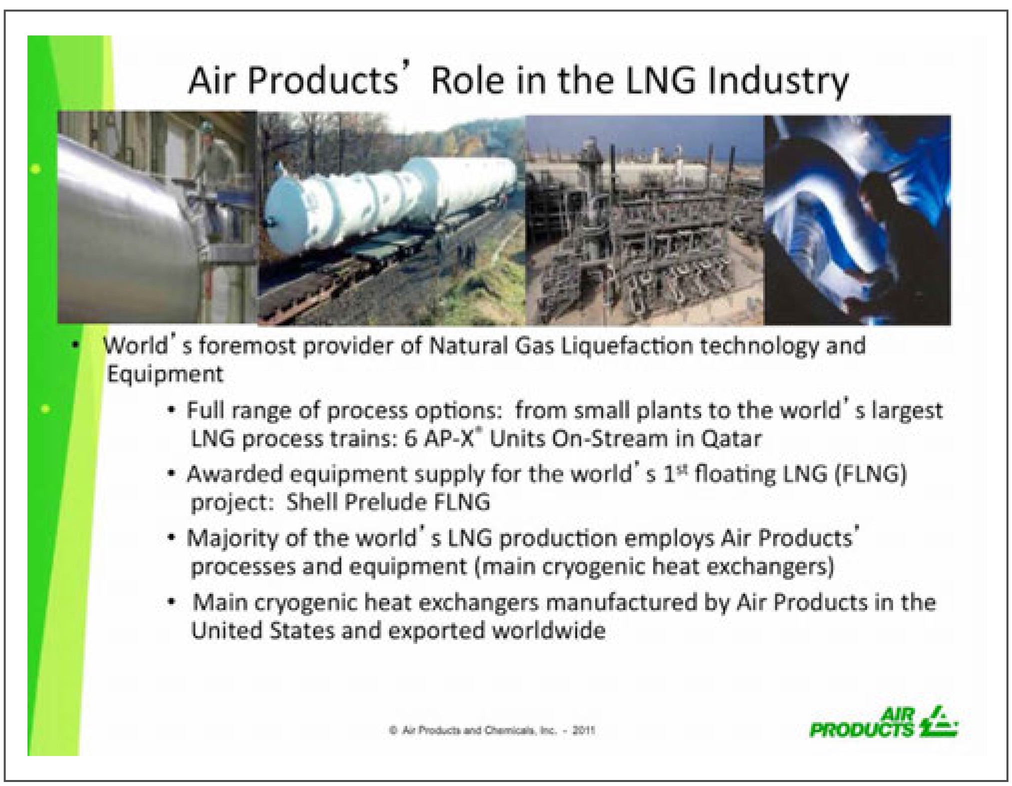
Air Products' Role in the LNG Industry
• World's foremost provider of Natural Gas Liquefaction technology and Equipment
• Full range of process options: from small plants to the world's largest LNG process trains: 6 AP-X® Units On-Stream in Qatar
• Awarded equipment supply for the world's 1st floating LNG (FLNG) project: Shell Prelude FLNG
• Majority of the world's LNG production employs Air Products' processes and equipment (main cryogenic heat exchangers)
• Main cryogenic heat exchangers manufactured by Air Products in the United States and exported worldwide
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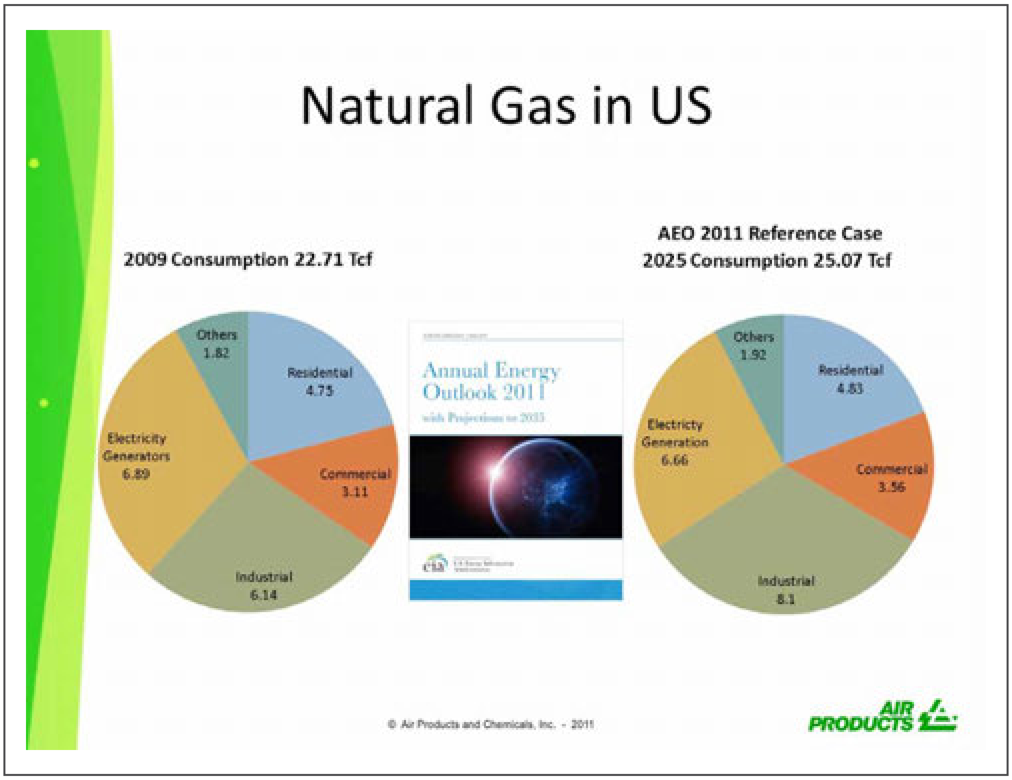
Natural Gas in US
2009 Consumption 22.71 Tcf
Others 1.82
Residential 4.75
Commercial 3.11
Industrial 6.14
Electricity Generators 6.89
Annual Energy Outlook 2011
AEO 2011 Reference Case
2025 Consumption 25.07 Tcf
Others 1.92
Residential 4.83
Commercial 3.56
Industrial 8.1
Electricty Generation 6.66
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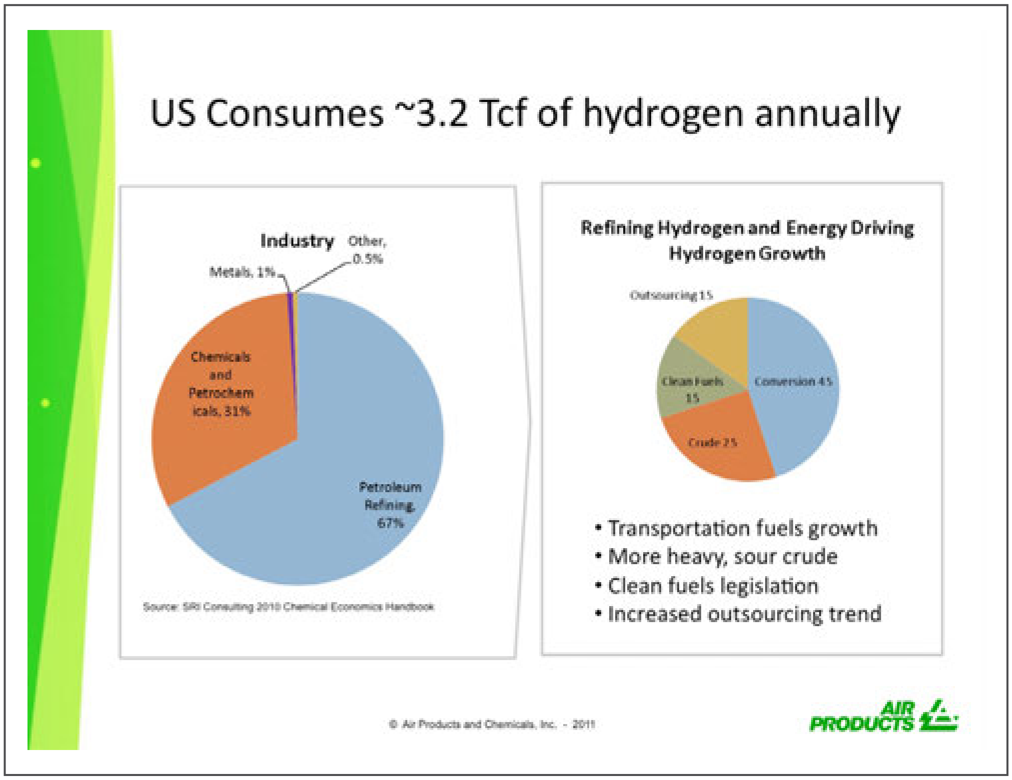
US Consumes ~3.2 Tcf of hydrogen annually
Industry
Other, 0.5%
Metals, 1%
Chemicals and Petrochemicals, 31%
Petroleum Refining, 67%
Source: SRI Consulting 2010 Chemical Economics Handbook
Refining Hydrogen and Energy Driving Hydrogen Growth
Outsourcing 15
Conversion 45
Clean Fuels 15
Crude 25
• Transportation fuels growth
• More heavy, sour crude
• Clean fuels legislation
• Increased outsourcing trend
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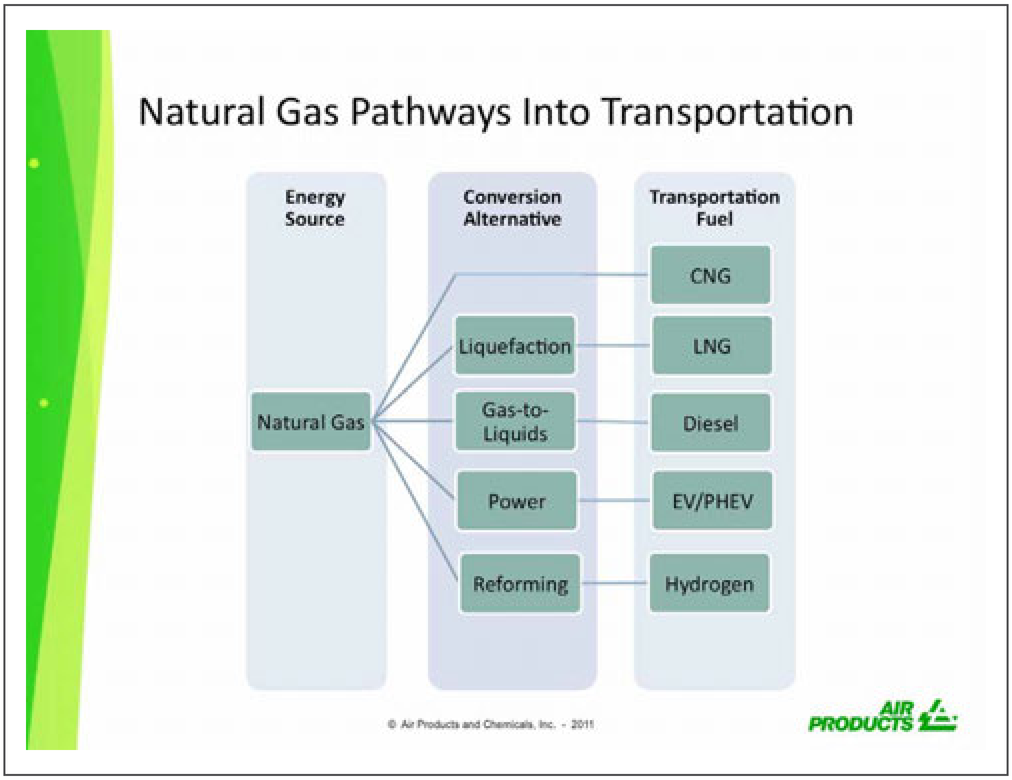
Natural Gas Pathways Into Transportation
Energy Source
Conversion Alternative
Transportation Fuel
Natural Gas
Liquefaction
Gas-to-Liquids
Power
Reforming
CNG
LNG
Diesel
EV/PHEV
Hydrogen
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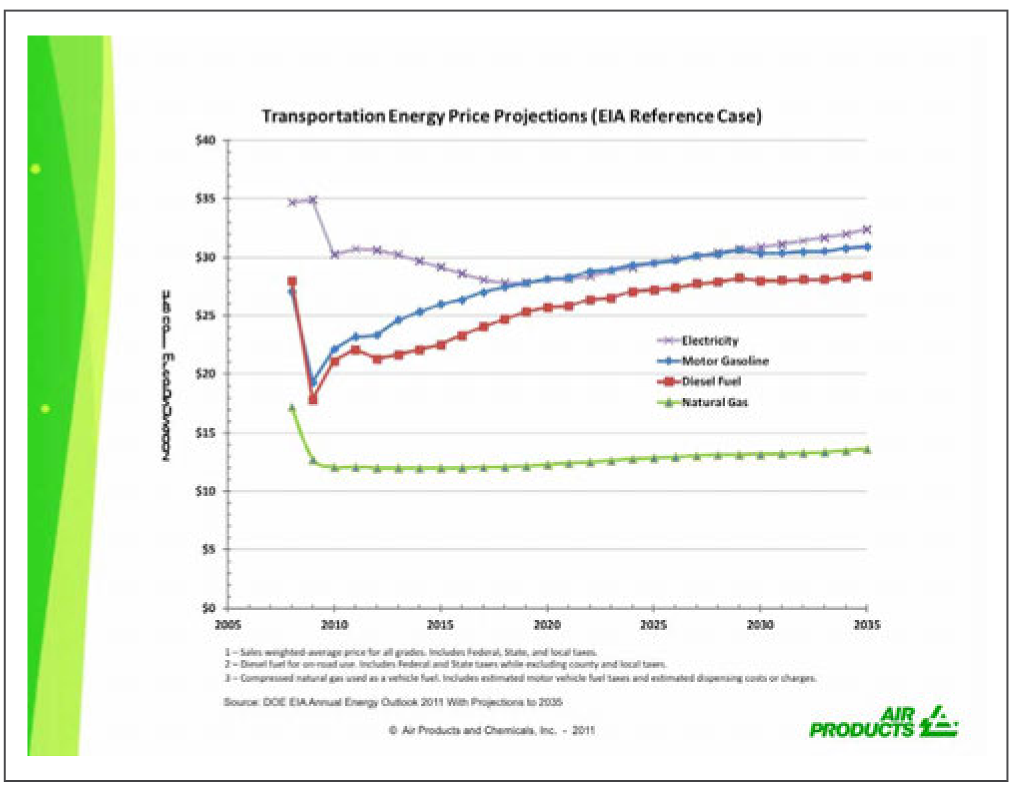
Transportation Energy Price Projections (EIA Reference Case)
$40
$35
$30
$25
$20
$15
$10
$5
$0
2005
2010
2015
2020
2025
2030
2035
Electricity
Motor Gasoline
Diesel Fuel
Natural Gas
1 – Sales weighted-average price for all grades. Includes Federal, State, and local taxes.
2 – Diesel fuel for on-road use. Includes Federal and State taxes while excluding county and local taxes.
3 – Compressed natural gas used as a vehicle fuel. Includes estimated motor vehicle fuel taxes and estimated dispensing costs or charges.
Source: DOE EIA Annual Energy Outlook 2011 With Projections to 2035
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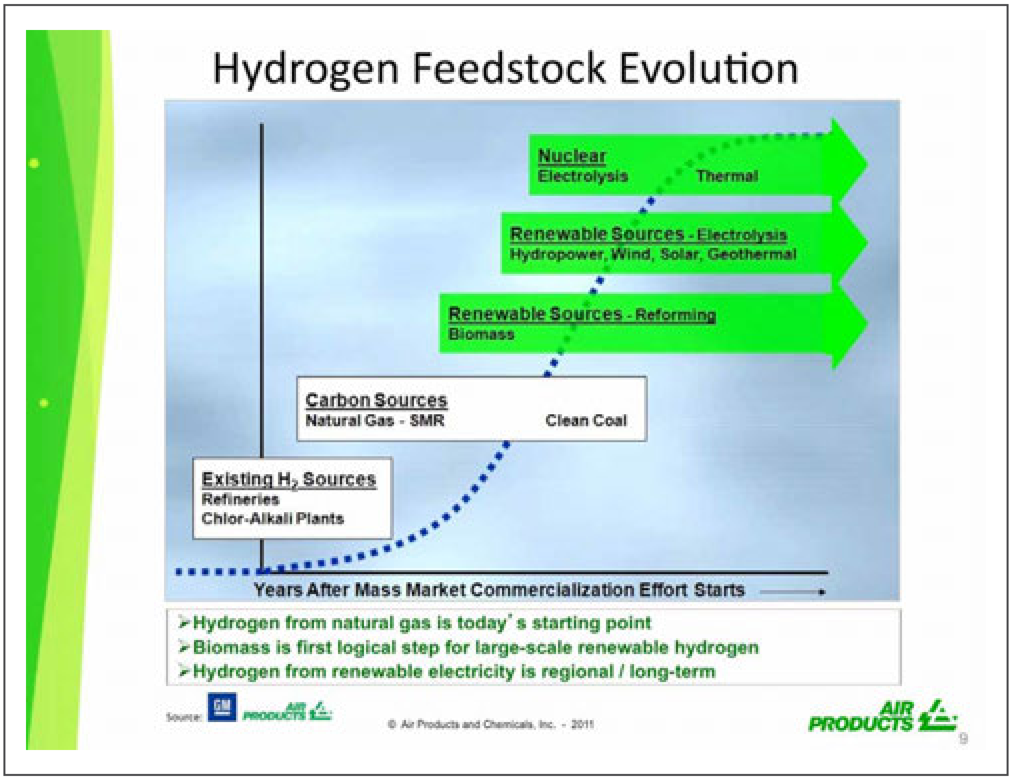
AIR PRODUCTS


Hydrogen Feedstock Evolution
Nuclear
Electrolysis
Thermal
Renewable Sources - Electrolysis
Hydropower, Wind, Solar, Geothermal
Renewable Sources - Reforming
Biomass
Carbon Sources
Natural Gas - SMR
Clean Coal
Existing H2 Sources
Refineries
Chlor-Alkali Plants
Years After Mass Market Commercialization Effort Starts
➢Hydrogen from natural gas is today's starting point
➢Biomass is first logical step for large-scale renewable hydrogen
➢Hydrogen from renewable electricity is regional / long-term
Source:
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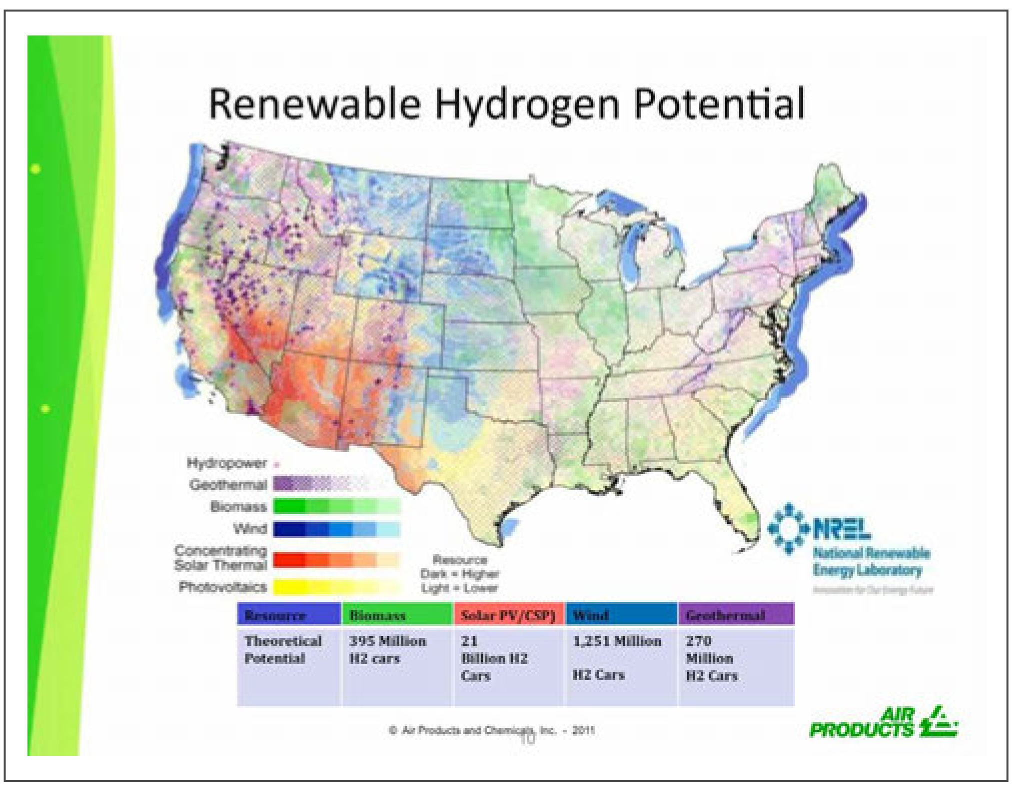
Renewable Hydrogen Potential
Hydropower
Geothermal
Biomass
Wind
Concentrating Solar Thermal
Photovoltaics
Resource
Dark = Higher
Light = Lower
NREL
National Renewable Energy Laboratory
Resource | Biomass | Solar PV/CSP) | Wind | Geothermal
Theoretical Potential | 395 Million H2 cars | 21 Billion H2 Cars | 1,251 Million H2 Cars | 270 Million H2 Cars
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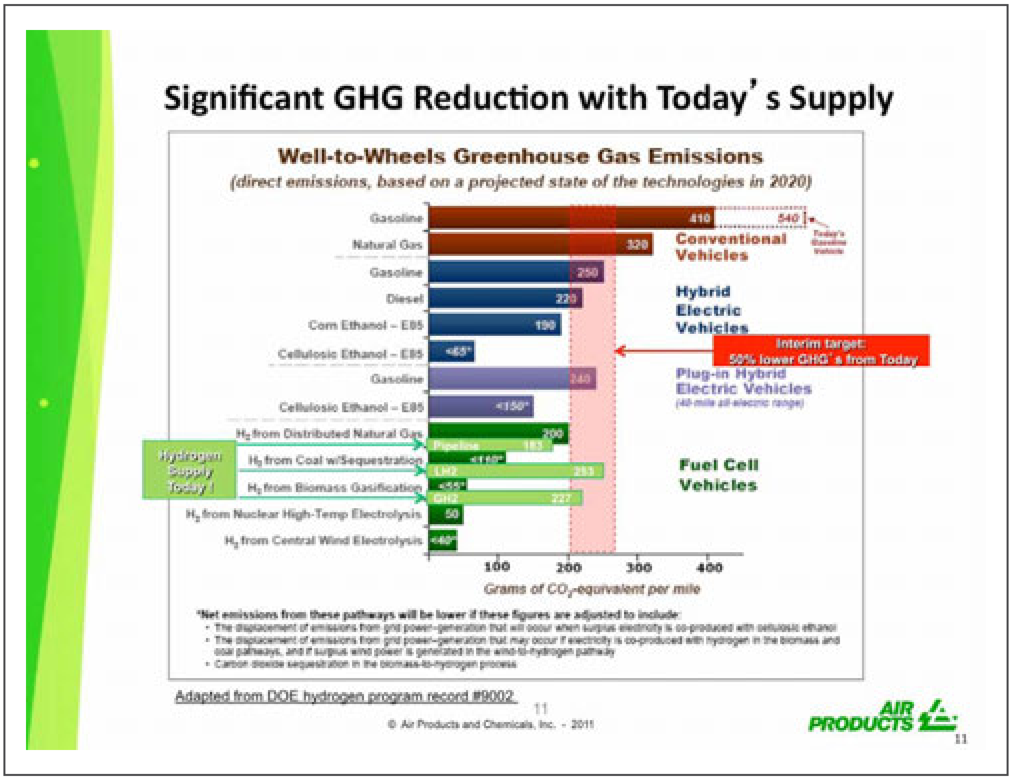
Significant GHG Reduction with Today's Supply
Well-to-Wheels Greenhouse Gas Emissions
(direct emissions, based on a projected state of the technologies in 2020)
Gasoline
Natural Gas
Gasoline
Diesel
Corn Ethanol – E85
Cellulosic Ethanol – E85
Gasoline
Cellulosic Ethanol – E85
H2 from Distributed Natural Gas
H2 from Coal w/Sequestration
H2 from Biomass Gasification
H2 from Nuclear High-Temp Electrolysis
H2 from Central Wind Electrolysis
Hydrogen Supply Today!
410
540
320
250
220
190
<65*
240
<150*
200
Pipeline 183
<110*
LH2 253
<55*
GH2 227
50
<40*
Conventional Vehicles
Hybrid Electric Vehicles
Interim target: 50% lower GHG's from Today
Plug-in Hybrid Electric Vehicles
Fuel Cell Vehicles
100
200
300
400
Grams of CO2-equivalent per mile
*Net emissions from these pathways will be lower if these figures are adjusted to include:
Adapted from DOE hydrogen program record #9002
11
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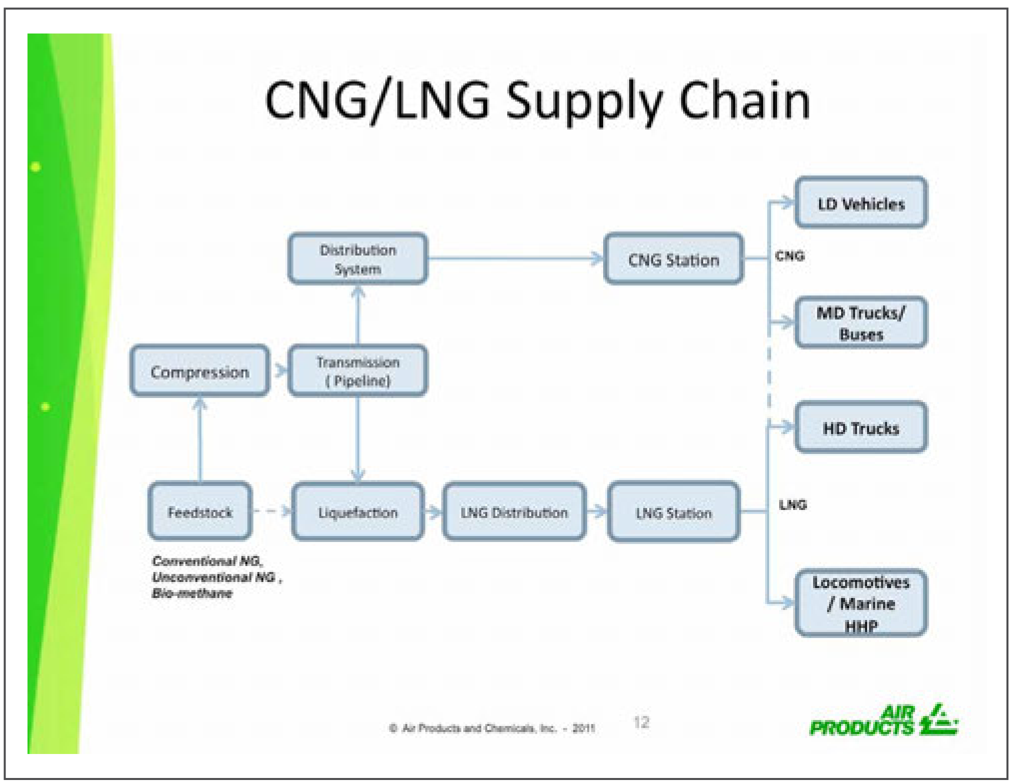
11


CNG/LNG Supply Chain
Distribution System
CNG Station
LD Vehicles
CNG
MD Trucks/ Buses
Compression
Transmission (Pipeline)
HD Trucks
Feedstock
Liquefaction
LNG Distribution
LNG Station
LNG
Locomotives / Marine HHP
Conventional NG, Unconventional NG, Bio-methane
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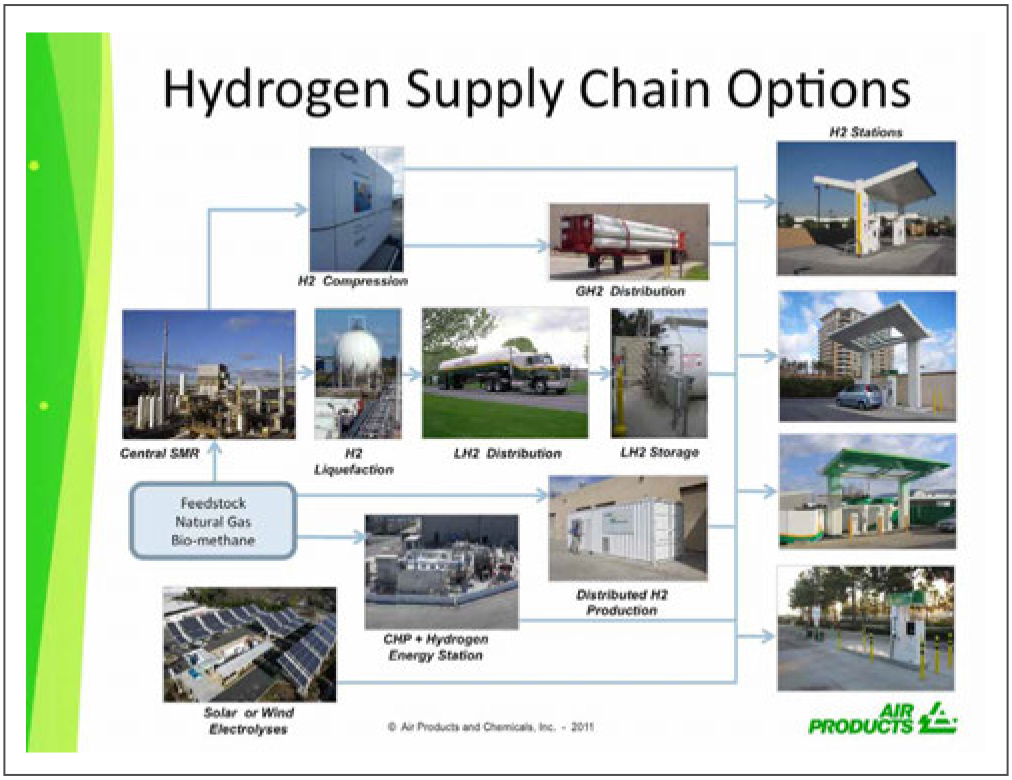

Codes & Standards

Importance of Codes & Standards

- Improves Safety
  - Paramount importance to all
- Provides Education to AHJ
  - Example: CGA pamphlets
- Provides Consistency
- Assists with Permitting
  - Appropriate C&S help AHJ's make decisions
- Helps with legal issues
- Levels playing field for all participants

Progress in Codes and Standards Development

- It's frequently said "There are no Codes and Standards for Hydrogen Fueling".
- This is not the case.
- In fact, there are so many, we can't cover them all here today
- Industrial Codes and Standards
  - Adopted by reference
- Specific Fuel Station Codes and Standards
  - NFPA
  - I-Codes
  - SAE J2719
  - SAE J2601

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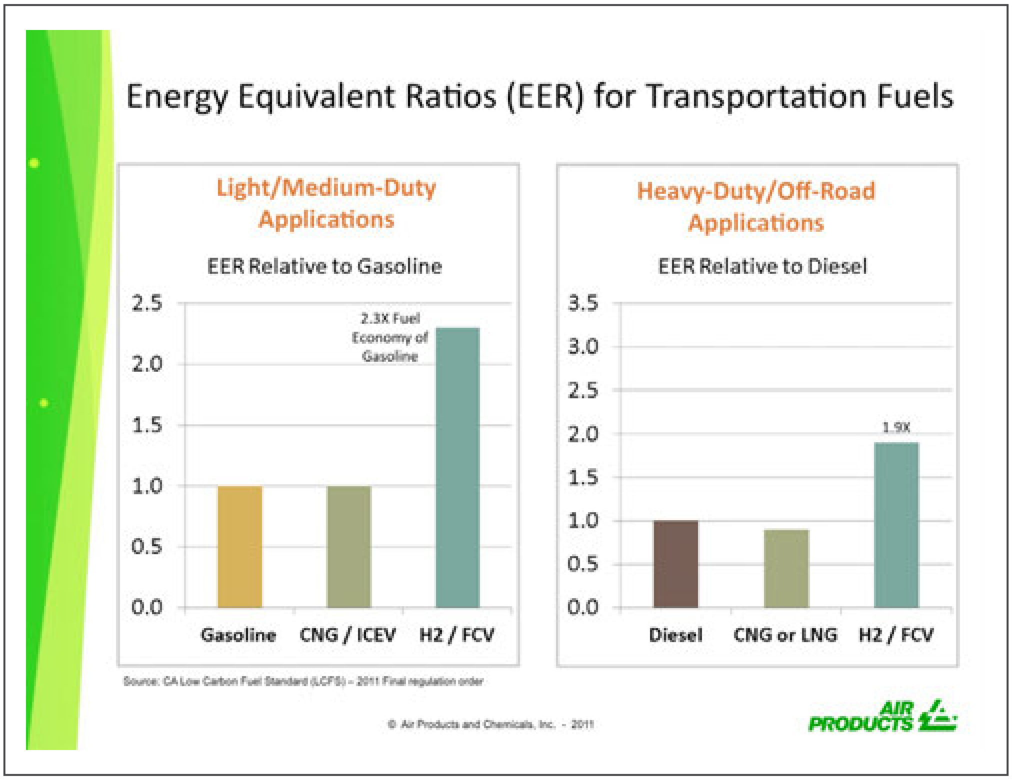
Energy Equivalent Ratios (EER) for Transportation Fuels
Light/Medium-Duty Applications
EER Relative to Gasoline
2.3X Fuel Economy of Gasoline
Gasoline
CNG / ICEV
H2 / FCV
Heavy-Duty/Off-Road Applications
EER Relative to Diesel
1.9X
Diesel
CNG or LNG
H2 / FCV
Source: CA Low Carbon Fuel Standard (LCFS) – 2011 Final regulation order
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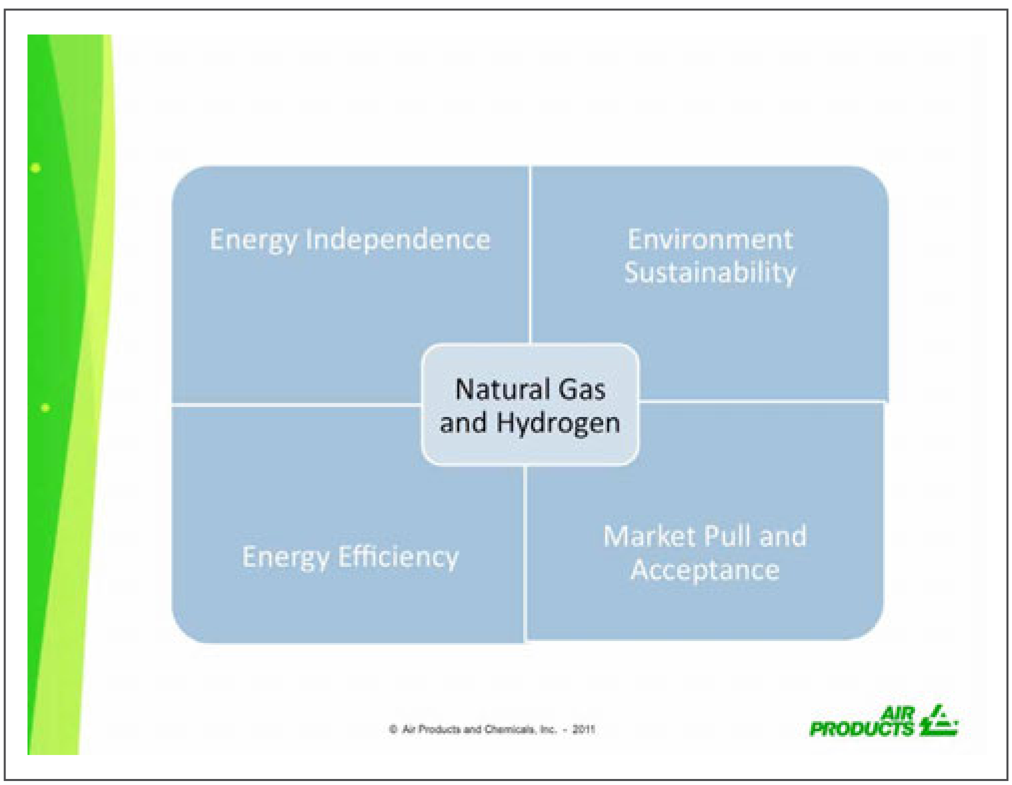
Energy Independence
Environment Sustainability
Natural Gas and Hydrogen
Energy Efficiency
Market Pull and Acceptance
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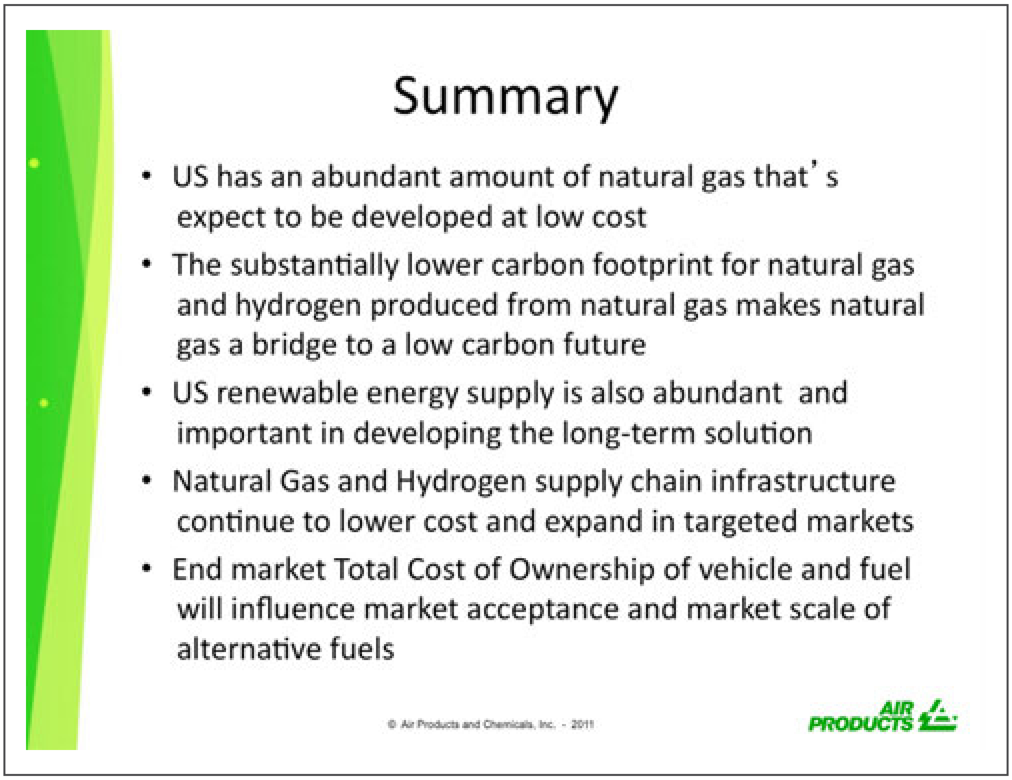
Summary
• US has an abundant amount of natural gas that's expect to be developed at low cost
• The substantially lower carbon footprint for natural gas and hydrogen produced from natural gas makes natural gas a bridge to a low carbon future
• US renewable energy supply is also abundant and important in developing the long-term solution
• Natural Gas and Hydrogen supply chain infrastructure continue to lower cost and expand in targeted markets
• End market Total Cost of Ownership of vehicle and fuel will influence market acceptance and market scale of alternative fuels
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Thank You!
www.airproducts.com/h2energy
Brian Bonner
bonnerbb@airproducts.com
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Presentation Slides: Natural Gas and Fuel Cell Vehicle Light-Duty Transportation Perspectives

Matt Fronk, Matt Fronk & Associates, LLC

NGV AND FCV LIGHT DUTY TRANSPORTATION PERSPECTIVES

Matt Fronk
Matt Fronk & Associates LLC

Natural Gas & Hydrogen Infrastructure Opportunities Workshop

October 19, 2011

Agenda

CAFÉ through 2025

Technology Options

Natural Gas & Hydrogen

Infrastructure developments

Next Steps

CAFE standards set to rise to 54.5 mpg for 2025

President Barack Obama on (7/29/2011) revealed ambitious plans to raise the corporate average fuel economy standard for cars and light trucks to 54.5 mpg by the 2025 model year, a landmark move that will dramatically remake carmakers' product portfolios and consumers' buying habits.

"**GM** plans to pursue the technical challenge ahead and to lead in delivering **new fuel-saving technologies** in cars and trucks customers want to buy and can afford," the company said in a statement. "Reducing fuel consumption and lessening the automobile's impact on the environment is important to our business because it's important to our country and our customers."

Toyota concurred:
"Toyota has embarked on the most aggressive expansion of hybrid, electric and **hydrogen-fuel-cell cars** of any automaker, and we are committed to continuing our demonstrated environmental leadership," Toyota Motor Sales COO Jim Lentz said in a statement. "We share the administration's goal of achieving major advances in clean, fuel-efficient vehicles. Obviously, there is still a great deal of uncertainty as to how the market will respond and what vehicle technologies consumers will embrace, which is why we are rolling out and testing a range of alternative fuel options."

Agenda

CAFÉ through 2025

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Natural Gas & Hydrogen

Infrastructure developments

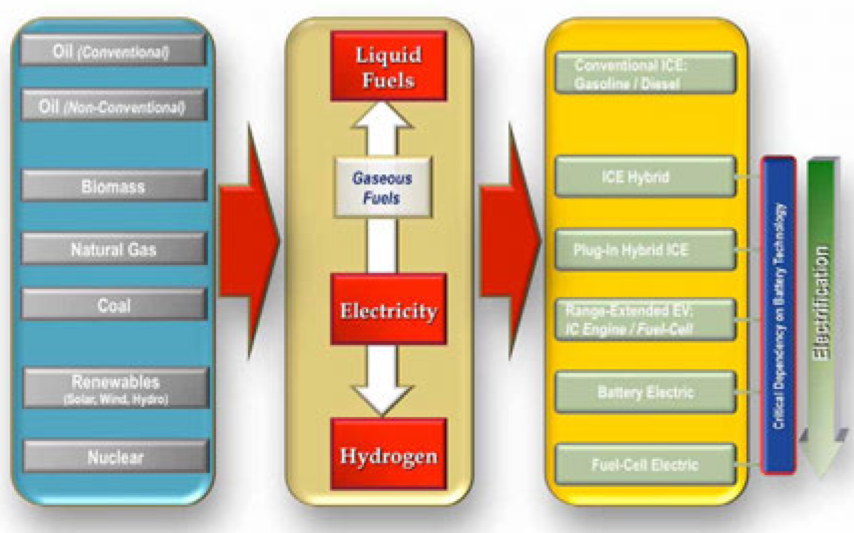
Next Steps

"Cleaner" Options – No Silver Bullet Portfolio Approach

- Gasoline/diesel
- Corn Ethanol
- Current US Electric Grid for Electric Vehicle Charging
- Compressed Natural Gas
- Cleaner Electric Grid for Electric Vehicle Charging
- Natural gas to Hydrogen for FCVs
- Cellulosic biomass to liquid fuel/vehicle charging/Hydrogen
- Nuclear electricity for electric vehicle charging/Hydrogen
- Renewable Electricity for electric Vehicle charging/Hydrogen

Energy & Technology Options

Despite Variety of Resources, 3 Predominant Energy Carriers



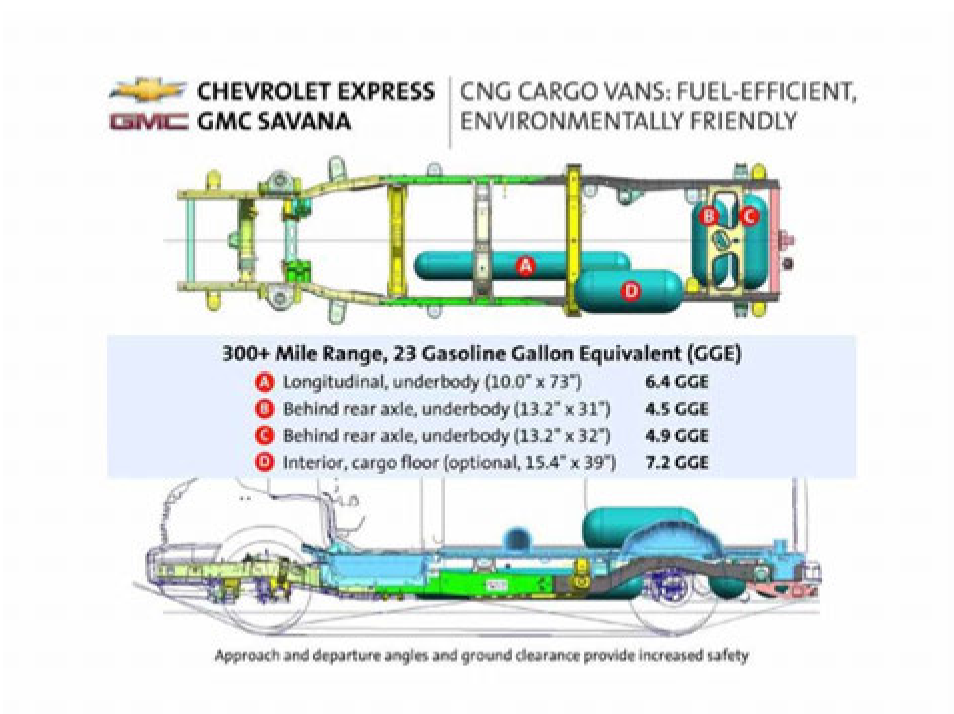
Goodbye gasoline? GM gives natural gas cars a boost

Edward McAllister Automotive News - July 2, 2011

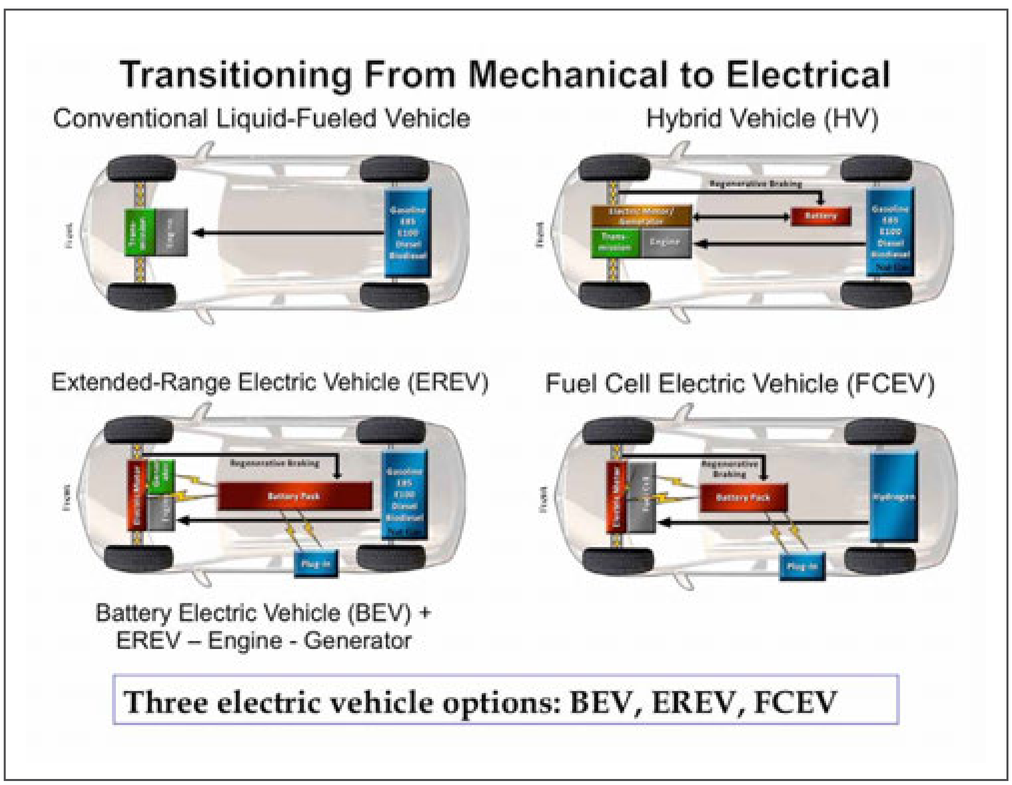
Natural gas is used mainly in electricity generation and for industry, but with just 120,000 natural gas vehicles on the road and only 900 filling stations, transport remains a tiny fraction of total demand.

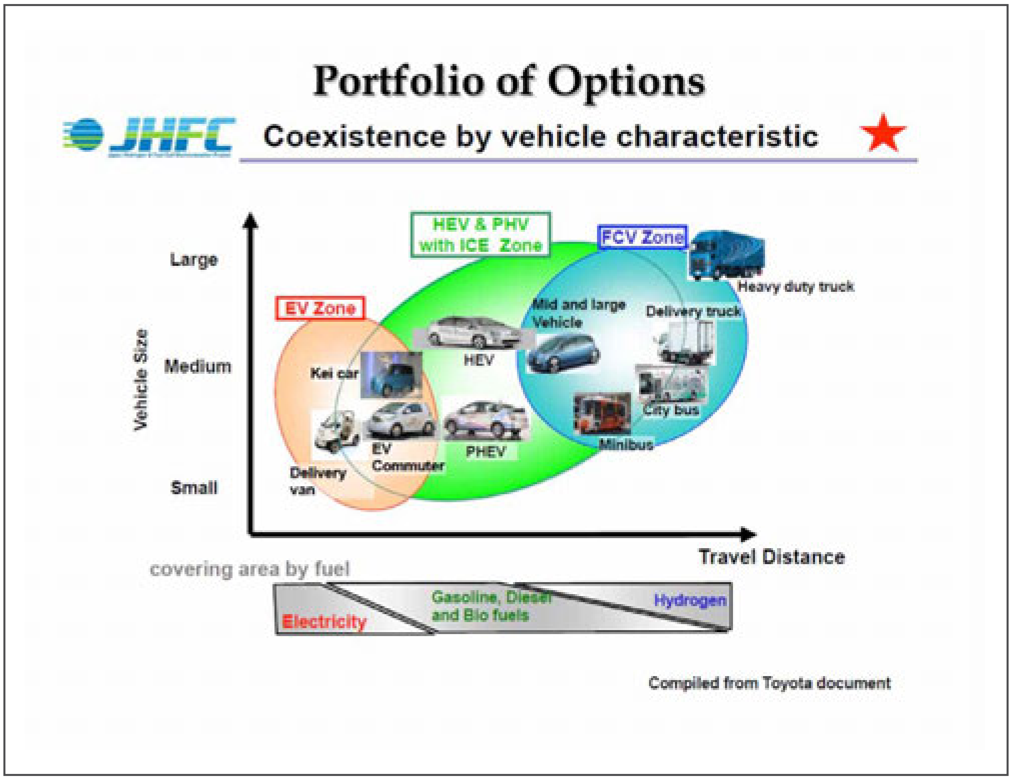
However, assuming production forecasts are correct, natural gas will likely remain cheap for years and could help cut U.S. reliance on oil. While crude prices soared above $110 a barrel this year due to unrest in the Middle East, U.S. natural gas prices, impervious to international influence, remained low as there was no shortage of natural gas at home.

Drivers who fill up with natural gas at the pump saved up to $2 per gallon when gasoline prices hit $4 a gallon.




Telecommunications giant AT&T has taken interest in
The General's offering of full-sized compressed natural gas (CNG) vans and has ordered exactly 101 Chevy Express 2500 cargo vans for its service fleet.
LINE 1
The only downside is that the package itself costs $15,910 upwards, plus the cost of whatever Express van it's to be fitted in.


Transitioning From Mechanical to Electrical
Conventional Liquid-Fueled Vehicle
Hybrid Vehicle (HV)
Extended-Range Electric Vehicle (EREV)
Fuel Cell Electric Vehicle (FCEV)
Battery Electric Vehicle (BEV) +
EREV – Engine - Generator
Three electric vehicle options: BEV, EREV, FCEV



Agenda

CAFÉ through 2025

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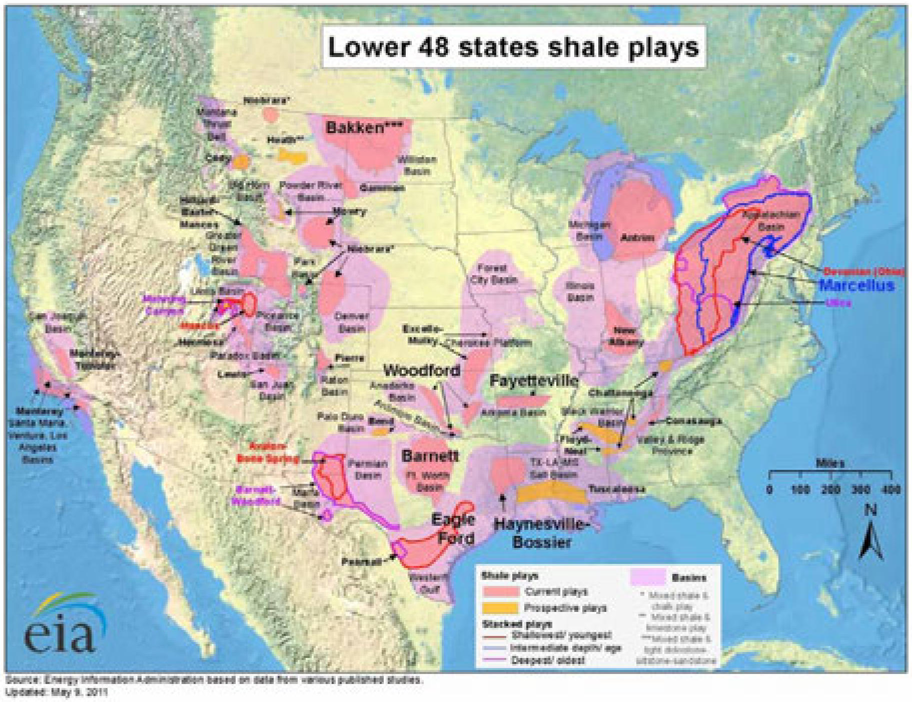
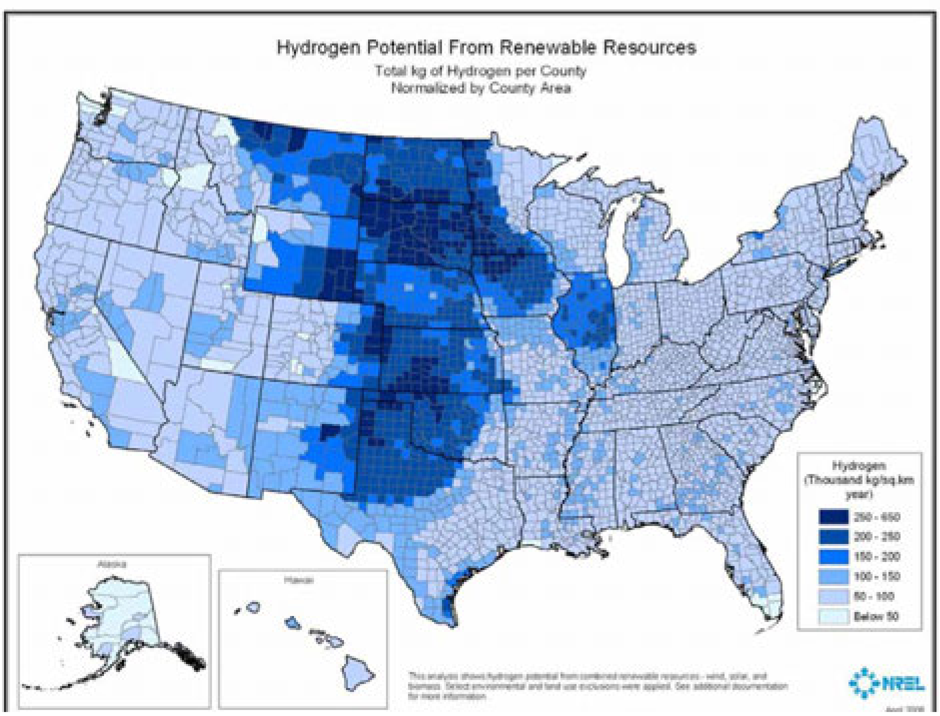
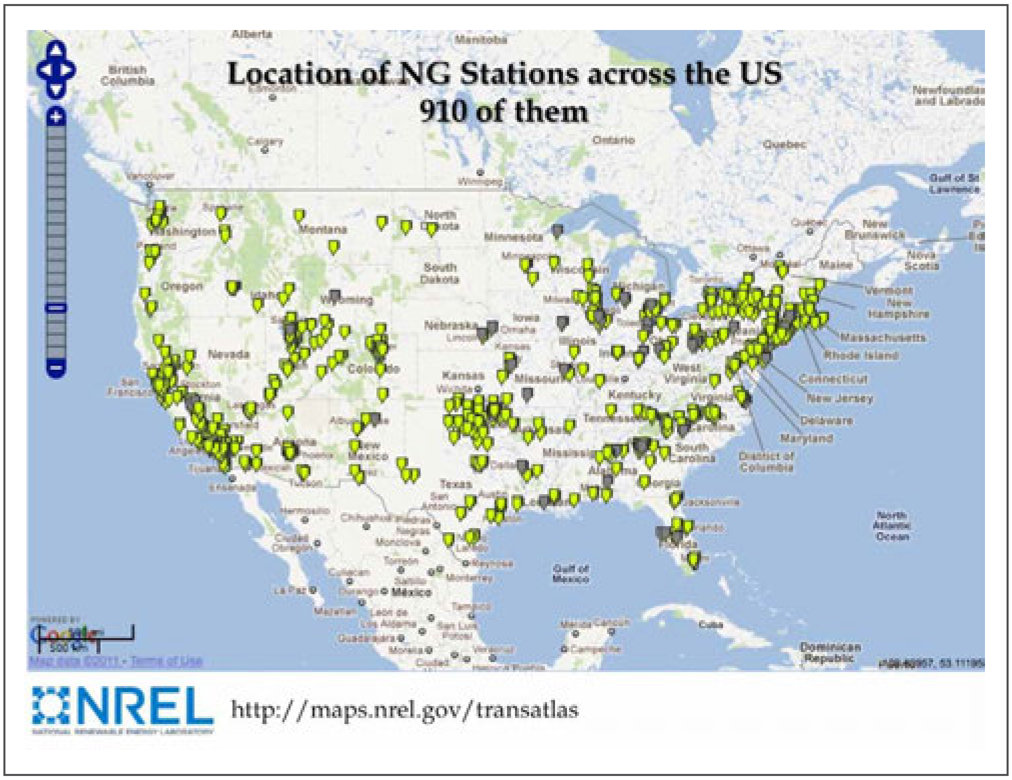
Natural Gas & Hydrogen

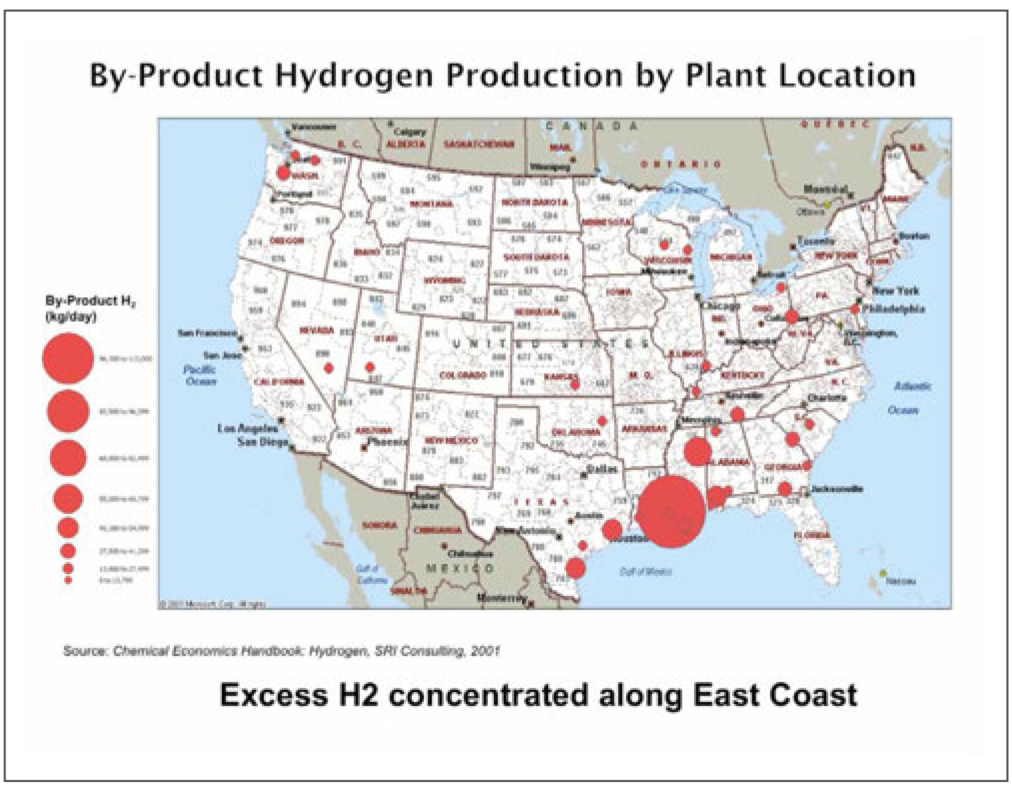
Infrastructure developments

Next Steps


Lower 48 states shale plays
Bakken***
Marcellus
Woodford
Fayetteville
Barnett
Eagle Ford
Haynesville-Bossier
Antrim
eia
Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011


Hydrogen Potential From Renewable Resources
Total kg of Hydrogen per County
Normalized by County Area
Hydrogen
(Thousand kg/sq.km year)
250 - 650
200 - 250
150 - 200
100 - 150
50 - 100
Below 50
NREL


Location of NG Stations across the US
910 of them
http://maps.nrel.gov/transatlas
NREL
Gulf of Mexico
North Atlantic Ocean


By-Product Hydrogen Production by Plant Location
By-Product H_2 (kg/day)
Source: Chemical Economics Handbook: Hydrogen, SRI Consulting, 2001
Excess H2 concentrated along East Coast

Agenda

CAFÉ through 2025

Technology Options

Natural Gas & Hydrogen

Infrastructure developments

Next steps

Infrastructure Developments

- Technology for both NG and hydrogen refueling is available
- Commercial stations in play around the world
- On board storage still requires more development
- To implement a national plan requires a team effort between Fed/State Gov't, Auto OEMs, Gas suppliers, and other interested parties - a team sport:
  - ✓ Energy Independence & Security
  - ✓ Industrial Competitiveness – NGVs and FCVs
- There are some state infrastructure initiatives already in play – CA, Hawaii, and NY as examples

Letter of Understanding Signed in Germany – Sept 8, 2009
Automotive Industry Support for Battery & Fuel Cell Technology

DAIMLER Ford GM OPEL HONDA
KIA RENAULT NISSAN TOYOTA

Letter of Understanding
on the Development and Market Introduction of Fuel Cell Vehicles

To: Oil and Energy Companies, Government Organizations and NOW GmbH

- Battery and fuel cell vehicles complement each other
- Fuel Cell Electric Vehicle commercialization from 2015 onwards anticipated
- Hydrogen infrastructure network with sufficient density required by 2015
- Germany is starting point for Europe

Japan 2015 Announcement (Jan '11)

Japanese gas suppliers and oil companies will seek to build some **100** hydrogen supply stations at **four major city** areas to prepare for the launch of mass-produced hydrogen-powered fuel cell vehicles in 2015.

A total of 10 energy companies made the announcement in a statement jointly issued with Toyota Motor Corp, Nissan Motor Co and Honda Motor Co, signaling their **coordinated efforts** to expand the next-generation eco-friendly vehicle in Japan.

"Automakers and hydrogen fuel suppliers will work together to expand the introduction of FCVs and develop the hydrogen supply network throughout Japan," the statement said, while also calling on the government to support their efforts.

The four areas where the companies would seek to build hydrogen fueling stations center on Tokyo, Aichi, Osaka and Fukuoka.

Case Study - NY State

NY is in a position to:

- ✓ Support the US H2 infrastructure and Commercial FCV Vehicle deployment in 2015 for the Northeast/East Coast sector
- ✓ Participate in the jobs creation that the introduction of a new, game changing technology would provide (Infrastructure & System Mfg)
- ✓ Demonstrate National leadership
  - ✓ Walk the talk on 80 by 2050 CO2 reduction
  - ✓ Energy Independence – utilize NY State resources of NG, Hydro, Nuclear, Wind & Solar to make Hydrogen
  - ✓ Energy Security
  - ✓ Industrial Competiveness
- ✓ Position the US to compete globally with Germany and Japan
- ✓ The time is now to do this as both Ca and Hawaii have funded plans in place

East Coast/National Hydrogen Infrastructure

Boston-Miami=1500mi
6 major cities
>100m people

Massachusetts - Billerica, Boston
Nuvera forklifts
Transit buses

Connecticut - Wallingford, Hartford, East Hartford
Sun Hydro, Proton,
UTC, U.Conn,
Transit Authority buses/station

New York - NY City, Rochester, Buffalo, Albany
NYHY2 Initiative, JFK, White Plains, Hempstead
Praxair green H2, ATK, GM stations, RIT, Plug Power station

New Jersey - Jersey City
Hess, Daimler

Pennsylvania – Allentown, Susquehanna
Air Products station, Defense Logistics station

Ohio - Engelwood
Millennium Reign Energy

WDC / Virginia Fairfax County station
Fort Belvoir, additional station

Tennessee
United Hydrogen

Georgia – Atlanta
United Hydrogen stations

Florida – Miami, Orlando, Cape Canaveral
NASA - station
Proton, Lumber Liquidators, home refueler

NY Job Creation

In February, 2011, the US Department of Energy released a comprehensive study concluding that the fuel cell and hydrogen industries could generate substantial revenues and job growth. Over the next two decades, assuming hydrogen does indeed play a central role in our energy future (an assumption which is still very likely, despite the US falling behind other nations), it would create **between 360,000 and 675,000 jobs**.

Should New York State see but 10 percent of the benefit from this economic growth, it would still translate to the creation of between 36,000 and 67,500 jobs over two decades. When looking at the public expenditure this proposal calls for, the return on investment would be substantial.

Why NY?

Vision

- ✓ Executive Order sets a goal for 80% reduction of greenhouse gas (GHG) emissions by 2050
- ✓ State Planning Legislation in place that requires developing an inventory of GHG emissions and identification of GHG reduction strategies
- ✓ NY Climate Action Plan Nationally recognized for approach and thoroughness http://www.nyclimatechange.us/index.cfm

Early Strategy in Place

- ✓ NY BEST (NY Battery & Energy Storage Technology Consortium) – http://www.ny-best.org/ - Batteries, Fuel Cells, Ultracapacitors, & Electrolysis technologies
  - NY, US, and International Members

Will

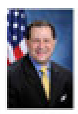
- ✓ World Class Public/Private team in place to **Lead/Execute** a Hydrogen Infrastructure and Fuel Cell vehicle deployment program in parallel with Germany and Japan
- ✓ We need government to take a leadership role – set a vision - **The US is falling behind Germany & Japan**

Public/Private Partnership

Automotive OEMs
- GM
- Toyota
- Daimler
- Honda
- Hyundai
- Ford

Hydrogen Suppliers
- HESS
- Linde
- Praxair
- Air Products
- Proton
- H2 Pump LLC
- Hydrogenics

Government
- NY State Legislature
- NYSERDA
- Brookhaven National lab



Additions Since June

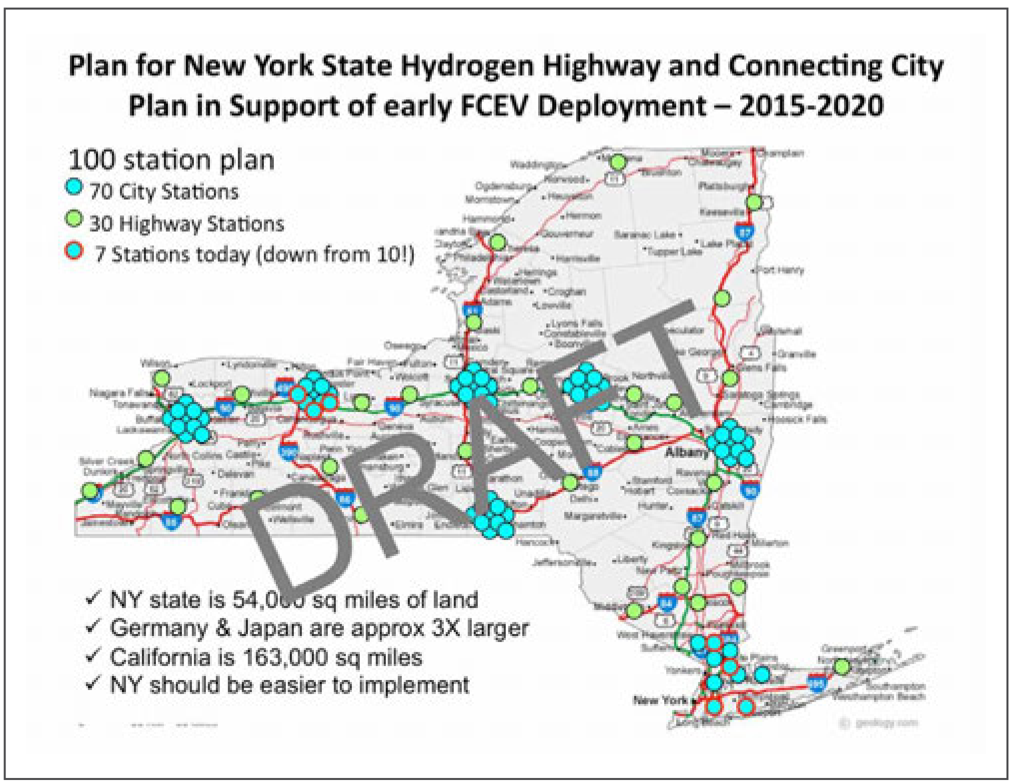
Hydrogen Suppliers
- United Hydrogen (JFK)

Industry
- ATK – Station Installer
- Parsons – Station Installer
- Nuvera – Fuel Cell and Refueling

Vehicle/Station Users
- Port Authority
- White Plains
- Town of Hempstead
- Monroe County
- CAT – CT Transit

Academia
- R.I.T.
- UConn

What is Needed?



Proposed Infrastructure Rollout

Calendar Year	Min # Cars Required	Total Cars in NY	Fed Gov't Incentive per car ($k)	Total Gov't Incentive ($k)	Number of Cities in Program	City cluster station total	Total Highway station #	Yearly new station #	Estimate Station cost	Total Station Cost ($M)	Station funding % cost share	NYS Investment	*Total NY/ Fed Cost ($M)
2015	1500	1500	7.5	11250	2	20	0	20	2.2	44	0.5	22	33.25
2016	3000	4500	7.5	22500	3	30	5	15	2.2	33	0.4	13.2	35.7
2017	5000	9500	5	25000	4	40	10	15	1.8	27	0.3	8.1	33.1
2018	8000	17500	3.5	28000	5	50	15	15	1.4	21	0.2	4.2	32.2
2019	12500	30000	3	37500	6	60	20	15	1.1	16.5	0.1	1.65	39.15
2020	20000	50000	2	40000	7	70	30	20	0.8	16	0.1	1.6	41.6
Total		50000		164250	7	70	30	100		157.5		50.75	215

Goals: Lead in Industry Vehicle Deployment, H2 Filling Stations, etc.
7 cities by 2020 - Albany, Rochester, NY City, Buffalo, Syracuse, Binghamton, Utica,
100 stations by 2020 (10 per city) = 70 + 5 per year on connecting "Highwa wy Total)
50,000 total cars by 2020

*** Includes anticipated $164,250,000 Federal Custo Vehicle currently i lace for Adv Technology vehicles**

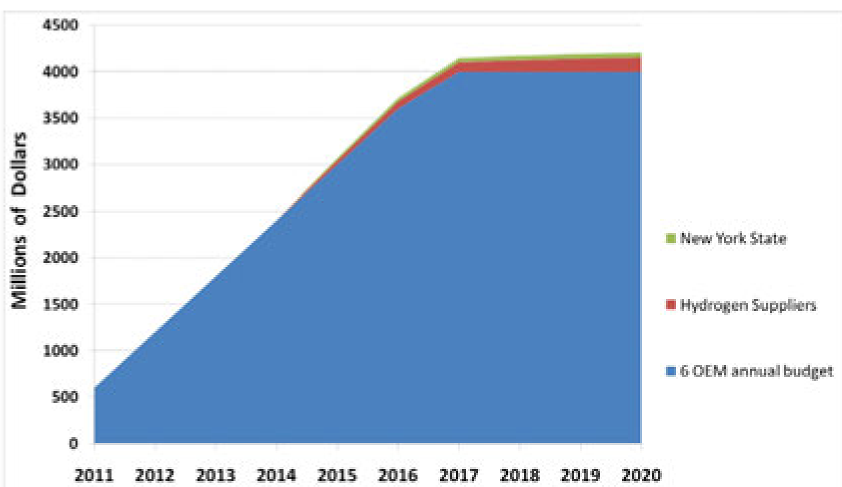
2015 – Initial NYC (10) and Upstate City #1 (10) for initial launch
2016 – Add Upstate City #2 (10) and add 5 highway station along Thruway
2017 – Add Upstate City #3 (10) and add 5 highway stations
2018 – Add Upstate City #4 (10) and add 5 highway stations
2019 – Add Upstate City #5 (10) and add 5 highway stations
2020 – Add Upstate City #6 (10) and add last 10 highway stations

**** Station location selection based on input from Greet/Street Model***

DRAFT

Public-Private Investments in 2011-2020 timeframe

Cumulative Program Spending by Sector



Agenda

CAFÉ through 2025

Technology Options

Natural Gas & Hydrogen

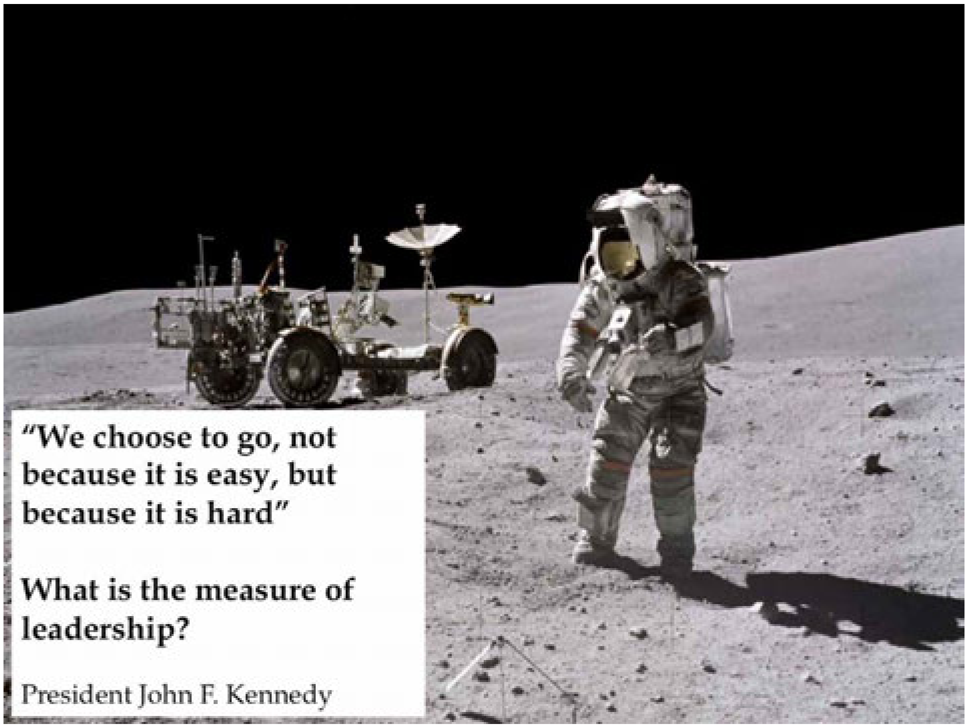
Infrastructure developments

Next steps

Next Steps

It really is about leadership and connecting all of the appropriate organizations to support a vision to make these initiatives happen

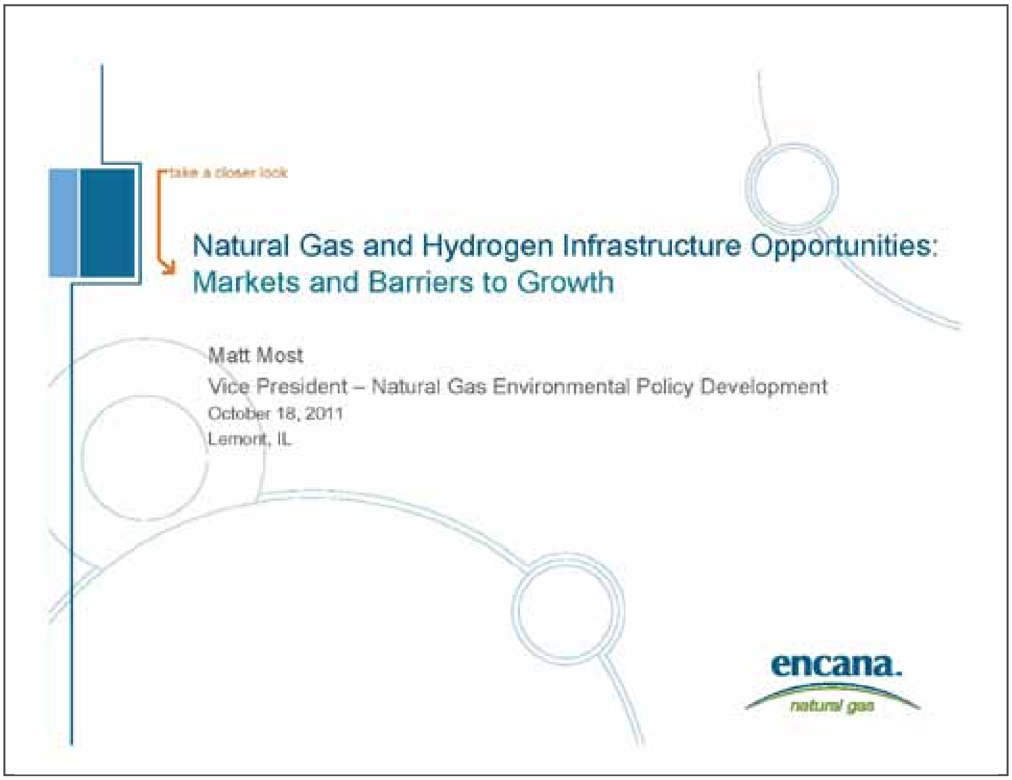
It will also take all of us as a team and as individuals to make this happen


"We choose to go, not because it is easy, but because it is hard"
What is the measure of leadership?
President John F. Kennedy

Thank You

Presentation Slides: Natural Gas and Hydrogen Infrastructure Opportunities: Markets and Barriers to Growth

Matt Most, Encana Natural Gas



encana.

Advisory Regarding Reserves Data & Other Oil & Gas Information Disclosure Protocols

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encana.

Natural Gas Value Proposition
Four Deliverables

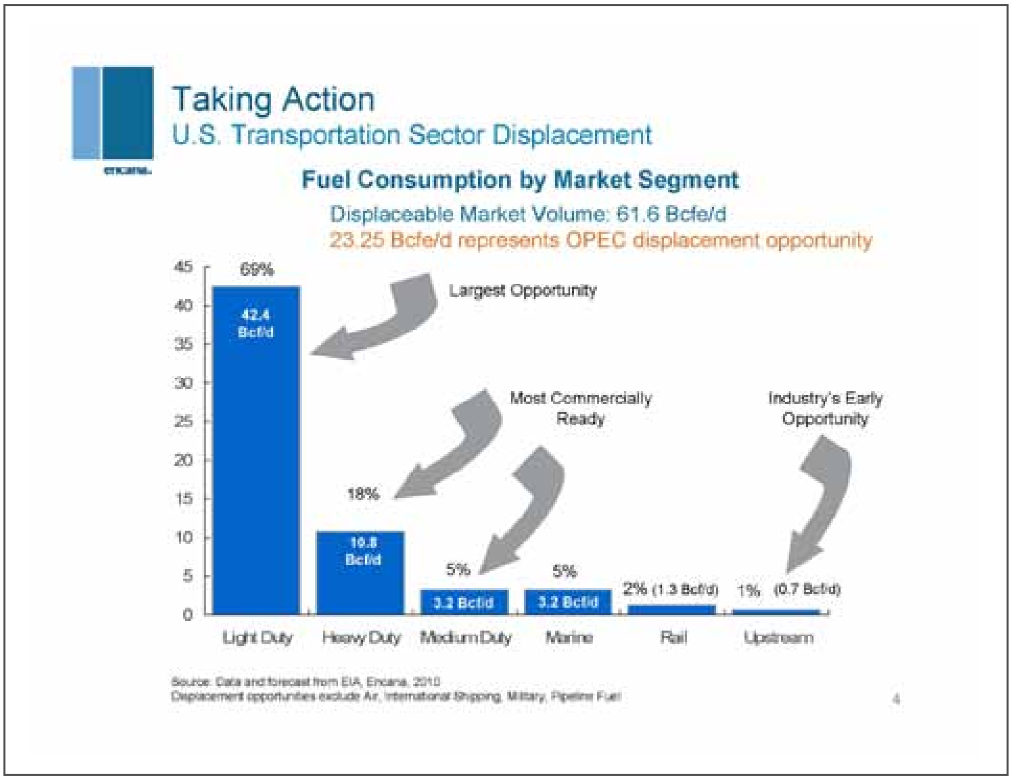
Environmental Benefits
- Reduced GHG emissions (20-30%)
- Reduced associative emissions
  - CO, SO2, NOX
- Lower engine noise

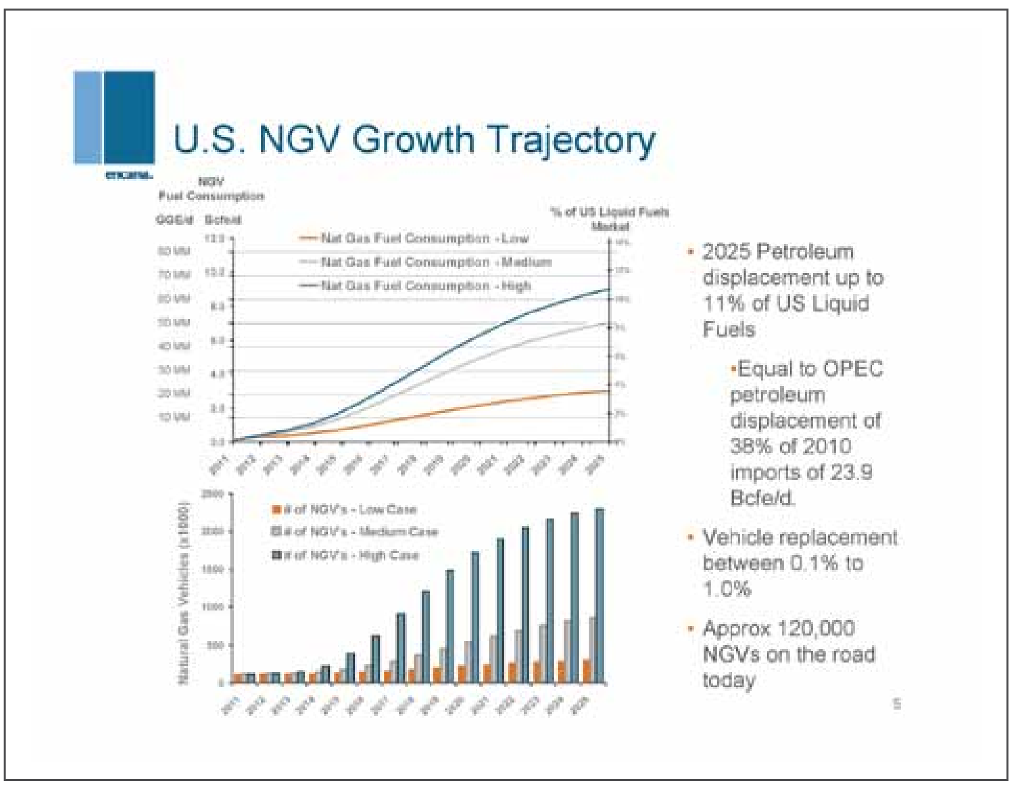
Social Benefits
- Production related revenues
  - Royalties, taxes, job creation
- Fueling infrastructure revenues
  - Job creation, taxes, economic spin-off

Economic Benefits
- Lower fuel price than diesel / gasoline
- Reduced maintenance costs
  - DPF maintenance eliminated
  - Extended time between oil changes
- Jurisdiction dependent grants / credits

Energy Security Benefits
- Domestic energy source
  - Economic benefits through value chain
- Displaces foreign oil
  - 49% US petroleum is imported
  - 40% CDN petroleum is imported

3


Taking Action
U.S. Transportation Sector Displacement
Fuel Consumption by Market Segment
Displaceable Market Volume: 61.6 Bcfe/d
23.25 Bcfe/d represents OPEC displacement opportunity
Largest Opportunity
Most Commercially Ready
Industry's Early Opportunity
69%
42.4 Bcf/d
18%
10.8 Bcf/d
5%
3.2 Bcf/d
5%
3.2 Bcf/d
2% (1.3 Bcf/d)
1% (0.7 Bcf/d)
Light Duty
Heavy Duty
Medium Duty
Marine
Rail
Upstream
Source: Data and forecast from EIA, Encana, 2010
Displacement opportunities exclude Air, International Shipping, Military, Pipeline Fuel
4


U.S. NGV Growth Trajectory
NGV Fuel Consumption
% of US Liquid Fuels Market
Nat Gas Fuel Consumption - Low
Nat Gas Fuel Consumption - Medium
Nat Gas Fuel Consumption - High
# of NGV's - Low Case
# of NGV's - Medium Case
# of NGV's - High Case
Natural Gas Vehicles (x1000)
• 2025 Petroleum displacement up to 11% of US Liquid Fuels
•Equal to OPEC petroleum displacement of 38% of 2010 imports of 23.9 Bcfe/d.
• Vehicle replacement between 0.1% to 1.0%
• Approx 120,000 NGVs on the road today
5

Barriers and Opportunities for Transportation

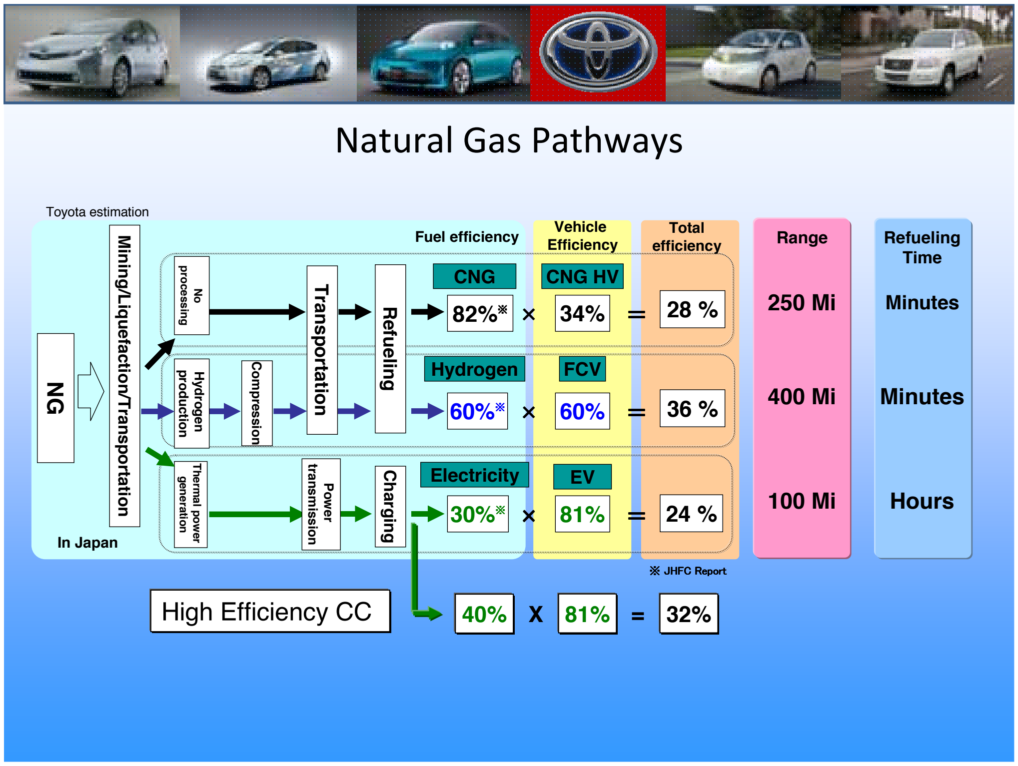
	Infrastructure	Incentives	Policy Drivers	Vehicle Costs	OEM Vehicles
Path to VIABLITY	↑	↑	↑	↓	↑

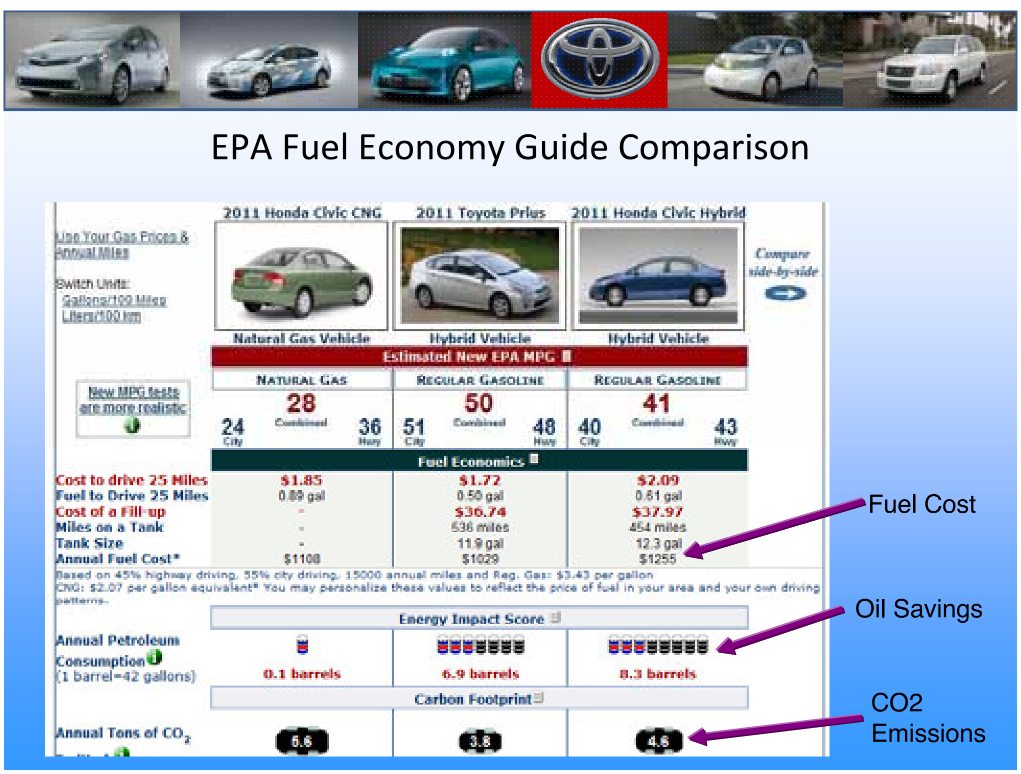
How Can the DOE Research Agenda Help?

- Technology accelerates market penetration, key challenges:
  - capital cost
  - tank design limitations
  - Vehicle range
- Adsorbed natural gas substrate conformable storage tank
  - Replacement for bulky, heavy-walled CNG tanks
  - Flat, lightweight tank stores natural gas in adsorbed form
  - Utilizes spent corn cobs inside the tank to absorb natural gas
  - Holds 180 times more gas per volume
  - Can be mounted under the floor

Presentation Slides: Natural Gas Pathways and Fuel Economy Guide Comparison

Bob Wimmer, Toyota





Slide Presentation: Hydrogen Generator Appliance

Gus Block, Nuvera Fuel Cells

PowerTap Retail Automotive (2015)

Nuvera PowerTap™ GENIII+ Hydrogen Generator Appliance
250kg/day Ultra-High Purity Grade H_2 Capacity, 800-bar Output
Target Footprint Dimensions: 12'Lx6'W

NUVERA FUEL CELLS

Nuvera Fuel Cells, Billerica, USA is ISO 9001: 2008 certified