Using Checklists to Assess Your Transition to Alternative Fuels: A Technical Reference

Energy Systems Division

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INTRODUCTION TO THE CHECKLIST UPDATE¹

The *Checklist for Transition to New Alternative Fuel(s)* was published in September 2011 by Chuck Risch and Dan Santini. Many improvements, described below, have been incorporated into this current document, *Checklists for Assessing the Transitions to New Highway Fuels*.² Further, the original authors and Larry Johnson, co-author of the current report, identified a need for a succinct version of the full report and prepared a brochure based on it to aid busy decision-makers: *Check It Out: Using Checklists to Assess Your Transition to Alternative Fuels*.² These checklists are tools for those stakeholders charged with determining a feasible alternative fuel or fuels for highway transportation systems of the future. The original had four major players whose needs had to be satisfied for a successful transition. The term “activist,” intended to encompass environmental and other special interests, was included in the “customers” category. Activists are customers of the government in the sense that they organize citizens to exert political pressure to regulate the design of vehicles, fuel infrastructure, and roadway networks. Many who evaluate alternative fuels view activists, particularly environmental activists, as a separate category. Further, “activist” has become a pejorative term to many people. Therefore, we have used the word “advocate” or “activist/advocate” instead. Thus, in this update we recognize that environmental and other activists/advocates have been—and will continue to be—a powerful force promoting change in the nature of the fuels that are used in transportation.

Revised discussions of the breadth of each category are included. For example, the fuel industry is now described as including the “life cycle” of that industry’s fuel, from extracting the raw material to the network that processes and delivers the fuel to wholesalers, and then to retailers that deliver fuel to consumers. Another nuance, highlighted by our reviewer Dr. Jeffrey Seisler, is that the development and enforcement of standards and codes is hardly an exclusive function of government. Industry and private-sector laboratories and associations, under the scrutiny of advocate organizations, collaboratively develop and review standards and codes in tandem with responsible government bodies (authorities having jurisdiction). Consumers depend on this process to develop reliable, clean, and efficient vehicles that affordably meet their needs for personal transportation.

These checklists now call attention to the fact that promotional incentives provided by governments to promote alternative fuels and vehicles can and should change over time to limit total government expenditures as sales volumes increase. Although early success may be followed by a period of revenue neutrality, eventually alternative fuels will be—as gasoline and diesel fuel have long been—an important tax revenue source. To the extent that roadway networks continue to be financed by local, state, and federal taxes on the use of vehicles and fuels, new alternative fuels and vehicles must ultimately pay their fair share (as should existing fuels and vehicles). Funding the development of promising alternative fuels and vehicles via initial subsidy is necessary, but must ultimately be temporary. Risk assessment of technology development funding pathways is a very important element that the major players must consider.

¹ Funding for this work was provided by the U.S. Department of Energy, Energy Efficiency and Renewable Energy, Vehicle Technologies Program.

² Available at www.anl.gov/energy-systems/downloads/using-checklists-assess-your-transition-alternative-fuels

This document is for a U.S. vehicle and motor fuel audience, but it could be adapted for any region in the world and other fuel uses. The authors hope these checklists will be useful tools as stakeholders assess the various alternative motor fuel options.

We also note that the International Energy Agency Advanced Motor Fuels Implementing Agreement used our original checklist to organize their study *Feasibility of Natural Gas Pathways: An International Comparison*. We are in agreement with this statement in their report:

Transitioning to a new fuel can take years, and replacement of today's conventional fuels (i.e. gasoline and diesel) should not be expected anytime soon. Coexistence of the new fuel(s) with these conventional fuels is likely to last decades, allowing time for the fuel and supporting infrastructure to be developed. Of course, sound analysis is pertinent prior to major moves toward a new fuel in order to make the best decisions.

Note: During the process of developing this document, the authors became aware of the bestseller *The Checklist Manifesto: How to Get Things Right*, by Dr. Atul Gawande (2009). His book presents various applications of checklists and their high-value benefits, especially for people in professional fields who deal with increasing complexity. While the authors of this report were already believers in checklists, his book reaffirmed their position.

Two quotes from Dr. Gawande's book provide an explanation for why checklists are overlooked in spite of their acknowledged benefits. First:

Yet it is far from obvious that something as simple as a checklist could be of substantial help. We may admit that errors and oversights occur—even devastating ones. But we believe that our jobs are too complicated to reduce to a checklist.

Second:

That means we need a different strategy for overcoming failure, one that builds on experience and takes advantage of the knowledge people have but somehow also makes up for our inevitable human inadequacies. And there is such a strategy—though it will seem almost ridiculous in its simplicity, maybe even crazy to those of us who have spent years carefully developing ever more advanced skills and technologies.

It is a checklist.

1 OVERVIEW

Transportation is vital to the U.S. economy and society. Past presidents, and many advocate organizations, have contended for decades that our nation is too dependent on petroleum. More recently, environmental science regarding the causes of climate change³ has led to concern over the use of any fossil fuel, including imported or domestic petroleum. Fossil-based domestic alternative fuels have long been regarded as sources of fuel for a transition to greater energy security. When scientific estimates of climate change effects are considered, near-term fossil fuel choices narrow to a few fuel delivery pathways that use abundant domestic natural gas as the original source of energy.ⁱ Increasing emphasis is being placed on transport energy derived from wind, solar, biomass, hydrologic, or other renewable energy sources.

Throughout history, highway transportation fuel transitions have been completed successfully both in United States and abroad. Other attempts have failed, as described in Appendix A: Historical Highway Fuel Transitions. Transitioning to a new highway fuel will be a costly, time-consuming, and complex effort, so getting the analysis right is important.

Planning for a transition is critical because the changes can affect our nation's ability to compete in the world market. A transition will take many years to complete.ⁱⁱ Although it is tempting to make quick decisions about the new fuel of choice, it is preferable and necessary to analyze all pertinent criteria to ensure correct decisions are made. Doing so will reduce the number of changes in highway fuels. Obviously, changes may become necessary because of such occurrences as significant technology breakthroughs or major world events. With any and all of the possible transitions to new fuels, the total replacement of gasoline and diesel fuels is not expected. These conventional fuels are envisioned to coexist with the new fuels for decades, while the alternative fuel and vehicle infrastructures are implemented.

The transition process must analyze the needs of the primary "players," which consist of the automotive industry, the motor fuels industry, the government, activist/advocates (which includes environmentalists and other fuel change groups), and customers. To maximize the probability of future successes, the major concerns of all of these groups must be addressed.

Realistically, all of the various fuel players will never agree on a new competing fuel. Thus, when evaluating an individual new fuel, the beginning of a transition to that fuel is much more likely when there is a perceived positive sum gain for that fuel industry's stakeholders and a significant amount of automotive industry and government support for that fuel. Expansion of the transition must first be enabled by support of advocates and ultimately many consumers.

Section 2 presents a succinct outline of the checklists. Section 3 provides a brief discussion about the items on the checklists.

³ Global warming is the term used to describe the current increase in the Earth's average temperature. Climate change refers not only to global changes in temperature but also to changes in wind, precipitation, and the length of seasons, as well as the strength and frequency of extreme weather events like droughts and floods. We have chosen to use the word climate change, by which we mean changes caused by global warming, in this report.

2 CHECKLISTS

2.1 AUTOMOTIVE INDUSTRY

This stakeholder group includes the full spectrum of automotive industry players, from those who extract raw materials for vehicles to those involved with local vehicle service and end-of-life recycling/disposal. The industry encompasses the manufacturers of cars, trucks, and buses. All aspects of the automotive industry should establish a solid business plan with special consideration for the items on the following checklist.

Item to Check	New Fuel Compared to Conventional Fuels	✓
Technical Feasibility (for customer acceptance, see Customer section, page 8)	Has the technology been developed or demonstrated to produce vehicles that are compatible with the new fuel and that cost-effectively meet customer needs, as well as federal, state, and local codes and standards?	
Transition Plans	Have plans been developed that show the feasibility of vehicles running on the new fuel during the transition from conventional fuels?	
Infrastructure Investment	Has an examination been conducted to determine the sources of funds (auto industry, government, other) that will supply the investment (particularly in the growth phase) and how much investment will be needed?	
Operating Financial Implications (short term)	Has a risk assessment been conducted to examine potential changes in the next 10 years of any incentives program?	
Operating Financial Implications (long term)	Can the new fuel be self-sustaining in the next 15 to 25 years (i.e., paying its share of taxes and not requiring subsidies)?	
Competing Actions (from current fuel and automotive industries)	Competing actions from conventional fuel suppliers can have implications for vehicle manufacturers developing technologies to use the new fuels. Have these implications been analyzed and are they acceptable? For example, small changes to crude oil demand or supply can dramatically affect the price of conventional fuels.	
Multi-National Business Strategies	Have “what-if” scenarios been conducted? For example, what if one of our competitors beats us to the market with the technology for vehicles to use the new fuel? What if a breakthrough in a competing alternative fuel makes our technology too expensive?	
Corporate Image	Does marketing vehicles that run on the new fuel enhance the image of the company as an advanced technology leader in alternative fuels or as a leader in the auto industry for environmental stewardship?	

Item to Check	New Fuel Compared to Conventional Fuels
Raw Material Adequacy and Reliability	Are the materials for the new vehicles adequate and, if imported, are they from secure sources in the short-term, mid-term, and long-term phases of the transition?	
Lead Time	What is the program risk if the internal lead time for the company-generated new vehicle/fuel program is not consistent with the government program timing and fuel industry programs? Are these risks acceptable?	
Customer Acceptance (see Customer section, page 8)	Has an acceptable analysis (e.g., of power, torque, payload, range, fill time, maintenance reliability, cost vs. benefit) projected a positive response by consumers to vehicles using the new fuel?	
Dealer Network	Have adequate plans been developed for an educated/trained dealer network that can interface with customers and service the vehicles using the new fuel?	

Note: Although the fuel and automotive industries have similar topics of interest, the evaluation criteria are industry dependent (refer to Section 3).

2.2 MOTOR FUELS INDUSTRY

This industry encompasses companies that range in size from large multi-national energy corporations that are primarily petroleum companies to small entrepreneurial start-ups that market alternative highway fuels. This stakeholder group includes the full spectrum of fuel industry players, from those who extract the raw materials through processing (refining) and distribution to the final delivery to consumers. The motor fuels industry typically examines various options that could meet market demand and government mandates for alternative fuels. Within their capital and operating budgets, companies will select the options that best fit within those constraints. In addition, new fuels and components that are compatible with existing vehicles and fuel production and distribution infrastructure will have an advantage relative to other options. All aspects of the fuel industry should establish a solid business plan with special considerations for the items on the following checklist.

Item to Check	New Fuel Compared to Conventional Fuels	✓
Technical Feasibility	Has technology been developed or demonstrated) to produce the new fuel that meets customer needs and is cost competitive with conventional fuels?	
Regulatory and Legislative Compliance	Has the technology been developed or demonstrated to produce the new fuel that meets both current and projected regulatory requirements (e.g., emissions, safety, and codes/standards) and is cost competitive with conventional fuels?	
Transition Plans	Have plans been developed to show that it is feasible to market the new fuel alongside conventional fuel as the transition takes place?	
Infrastructure Investment	Has an examination been conducted to determine who within the industry (fuel producers, suppliers, and dealers) or from the outside will supply the investment for any needed infrastructure and how much will be required? Are the planned investments sufficient? Do fuel retailers (largely independent, small businesses) have an incentive to offer a new fuel?	
Operating Financial Implications (short term)	Has an evaluation, including return on investment, been conducted to determine which fuel opportunities are good investments? Has a risk assessment been conducted to examine potential changes in the next 10 years of any incentives program?	
Operating Financial Implications (long term)	Can the new fuel be self-sustaining in the next 15 to 25 years (i.e., it will not require subsidies and instead will pay its share of taxes)?	
Competing Actions (from the current petroleum industry)	Competing actions from within the fuels industry can have implications beyond the industry. Have these implications been analyzed and are they acceptable?	
Multi-National Business Strategies	Have “what-if” scenarios been conducted? What if some energy companies decide to pull out of, or reduce, U.S. operations? What if other energy companies decide to market the same new fuel? What if conventional technology advances make the new fuel technology obsolete before significant market penetration? Does the range of scenarios cover the breadth of likely futures?	
Corporate Image	Has consideration been given to whether marketing the new fuel enhances the image of the company as an advanced technology leader in alternative fuels or as a leader in industry for environmental stewardship?	
Feedstock Adequacy and Reliability	Is the feedstock for the new fuel sufficient in the short-term, mid-term, and long-term phases of the transition? Will the price of the feedstock change dramatically with scale-up?	

Item to Check	New Fuel Compared to Conventional Fuels	✓
Lead Time	What is the program risk if the internal lead time for the company-generated new fuel program is not consistent with the government program timing and the auto industry programs? Is the risk acceptable?	
Consumer Acceptance	Has an acceptable analysis (e.g., using focus groups) determined the likely response by consumers to using the new fuel?	

2.3 GOVERNMENT

The federal government and some state governments, notably California, play an important role in new highway fuels development, especially with car companies. The regulatory role is particularly crucial for emissions and fuel economy. Safety is another important regulatory role for the federal government. Federal and several state governments also provide a range of incentives to promote new fuel development and sales. This stakeholder group includes all levels and branches of government: federal, state, county, city, and coalitions of government bodies with legal authority. Depending on the level of authority of the governing bodies, these organizations should implement a consistent long-term regulatory approach with special considerations for the items in the following checklist. The higher the level of governing authority, the greater the need for consistency.

Item to Check	New Fuel Compared to Conventional Fuels	✓
Environmental Impacts	Have all aspects of fuel production and use—raw material extraction, processing, by-products, distribution, use in the vehicle, and disposal—received an acceptable life cycle analysis (LCA)? Will the new fuel have indirect, negative impacts on land use?	
Energy Efficiency	Has an appropriate LCA been conducted for total energy of conventional and new fuels? Is the new fuel acceptable in terms of long-term economics (with and without fuel tax equalization)?	
Infrastructure Investment	Has a full analysis been done to determine the costs to the auto industry and fuel suppliers to transition to and sustain their respective investments to supply new vehicle technologies and fuels?	
Energy Independence and Energy Security	Independence—sufficient energy can be produced within our borders. Security—sufficient energy can be produced by a combination of domestic resources and supplies from secure sources. Is the level of energy independence and/or energy security of the new fuel acceptable?	

Item to Check	New Fuel Compared to Conventional Fuels
Disaster Refueling	Disasters can occur on a national, state, or local level. Can emergency vehicles and critical commerce vehicles using the new fuel still be refueled immediately after a disaster, even if with a temporary approach? Is this capability an improvement or not compared to disaster refueling with conventional fuels?	
Feedstock Adequacy and Reliability	Does the new fuel require new feedstocks or materials for its use? Are these new feedstocks or materials sufficiently available domestically or from secure sources?	
Taxpayer Affordability	Has analysis been done to determine to what degree government incentives (including support for infrastructure costs) are needed (and for which stakeholders) between the start of an incentives program and the start of the time when the new fuel begins to pay its fair share of taxes? Does the cost vs. benefit justify use of taxpayer funds to support the transition?	
Policy Continuity	Does the new fuel have sufficient consumer and long-term political support to enable the anticipated transition to a new fuel?	
Refueling Locations	Is there a plan for sufficient refueling at strategic locations for customers to be reliably served and comfortable with the alternative fuel vehicle purchase?	
National Economic Impacts	How does the new fuel change the costs of operations in the United States and affect the nation's competitiveness in the world?	
International Considerations	Has an acceptable analysis been performed to determine the impact on international economic actions if the new fuel displaced large amounts of conventional fuels (e.g., are there risks for political instability or trade sanctions)?	

2.4 ACTIVISTS/ADVOCATES

These terms include all levels of environmental and other fuel change activist and advocacy groups. Other major motivations of advocates include national security and economic improvement/stability. In generic terms, these will include organized groups of investors, professional associations, scientists, conservationists, unions, faith institutions, industry associations, utilities, political organizations, the media, and others.

Once a concern has been identified, activists and advocates will call on the moral and legal responsibility of government to protect human health and safety and/or assure employment opportunities. They may seek rulings from courts and regulatory bodies under existing laws

and/or seek changes in laws deemed inadequate.⁴ Activists questioning the advocacy positions will also use the powers of the courts, as well as moral arguments, to resist the transition. The following factors must be tracked and evaluated, regardless of activist/advocate position with respect to the transition.

Item to Check	New Fuel Compared to Conventional Fuels	✓
Life Cycle Analysis (LCA)	Has an acceptable LCA been conducted for greenhouse gases, regulated emissions, and energy use of the new fuel from the source to the final use? LCA could also address water, biosphere, land use, and solid waste disposal issues.	
Automotive Criteria Pollutant Emissions	Does the new fuel meet national regulations and standards for vehicles and local fuel production and delivery systems?	
Regional and Seasonal Air Quality Impacts of Criteria Pollutant Emissions	Are there local air quality problems with the new fuel due to its use in vehicles and issues with local fuel production and delivery systems? Are these problems predicted to be overcome?	
Scientific Trends for Air Quality Standards	Considering ongoing scientific investigations, if air quality standards are tightened in the future, will this hinder or enhance the success of the new fuel?	
Presently Designated and Potential Future Greenhouse Gases	How well does the new fuel meet national and international GHG standards, both current and projected, from vehicles and local fuel production and delivery systems?	
Water Consumption and Contamination Restrictions	Are the impacts of the new fuel better or worse in terms of water usage? If worse, is the new level acceptable in light of the net benefits in other areas?	
Wildlife and Vegetation Impact (the biosphere)	Are the impacts of the new fuel better or worse in terms of wildlife and vegetation? If worse, is the new level acceptable in light of the net benefits in other areas?	
Nuclear Risks (local, regional, and global; near and long term)	Does the new fuel have any nuclear risks associated with expanded electricity production to support new electric vehicles (EVs) or the production of hydrogen? If so, what are the risks?	

⁴ There is a labyrinth of existing laws and regulatory codes that specify attributes of vehicles and fuels. Major laws that influence the necessary introduction and performance of alternative fuels are the National Environmental Policy Act, the Clean Air Act and its many amendments, and multiple Energy Policy Acts. Many more are important. Important regulatory bodies include the U.S. Environmental Protection Agency, the California Air Resources Board, and the National Highway Traffic Safety Administration. Air Pollution Control and Air Quality Management Districts across the nation are important regional coalitions of governments involved in long-term planning. The U.S. Department of Energy-supported network of Clean Cities activists/advocates is important for education and project facilitation. Knowledge of the content of the laws named and the operation of related regulations is only the beginning of the knowledge activists/advocates must have when seeking a change in fuels and vehicles. Many other levels of legal authority have a bearing on the feasibility of alternative fuels.

Item to Check	New Fuel Compared to Conventional Fuels	✓
End-of-Life Solid Waste Disposal	Are the impacts of the new fuel better or worse in terms of solid waste disposal? If worse, is the new level acceptable in light of the net benefits in other areas?	
Energy Independence/Security	Is the level of energy independence/security improved or made worse with the new fuel?	
Safety	Is the level of consumer safety with the new fuel better or worse? If worse, is the new level acceptable in light of the net benefits in other areas?	

2.5 CUSTOMERS

A new car purchase is one of the most stressful decisions consumers make. Add a new fuel, and the decision can become more stressful. Customers rarely go through a formal checklist, although they might make wiser decisions if they did. However, they intuitively take into consideration at least several of the items in the checklist below. Customers expect that any new product they purchase will have an overall advantage relative to the status quo and will value the following differently. Vehicle and fuel suppliers spend many resources to understand customer motivation to assist in making purchase decisions. Individuals as consumers do not make this significant purchase based on consistent decision criteria. If consumers' decisions were more consistent and if vehicle and fuel suppliers better understood their motivations and needs, then the transition to new vehicles and fuels would be enhanced.

This stakeholder group includes purchasers of vehicles, tools, and aftermarket parts. Fleet operators and the government (at federal, state, and local levels) are also customers. For the fleet operators (public or private), ownership costs and refueling considerations will be more narrowly focused on functionality and overall cost minimization than on image and peer influences. Areas of special interest include the items on the following checklist.

Item to Check	New Fuel Compared to Conventional Fuels	✓
Motivation	Is there sufficient information on the need for a new fuel that customers will be motivated to purchase an alternative fuel vehicle?	
Vehicle/Fuel Attributes	Is the new fuel acceptable for fuel economy, driving range, start-up time, acceleration, highway speed, impact of new technology on passenger/trunk volume, heater warm-up time, or other unique operating characteristics?	

Item to Check	New Fuel Compared to Conventional Fuels
Cost of Ownership	Has the cost of a vehicle that uses the new fuel (including initial vehicle cost, operating costs, fuel and maintenance costs), reliability, government incentives, and resale value, taking into consideration vehicle longevity, been compared to that of a conventional vehicle? Are costs versus any trade-offs acceptable?	
Safety	Are the real and perceived levels of safety equal to, or preferably better than, those of conventional fuels?	
Refueling	Has the ease of refueling and length of time to refuel been examined? Are the number, location, and accessibility of service (refueling) points adequate?	
Peer Influences	Are sufficient numbers of people purchasing these alternative-fueled vehicles to influence the purchase decision? Does the new product convey a positive image? Has the alternative fuel vehicle become a status symbol?	
Unique Purchase Incentives and Intangible Benefits	Do the intangible benefits (feelings of environmental merit, contribution to energy independence or security, and/or the appeal of advanced technology) positively influence the purchase of an alternative fuel vehicle?	
Ease of Vehicle Purchase	Have automotive companies taken sufficient actions to make the vehicle purchase decision as easy as or easier than buying a conventional vehicle? Does the dealer have sufficient product information, trained sales staff, and inventory to have a positive impact on the purchase decision?	
Long-Term Maintenance	Will the seller be able to facilitate and guarantee the long-term servicing and maintenance of the vehicle?	

3 CHECKLIST DISCUSSION

3.1 AUTOMOTIVE INDUSTRY

This stakeholder group includes the full spectrum of players from the automotive industry, from those who extract the raw materials to those involved with local vehicle service and end-of-life recycling/disposal. It also encompasses the manufacturers, of cars, trucks, and buses. Individual companies are expected to have differing assessments.

Every industry project needs a solid business plan that demonstrates a profitable return for the company's shareholders. Thus, the transition to new transportation fuel(s) requires analyses of all aspects of the vehicles (e.g., materials used, manufacturing facilities, dealer networks, aftermarket repair facilities, and end-of-life recycling/disposal). Such analyses must be made on short-term, mid-term, and long-term bases. Special considerations for a transition to vehicles designed for new fuel(s) include:

- **Technical Feasibility** must be developed or demonstrated to meet geographically varying customer needs, as well as current and future government requirements for vehicles (e.g., emissions, fuel economy, safety, and standards/codes)—primarily driven by federal regulations and California requirements, but also by codes at the state and local levels and by standards established by industry agreement working with private standard-setting bodies. As future requirements are established and implemented, there must be assurance that unintended “roadblocks” will not be inadvertently created.
- **Transition Plans** for vehicles that will use the new fuel(s) must be thoroughly analyzed and agreed upon by all affected parties. For example: Which comes first, the fuel or the vehicles? Regardless, major new automotive production investments may be required, while others will be displaced. The displaced portions of the automotive industry production capacity may be notable, depending on the fuel and energy conversion device chosen, as discussed below. These effects must be analyzed. Adaptation and phase-out costs must be incorporated into estimates of the costs of transition, and consequences must be addressed.
- **Infrastructure Investment** and program timing will vary greatly among powertrain and fuel combinations. For example, the impact of the ethanol-fueled (E85) internal combustion engine on auto industry production facilities will be minimal compared to impacts from high-pressure hydrogen fuel cells. In this comparison, the ethanol fuel tank will have minor implications for vehicle architecture, investment, and program timing. Similarly, engine manufacturing facilities will be minimally affected by a switch to ethanol. Conversely, fuel cells will have major implications for vehicle designs and manufacturing facilities. The automotive industry will not make major investments in new production capacity unless there are adequate government startup incentives combined with

confidence for future customers. Industry must make a risk assessment for probable changes in the incentive program, especially as sales volume increases.

- **Operating Financial Implications** may necessitate varying, adaptable government incentives for short-term (next 10 years), mid-term, and long-term periods (15 to 25 years). Long-term incentives must be sustainable or eventually eliminated. Industry must conduct a risk assessment for possible changes in the incentive program. A new vehicle type and/or fuel could go from receiving credits to being revenue neutral or even to becoming a taxation source to support transportation services generally.
- **Competing Actions** from the current fuel and automotive industries must be considered, because they would affect the desirability of alternative fuel vehicles. For example, manufacturers of conventional vehicles could use price reductions to deter sales of alternative-fuel vehicles, while producers of conventional fuels might also reduce their fuel prices. Either action could result in the need for greater government incentives to promote the new fuel. This would have an impact on taxpayer support, policy continuity, and the national economy, as mentioned in Section 3.3. In addition, the automotive industry may not have the flexibility or resources to periodically switch among fuels and energy conversion devices without significant incentives to offset the costs of such occurrences.
- **Multi-National Business Strategies** would be affected if the United States moves in a different direction than the rest of the world. For economies of scale, vehicles are designed with worldwide commonality to the extent possible. Increasing the differences between U.S. vehicles and those of the rest of the world has the potential to raise the cost of vehicles worldwide.

Commonality of transportation fuels and vehicles is very desirable in North America, where vehicles frequently travel among the United States, Canada, and Mexico. Business strategies that facilitate cross-border travel need to be developed.

- **Corporate Image** is how a company is perceived by outsiders. Trust, or lack thereof, will affect customers' purchase decisions. Corporate image and trust among those influenced by alternative fuel advocates could potentially be enhanced by companies that choose to become leaders in alternative fuel(s).
- **Raw Material Adequacy and Reliability** for the automotive industry is twofold. To prompt automotive industry investment, if vehicles are to run exclusively on a new fuel, then the new fuel must be projected to be readily and reliably available. The same is true for any unique materials related to powertrains that use the new fuel, such as lithium for batteries, rare earths for some types of electric machinery, and/or platinum for fuel cells. Therefore, those materials should come from secure sources.

- **Lead Time** for internal company-generated programs is set by each company. In the event of excessively aggressive government regulations or corporate production goals, the potential exists for the accelerated program timing to be very costly. This could result in transition costs that are unnecessarily expensive. A related risk of rushing products to market is that not all design considerations and verifications may be fully performed. This scenario raises concern for possible product problems that would taint the reputation of the fuel and/or vehicle technology—potentially for a very long time. When industry and government develop technology and need supporting standards as they promote alternative fuels, determining the appropriate lead time must be a cooperative effort among all parties.
- **Consumer Acceptance**, which is difficult to predict, can be evaluated by using several different market research techniques, such as focus groups, phone surveys, and mail-in questionnaires. These techniques are used to help understand what potential customers actually want instead of what a company thinks they want. Although useful information can be gained, market research techniques are subject to bias. The key criteria are listed in Section 3.5, Customers.
- **Dealer Networks** need educated and trained personnel to help customers make appropriate purchase decisions. Industry may also need to educate the general public ahead of product offerings (e.g., provide convincing information that pressurized fuels, even hydrogen, are safe). Servicing capability must also be established in advance of vehicle sales.

3.2 MOTOR FUELS INDUSTRY

This industry encompasses companies that range in size from large multi-national energy corporations that are primarily petroleum companies to small entrepreneurial start-ups that market alternative highway fuels. Separate assessments are required for each fuel type, such as petroleum (oil-well derived and new feedstocks) and new fuel(s).

Every industry project needs a solid business plan that demonstrates a profitable return for the company's shareholders. Thus, the transition to new transportation fuel(s) requires analyses of all aspects of the new fuel(s). These analyses should consider such aspects as feedstock supply, processing, and distribution through dispensing to the ultimate consumer. Such analyses must be made on short-term, mid-term, and long-term bases. Special considerations for a transition to new fuel(s) include:

- **Technical Feasibility** must be developed or demonstrated to meet or be projected to meet customer needs in a cost effective manner. Existing standards and codes of government bodies must be met, as must those of industry itself, where internal standards are used. Often the goals of government and industry regarding safety and reliability require revision of codes and standards or development of new ones. It is obvious that development of entirely new fuels with no gasoline on the

vehicle requires significant changes in infrastructure supported by careful engineering design. Perhaps less obviously, significant changes may be required when new fuels are blended into gasoline. Reduction of gasoline demand will affect refinery capabilities to produce other fuels and chemicals. Gasoline blends may result in fuel chemical properties that are incompatible with existing transport and storage.

- **Regulatory and Legislative Compliance** is critical if the new fuel is to be marketed. The new fuel must be developed or demonstrated to meet both current and projected regulatory requirements (e.g., emissions, safety, and local codes/standards) and to be cost competitive with conventional fuels.
- **Transition Plans** for each potential new fuel must be thoroughly analyzed and agreed upon by all affected parties. An important question must be addressed: Which comes first, the fuel or the vehicles? In other words, how can simultaneously important fuel infrastructure and vehicle build-outs be managed and coordinated?
- **Infrastructure Investment**, unless initially self-financed, may require significant investments from supporting fuel producers, suppliers, and retailers. This will necessitate startup government incentives combined with confidence in future free-market customers. Industry must conduct a risk assessment for probable changes in any incentive program, especially as sales volume increases.

Displaced portions of the petroleum industry infrastructure (e.g., refineries, distribution systems, filling stations, and feedstock investments) are expected to experience notable effects (disinvestment) with some fuels more than others. These must be analyzed. Support for adaptation and phase-out costs may be necessary.

- **Operating Financial Implications** may be significant enough that day-to-day operations may necessitate ongoing government incentives for short-term (10 years), mid-term, and long-term periods (15 to 25 years). Long-term incentives must be sustainable, or preferably eliminated. Industry must conduct a risk assessment for possible changes in the incentive program. A new fuel could go from receiving credits to becoming revenue neutral, then ultimately becoming a taxation source to support transportation services, as petroleum products have done for many decades.
- **Competing Actions** from conventional fuels and vehicle-producing industries can have implications for new fuels. World crude oil supply and demand have periodically changed dramatically in response to producer output decisions, oil recovery technology discoveries, and vehicle fuel economy shifts. Have each of these been considered? Such changes could affect taxpayer affordability and policy continuity and have national economic impacts, as mentioned in Section 3.3.

- **Multi-National Business Strategies** for fuel companies could be affected if the United States moves in a different direction than the rest of the world. Some existing petroleum companies may decide to reduce U.S. operations, to phase out U.S. operations, or to incorporate the new fuel(s) into their product line.
- **Corporate Image** is how outsiders perceive a company. Trust, or lack thereof, will affect customers' purchase decisions. Corporate image and trust among customers influenced by alternative fuel advocates could potentially be enhanced by companies that choose to become leaders in those alternative fuels.
- **Feedstock Adequacy and Reliability** must be sufficient in the short-term, mid-term, and long-term phases of the transition. Analysis should show whether the feedstock price will be significantly affected by scaling up production.
- **Lead Time** for internal company-generated programs is set by each company. When the government is involved, there is a potential for industry to be faced with program timing that is unrealistic. Industry itself may push too hard, thereby creating failure risks. This could result in transition costs that are unnecessarily expensive. Determining the most effective lead time must be a cooperative effort among all parties (see additional discussion in Section 3.1).
- **Consumer Acceptance** of the new fuel can be evaluated by using several different market research techniques, such as focus groups, phone surveys, and mail-in questionnaires. These techniques are used to help understand what potential customers actually want instead of what a company thinks they want. Although useful information can be gained, market research techniques are subject to bias.

3.3 GOVERNMENT

This stakeholder group includes all levels and branches of government: federal, state, county, city, and coalitions of government bodies with legal authority. Depending on the level of authority of the governing bodies, these organizations should implement a consistent long-term regulatory approach with special considerations for the items in the checklist in Section 2.3. The higher the level of governing authority, the greater the need for consistency.

The federal government and some state governments, notably California, play an important role in new highway fuels development, especially with car companies. The regulatory role is particularly crucial for emissions and fuel economy. Because of greater initial needs for emissions control in California than elsewhere in the United States, California sought and obtained the right to regulate more strictly than the federal government. Repeated rewrites of laws, combined with Supreme Court rulings, have created a two-tier emissions regulation system in the United States. Over the years, California obtained the right to regulate both criteria air pollutants and greenhouse gases (see Section 3.4). Other states can and have adopted California regulations. Thus, the automotive and motor fuels industries that wish to have a national plan for

an alternative fuels transition must simultaneously consider two separate sets of regulations applying to large regions of the country.

Safety is another important regulatory role that is a responsibility of all levels of government. Authorities having jurisdiction for establishing and enforcing safety codes vary from federal to state to municipal or other legal entity. These government jurisdictions usually rely on codes developed by recognized independent testing laboratories. Federal bodies often conduct supporting research and make recommendations but may not have the ultimate authority, which is often local.

Over the years, federal and state governments have also provided (and removed) a range of incentives to promote new fuel development and sales. Local governments often adopt zoning ordinances and codes that influence whether and where fueling points can legally exist. Special considerations for a transition to new fuel(s) include:

- **Environmental Impacts** of pollution are both a local and a global concern. Life Cycle Analyses (LCAs), also known as cradle-to-grave and well-to-wheels (WTW) analyses, are the standard methodology used to consider all pollution aspects from the source to the final use.

Frequently, there is a tendency to focus on automotive tailpipe emissions, including (1) criteria pollutants (non-methane organic gases, carbon monoxide, particulates, nitrogen dioxide, and recently added formaldehyde) and (2) greenhouse gases (primarily carbon dioxide, but also methane, nitrous oxide, and fluorinated gases). However, all environmental effects must be considered, including later (after tailpipe emissions) formation of “secondary” pollutants in the atmosphere, including ground-level ozone, secondary particulates, and sulfur oxides. To reduce sulfur oxides, fuel sulfur content regulations have been used instead of vehicle tailpipe emissions regulations. In fact, regulation and co-optimization of both fuels content and vehicle tailpipe emissions are consistently necessary to achieve emissions goals. Evaluations must also include aspects associated with raw material extraction (both fuel and automotive related), processing, manufacturing, by-products, disposal, and so forth. Thus, solid waste, land use, and water use/contamination must also be evaluated. Environmental considerations are shown in more detail in Section 3.4, Activists/Advocates.

- **Energy Efficiency**, similar to the analysis for the environmental impacts discussed above, must be analyzed for energy usage. Doing so will improve the likelihood of selecting alternative fuels with long-term viability. A generic consideration is that, although an alternative fuel may be very efficient on board the vehicle, there are often cases where the process for producing and delivering the fuel to the vehicle is very inefficient. Cost efficiency/effectiveness is another important factor that must be addressed.
- **Infrastructure Investment** in the transition to a new highway fuel should have benefits to the nation (e.g., reduced oil imports, improved air quality, lower

greenhouse gas emissions). However, along with the benefits come costs. The government should conduct a full analysis (1) to determine the costs to the auto industry and fuel suppliers to transition to new vehicle technologies and fuels and (2) to sustain their respective investments to supply them. Taxpayers will be affected when government funds are used to support the beginning of a transition. Further, phase-out cost as existing fuel consumption declines will need to be addressed. Decommissioning of fuel production and delivery infrastructure can be costly. Consumers may also incur such costs as reduced availability of the existing fuel. Taxing bodies will need to find alternative sources of revenue. The results may be an infrastructure disinvestment.

- **Energy Independence and Energy Security** both have advantages for the nation.
 - Energy independence can be obtained when energy is produced in sufficient supply from within our borders (e.g., coal, natural gas, and/or renewable feedstocks).
 - Energy security can be achieved by having sufficient ongoing energy feedstock acquired from a broad supply base from within our borders and from friendly nations.
 - It is possible that a viable solution will combine these goals.
- **Disaster Refueling** is a relatively new issue for local and regional governments as they develop plans to increase redundancy and fuel supply flexibility and/or to access locally produced fuels when critical portions of the national petroleum products supply system no longer functions adequately. Hurricanes and other storms, earthquakes, explosions of refineries, ruptures of pipelines, and/or blockage of waterways can cause significant supply interruptions. Such incidents can curtail the national, regional, or local flow of petroleum products, due either to transportation infrastructure damage or to U.S. crude oil supply failures (or both). Does adoption of an alternative fuel provide needed local redundancy that can make up for lost supply and thereby (1) maintain emergency services and (2) enable critical commercial activity to continue?
- **Feedstock Adequacy and Reliability** for the new fuel(s) and special materials (e.g., lithium for batteries, rare earths for some electric machinery, and platinum for fuel cells) on an ongoing basis is closely related to energy independence and energy security.

The ongoing feedstock availability must take into account the implications that transportation sector usage will have on that feedstock's existing usages. To illustrate this point, consider biofuel from food crops. Use of food crops for making transportation fuel may conflict with their usage to produce food, thereby exacerbating periods of shortage due to drought or high demand.

- **Taxpayer Affordability** becomes an issue when a level of government begins to promote an alternative fuel, particularly if that government body makes a long-term commitment to a new fuel. The assistance may include basic and applied research to reduce costs or remove market barriers, demonstration programs, deployment, and/or infrastructure investment. The effect of incentives on new fuel success is difficult to calculate, but the consequences of success are not. The maximum affordable incentive amounts should be considered in advance. The incentive program should be designed to phase out in the event of success, so that taxpayers will not be committed to indefinite and potentially large subsidy costs. For example, if an alternative fuel receives a highway tax exemption or reduction, this would not be sustainable as the volume of alternative fuel usage increases.

Should the government entity evaluating the incentives decide that continuous subsidy to offset operating shortfalls for the new fuels industry is desirable and necessary for success, reliable long-term sources of the needed funds should be identified and assigned to the new fuel program. Calculations supporting long-term subsidy may occur when the new fuel will be produced locally, replacing an otherwise imported fuel. The implications of financial shortfalls in the automotive and motor fuels industries are discussed further in Sections 3.1 and 3.2, respectively.

The greater challenge is to estimate levels and timing of incentives sufficient to entice the affected parties to make the transition. A risk assessment must be conducted when reducing incentives, when (and if) establishing a tax revenue-neutral period, and before making the new fuel a revenue source. At the national budget level, the cost of incentives could possibly be partly offset by reducing some of the indirect military and international alliance participation costs that are necessary to assure a reliable, stable national and world petroleum supply.

Some of the alternative fuel for the transportation sector may come from different locations, requiring investment in additional fueling infrastructure, such as new roadways, rail networks, pipelines, canals, or deeper river channels and harbors.

- **Policy Continuity** to achieve a successful transition to new transportation fuel(s) will require as much consistency as possible. Historically, there have been significant shifts in the fuel of choice and degree of emphasis for the transition, due in part to changes in political leadership, economic conditions, and technical developments. As a result, many resources have been spent unnecessarily and investments have been orphaned. Restraint must be exercised to preclude unwarranted shifts in fuel choices. Usage of the checklist in Section 2.3 will aid significantly in that process.
- **Refueling Locations** can be critical to the success of a transition to an alternative fuel. An insufficient number can result in failure. In addition to an adequate number, a high degree of reliability and accessibility for all customers are critical

features needed at each location. Government can assist the process financially and in planning.

- **National Economic Impacts** must be assessed. The United States must be competitive in the world market, even with significant shifts in the price of conventional and alternative fuels. Alternative fuel selections must not appreciably increase the cost of vehicle ownership. Ideally, the alternative fuel will be projected to cause a lower net cost of transportation services to the citizens of the nation, by promoting either greater competition or lower absolute cost.
- **International Considerations** are important because shifting the U.S. transportation sector to new fuels will affect other countries, depending on the nations involved and the rate of the transition. For example, as we have seen, Saudi Arabia alone has a history of holding significant spare reserves and production capacity. As a result, it has been able to quickly increase supply and sharply reduce the price of petroleum. Other nations (including the United States) have shown an ability to slowly push prices down through investment and increased production, which leads to lower world gasoline and diesel prices. Either price-reducing effect could result in (1) the need for larger or longer-duration government incentives to promote the new fuel(s) or (2) a guarantee that a tax would be added to preclude gasoline and diesel prices from falling below a specified level (highly unlikely given Congress' historic aversion to raising enough money through the highway fuel tax to maintain the nation's roads, bridges, and highways). Either would affect the federal budget. Another concern is a disruption to the balance of trade among nations, which could result in an array of trade-related countermeasures. Commonality of transportation fuels and vehicles is desirable for all of North America, where vehicles frequently travel among the United States, Canada, and Mexico.

3.4 ACTIVISTS/ADVOCATES

Activists/advocates include environmentalists, safety advocates, and special interest groups that are active at all levels of government. The environmental impacts of pollution are both a local and a global concern. Environmental analyses must consider all aspects of pollution, from the source of the alternative fuels to their final use (WTW). Special considerations for a transition to new fuel(s) include:

- **Life Cycle Analysis (LCA)** has become the standard methodology for conducting analyses of greenhouse gases, regulated emissions, and energy use of the new fuel. It addresses the source of raw materials extraction through material processing, manufacturing, and distribution to its use in a vehicle (including repair and maintenance) and final disposition, either recycled or disposed. LCA is particularly important for tracking greenhouse gas emissions, because unlike criteria pollutants, these have consistent global impacts. LCA should also address other environmental issues, such as water, biosphere, and solid waste generation

and disposal. LCA takes into consideration the projected market penetration in order to determine changes in the magnitude of impacts.

- **Automotive Criteria Pollutants Emissions** should be analyzed, by using both currently designated and possible future standards as regulated by California and the rest of the United States. These criteria pollutants include carbon monoxide (a winter problem), non-methane organic gases and nitrogen dioxide (particularly a summer ozone problem), sulfur oxides, particulates (regulations have continued to evolve, emphasizing smaller sizes), and toxic emissions (California considers diesel particulate matter to be toxic). Measurement and tracking of vehicle emissions is inadequate to tell how seriously highway motor vehicles will contribute to locally varying air quality problems (refer to the bullet below). Gasoline and diesel fuel compositions vary regionally and seasonally as a result of varying regional topography and climate; the costs of control have a bearing on the stringency of fuel quality requirements. New fuels may be expected to come under scrutiny—often in unpredictable ways—with regard to how they contribute to variations in local and seasonal emissions of motor vehicles and fuel production.
- **Regional and Seasonal Air Quality Impacts of Criteria Pollutant Emissions** from vehicles and local fuel production and delivery should be analyzed. These vary significantly across the United States in response to the following:
 - Temperature
 - Geography/topography
 - Other sources of pollution within the control district
 - Sources of pollution outside the control district that float in. These can be divided into two categories: primary and secondary.⁵

⁵ Primary refers to the quantity and nature of emissions immediately after they leave their source—a tailpipe or smokestack. A secondary pollutant is one that results from atmospheric chemistry that takes place over time and space. Ozone is a major regulated air pollutant that is a secondary pollutant. Ozone standards have tightened over the years, as science proved damages existed at lower and lower concentrations. Consequently, its control has been a key factor forcing repeated redesign of vehicle emissions control systems. However, it is not emitted as a primary pollutant. Science is used to “back calculate” needed levels of primary emissions control. Emissions of primary pollutants from vehicles depend on temperature; concentrations of those pollutants are often influenced by geography (surrounding mountains) or climate (wind speed and direction, sunlight). The primary pollutants from the motor vehicle and its fuel supplier mix in the atmosphere with other local pollutants from other sources to form secondary pollutants such as ozone and fine particles. Local conditions vary, so local demands for amounts of control of vehicles and fuel production also vary. Vehicle and fuel producers must work together to assure that the needs of specific major markets are met if a new fuel and motor vehicle combination is to succeed nationwide.

- **Scientific Trends Regarding Air Quality Standards** is the result of the evolution of knowledge about health effects. Fine particulates is an emerging concern that both fuel providers and vehicle producers are attentive to. Like ozone before it (see footnote 5), scientific knowledge about health effects resulting from particulate chemistry and size is constantly evolving, pointing to the need for increasingly strict control.
- **Presently Designated and Possible Future Greenhouse Gases** have been specified by international scientific collaboration under the auspices of the Intergovernmental Panel on Climate Change, operated under the umbrella of the United Nations and World Health Organization. The decisions of these organizations led to designation of a few major pollutants—most notably carbon dioxide—as gases with global warming potential (GWP). The size of the GWP for each chemical and the number of included chemicals can both change because they remain subject to evolving scientific knowledge and evaluation.
- **Water Consumption and Contamination Restrictions** are already enforced in some geographic areas, and it is probable that tightening and widening of those regulations will occur. Small quantities of toxic metals can contaminate local water supplies. Manufacturing motor vehicle parts sometimes involves the use of very valuable rare chemicals that require careful handling to prevent effluents from polluting water supplies. The temperature of the water in lakes and rivers is controlled to prevent die-offs of aquatic life. The amount of water withdrawable for cooling can be limited to maintain local aquatic life. The role of water vapor in global warming is one of the greatest areas of climate uncertainty. Differences in low-level emissions (highway fuels) and upper level atmospheric emissions (aircraft) are a subject of analysis. LCA experts have debated the degree of global warming arising from evaporation from hydropower reservoirs. This has a bearing on estimates of the global warming effects of use of hydropower for electric vehicles and perhaps on the designs of cooling ponds for chemical processing of fossil fuels.
- **Wildlife and Vegetation Impacts** are sometimes lumped together as impacts on the biosphere. An issue in LCA expert scientific debates is the extent to which particular fuels require that land be removed from food production or put into cultivation instead of being left undisturbed or in a more natural state. This is the “food vs. fuel” debate. Biomass production is likely to require monocultures to be efficient. Critics worry about biodiversity and species extinction in a world with large amounts of biofuels based on monocultures.
- **Nuclear Risks** may increase if electricity production expands to accommodate increased use of electric vehicles or the production of hydrogen as a fuel. Local, regional, and global near-term risks and long-lived wastes are the principal concerns. Although nuclear energy could reduce global warming in coming decades if used in conjunction with electric vehicles, there is a very long-term health risk associated with nuclear waste disposal, and history has demonstrated

that regulations have not been adequate to prevent catastrophic failures. Local and regional opposition to nuclear power tends to be severe because of nuclear accidents and their consequences.

- **End-of-Life Solid Waste Disposal** occurs at the end of vehicle and infrastructure life. A point of relatively high risk for local water and air contamination occurs when vehicle parts that have no reuse or recycling value are discarded. Localized toxic emissions are relatively likely at this point in the life cycle.
- **Energy Independence and Security** are related risks that need to be examined:
 - Energy independence can be achieved when a sufficient supply of energy is produced from within our borders (e.g., coal, natural gas, and/or renewable feedstocks).
 - Energy security can be achieved when sufficient ongoing energy feedstock is acquired from a broad supply base from within our borders and from friendly nations.
 - It is possible that a viable solution will combine these goals.
- **Safety** can be related to explosion, crash risk, skin toxicity risk, undesirable gas concentrations, and other concerns. Both real and perceived safety must be equal, or preferably superior, to the status quo products. (See further discussion for Customers in Section 3.5.) At their outset, alternative fuels and vehicles can be subject to intense scrutiny by activists/advocates who are protectors of the status quo. Early risks tend to be difficult to measure and/or translate for comparison to the existing fuel. Fires or explosions draw more attention for new technology. Causes of fires and explosions will be different and not well understood by the existing regulatory system and/or by relatively neophyte manufacturers. Those involved in implementing the new technologies should expect a learning curve based on experience from doing. They should also expect to deal with surprises along the way. Accidents represent a form of learning about what not to do with a technology. Although they can be “showstoppers,” they can also be suppliers of needed knowledge. Activism/advocacy requiring resolution of problems is to be expected. Each type of risk mentioned above tends to require working with different industry and government regulatory, standard-setting, or code-setting bodies.

3.5 CUSTOMERS

This stakeholder group includes not only the purchasers of vehicles, but also consumers of tools and aftermarket parts. Customers expect that any new product will have advantages and disadvantages relative to the status quo. The choice of automotive technology and fuel is clearly influenced by an array of factors, including automotive and fuel industry advertisements, trained

and supportive dealership networks, media judgments, fuel cost and availability, environmental and safety performance, social influencer support, and government incentives.

For the consumer, when the new final product or system design is radically different, the advantages must be sufficient to overcome the fear of being the “guinea pig” for a transportation system and associated products that could have early design problems and/or could become obsolete.

Fleet operators and the government (at federal, state, and local levels) are also customers. For the fleet operators (public or private), ownership costs and refueling consideration will be more narrowly focused on functionality and overall cost minimization than on image and peer influences. Special considerations for a transition to new fuel(s) include:

- **Motivation** is necessary to do almost anything. In a transition to an alternative fuel, it is important that the customer have adequate information to be willing to purchase the new fuel and/or the vehicle that uses it, even if the price of conventional fuels declines. Some oil-producing countries may respond to alternative fuels by increasing production in order to drive down oil prices (and, in turn, gasoline and diesel fuel prices) to reduce the competitiveness of alternative fuels. If the transition to an alternative fuel truly is a national goal, all of the stakeholders must hold a consensus view.
- **Vehicle/Fuel Attributes** are obvious determining factors for consumer purchases. When choosing between vehicles that use petroleum products and those that use a new fuel, customers will want to know the vehicle comparisons for fuel economy, driving range, drivability (including startup time, acceleration performance, and attainable highway speed), and comfort/utility (including passenger/trunk volume, accessories, and heater warm-up time).
- **Cost of Ownership** implications for vehicles that use the new fuels need to be correctly presented to the customer in a convincing manner. Considerations for such an analysis include initial vehicle cost (including applicable home refueling installation costs), operating costs (including fuel, maintenance, repairs, battery replacement, insurance, and so forth), and vehicle longevity and resale value. The conclusion from such an analysis may vary among customers. For example, a vehicle with a higher initial cost and lower operating costs might be the vehicle of choice for a high-mileage driver, but it could be undesirable for a low-mileage driver or vehicle lessee.

Early in the process of introduction, government incentives can overcome high production or operating costs at low volume. Customers should be aware that the incentives could change over time. For example, highway fuel tax relief or high occupancy vehicle (HOV) lane access could be reduced or eliminated, especially as the volume of alternative fuel use increases.

- **Safety** on both real and perceived levels must be equal, or preferably superior, to that of the status quo products. Real concerns include explosion, crash risk, electric shock, skin toxicity risk, and/or undesirable gas concentrations. Although customers may not recognize this terminology, it is accurate to say that government jurisdictions with authority (which are many) are expected to ensure the system-wide implementation of safe designs when industry standards alone are not deemed adequate. Effort must be made jointly by advocates, the government, the fuel industry, and the automotive industry to ensure that products are safe and that consumers are comfortable with them. This assurance (e.g., education) must start well in advance of product introduction, especially when there is a significant departure from the status quo.
- **Refueling** must be evaluated for ease of refueling, the time required to refuel, and reliable service station accessibility. Consumers expect the refueling time and convenience of the new products to be the same as or better than those of petroleum products. Further, they want the connection between the refueling station and the vehicle to be similar to the petroleum connection (open fuel door, remove fuel cap, insert fuel nozzle, and so forth), to be intuitive (easy to figure out on their own), or to involve a minimal learning process. Consumers also want refueling locations to be plentiful and easy to find. To eliminate anxiety about running out of fuel and needing roadside assistance, there must always be confidence that fuel can be located well before the tank is empty.

Another example of a refueling issue is developing plans to preclude non-alternative fuel vehicles from denying access to refueling (e.g., when non-electric vehicles [non-EVs] park in places reserved for EV charging). In addition, adequate and properly designed alternative fuel points for disabled customers must be provided.

- **Peer Influences** exist when the buyer asks, “Are there sufficient numbers of people purchasing these alternative-fueled vehicles for me to feel comfortable buying one?” Advocates also intentionally rely on peer influence to persuade target audiences of the desirable features of their chosen alternative fuel. Important peer influence is also exerted by satisfied (disappointed) customers who encourage (discourage) use of alternative fuels due to their positive (negative) experience.
- **Unique Purchase Incentives** are expected to be inherent with the new alternative fuels. The factors include environmental merit, energy independence, security benefits, and/or advanced technology appeal. Are there special incentives to encourage the new fuel (e.g., carpool lane access, special parking spots, and free parking)? These considerations have the potential to favorably influence consumer purchases, even when the aggregate of the previously mentioned attributes are unfavorable.

- **Ease of Vehicle Purchase** is significant whether the vehicle runs on conventional or alternative fuels but is particularly important when the customer is introduced to a new fuel. Customer interface with the sales process, dealership or otherwise, must be as intuitive and friendly as possible, which certainly requires educated and informed personnel, as well as clear and convincing literature.
- **Long-term Maintenance** capabilities should be a consideration for the customer to be assured that the dealer will be able to guarantee that servicing and maintenance for the alternative fueled vehicle over the long term will be comparable to that of a conventional vehicle.

4 CLOSING COMMENTS

In the past century, crude oil was the major force that supported expanding transportation services worldwide. It has arguably been foundational for the expansion and operation of advanced economies. However, taking a very long view, most experts believe that by the end of this century there must be, at a minimum, a greater diversity of sources of energy for transportation services.

Crude oil is distributed unevenly across the world and is traded widely among nations. Its inherent value to importing nations in support of economic growth is very high, and the world oil market is expanding. Use continues to expand due to rapid increases in demand in nations that are reaching the income threshold where vehicle use expands rapidly.

Low oil prices can be used temporarily by petroleum-producing nations to gain market share by enhancing the affordability of continued oil-based transportation, thereby making competing technology appear unwarranted. Although forecasting the long-term price of oil is a precarious undertaking, it would be prudent for those nations heavily dependent on imported oil to adopt appropriate alternatives. If history is a guide, greater quantities of oil imports due to today's low prices will eventually be followed by rising prices and likely by intermittent price shocks. For the U.S. economy, the post-1970s period of increased net oil dependence caused demonstrably greater fluctuation and slower overall growth. This implies that economies that do not take countermeasures will be even more vulnerable than when they first became dependent upon the variable supply of imported oil.

Accordingly, alternative fuel sources must be pursued on a timely basis, since transitions will take many years to accomplish. Over many decades, the oil-dependent transport system developed and supported its own infrastructure, rigidly binding the legacy structure of the economy. The built structure of an economy takes decades to replace. It is preferable to make fuel transitions as steadily and as patiently as possible, maintaining the effort even during times of low oil prices. This requires that the vast majority of stakeholders understand why a transition is necessary.

It is important to realize that any path may need multiple alterations. Fuel shifts and/or composition adjustments will inevitably be necessary to enable the desired reduction of vehicle emissions and fuel use. The degree of desirability of various paths will fluctuate as a result of international affairs, world pricing of fuels, domestic fuel discoveries, and scientific knowledge about environmental impacts. Analyses for the selection of new transportation fuel(s) must maximally satisfy evolving needs of all affected parties to enable long-term program success.

Participants in the highway fuels transition process must recognize that the seeds of mass-market success can begin at any level—locally, in a city, state, and/or region and slowly work their way into the national marketplace. Initially, opportunities and needs for a niche market entice forward thinking scientists, engineers, investors, and innovators to develop technology. Technology developed for the niche market achieves focused public acceptance and financial backing. The market expands. Then many consumers and organizations currently and

potentially influenced by the effects of the new market begin to be interested in how to make the market work for their benefit. Activism and advocacy supporting market manipulation and alteration begins, ultimately pressuring industry to set standards and/or governments (city and state first, then federal) to pass laws, to set standards and develop codes for which they have jurisdiction, and to create regulatory incentives to push the market in the desired direction. Federal laws and regulations result only after a consensus across many states.

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A strong impetus to update the 2011 Fuel Transitions report came from Jeff Seisler, who had been a reviewer of that report and subsequently a reviewer of this report. Jeff suggested that we use the word “Advocates” for our new and separate stakeholder group, which is distinct from Customers. Marcy Rood had suggested Activists. After deliberation, we decided that pairing Activists/Advocates best conveyed our intended meaning. But without the recognition by the U.S. Department of Energy that a transition in highway fuels from gasoline and diesel fuel to some alternative fuel is inevitable and that the analysis of such a transition is critically important, this update to the 2011 study, with a separate checklist, would not have happened. The Vehicle Technologies Office within the USDOE provided support for our work, and we gratefully acknowledge the review, guidance, and suggestions by Connie Bezanson, the program manager.

We were careful in selecting reviewers. We wanted people with real-world experience, because we didn’t want this to be just an academic exercise. The checklists are designed to be used in the real world. Therefore, we had the checklists reviewed by colleagues in the automotive industry, in the fuels industry, and in government research, as well as by alternative fuel advocates. The reviewers have considerable experience with or responsibility for the introduction of alternative fuels in the real world.

The reviewers had influence on a number of areas in the two documents. To illustrate, we made the following changes in the brochure and report as a result of their input:

- Emphasis is placed on all layers of government—federal, state, regional, and local—requirements. Attention is given to consideration of how California regulations have driven the auto industry.
- The synergistic requirements between industries are considered. For example, we addressed the “chicken and egg” issues regarding development of vehicles to run on a new fuel versus the widespread availability—and affordability—of that fuel being provided by the energy industry.
- In the Fuels Industry, “technical feasibility” is divided into separate technical feasibility and regulatory/legislative feasibility categories.
- Taxpayer affordability considers infrastructure costs, as well as vehicle and fuel costs.
- Codes and standards are emphasized more.

Although this is not mentioned elsewhere, we acknowledge here that the introduction of a new motor fuel raises liability issues that companies must evaluate. The authors struggled with this reviewer point, but ultimately did not include this as a separate item in the checklist because reviews of liability may be needed in conjunction with performance of several of the checklist items. Realistically, in our litigious society there are liability risks with nearly every action, as

well as delayed action and inaction. We hope that our increased emphasis on the importance of codes and standards is implicit recognition of the importance of liability issues.

Our reviewers are responsible for many more valuable improvements to the checklist documents. In consideration of their very hectic schedules, we asked them to review only the checklist brochure. However, they gave us very thorough evaluations that carried over into the technical report, which is a more detailed version (supporting document) of the brochure. So we thank them very much. These reviewers include:

Internal Reviewers

• Douglas Longman	Argonne National Laboratory
• Marianne Mintz	Argonne National Laboratory
• Marcy Rood	Argonne National Laboratory

External Reviewers (excluding Argonne and DOE)

• Marcus Alexander	Electric Power Research Institute
• Karl Fiegenschuh	Ford Motor Company, retired
• Dan Goodwin and Rebecca Boudreaux	Oberon Fuels
• John Lapetz	Ford Motor Company, retired
• Steven Przesmitski	Aramco Research Center
• Jeffrey Seisler	Clean Fuels Consulting, Brussels
• William Studzinski	General Motors
• Other	Reviewed independently by staff from a major international oil company who preferred to remain anonymous

While the reactions of our reviewers were universally positive, they were not hesitant to point out where important elements were overlooked or needed clarification. In nearly all cases where a change was suggested, a carefully considered revision was made. However, the authors are solely responsible for the content. For the reader, the key point is that no reviewer requested the removal of any content because of its lack of importance.

Condensing the revised report into a brief brochure fulfilled our goal to create a succinct document for busy decision makers. A special thanks is due to several of Argonne's communications staff that took our final drafts, commented on them, and helped turn them into polished, finished documents. Michele Nelson revised and designed the brochure layout. Vicki Skonicki managed the document production process for both the report and brochure, and Carolyn Steele edited the technical report. As managing editor, Kevin A. Brown very carefully considered wording and meaning and contributed new ideas. The final title emerged from a collegial competition that included several great suggestions solicited from Kimberly DeClark. But we have to credit Mary Fitzpatrick with suggesting the brochure title, *CHECK IT OUT: Using Checklists to Assess Your Transition to Alternative Fuels*, which seemed to all of us the right balance between catchy and informative.

ENDNOTES

- i. Source: Sikes et al. (2015).

Research on carbon capture and storage might succeed at some time in the future, enabling use of coal and oil while sharply reducing global warming consequences.

- ii. The U.S. transition from leaded to unleaded gasoline is likely the fastest that can reasonably be expected for any future nationwide switch of fuels and engines. An important agreement among key players successfully started that transition. In the 1960s, small quantities of unleaded gasoline with octane ratings compatible with the engines of that decade were produced by Amoco.

In 1970, as a result of general agreement among government regulators, the oil industry, and automakers, future engines from 1975 were redesigned for a lower-octane unleaded gasoline than had previously been produced by Amoco. Pressure from environmental activists in particular and consumers generally pushed these players to come to agreement. From 1971 to 1974, quantities of the future lower octane unleaded gasoline were added at some pumps at existing gasoline stations. During these years, vehicles with detuned engines capable of running satisfactorily on that new regular unleaded gasoline (as well as existing regular leaded gasoline) were sold by General Motors.

In 1975, nearly all *new* passenger vehicles sold (retrofit of old vehicles was sometimes attempted) were required and designed to run *only* on unleaded gasoline. It then took until 1991—17 years—for the share of unleaded gasoline to rise from about 7% of the 1974 market to 96% of gasoline production (Newell and Rogers 2003). This means that it took a total of 20 years for new vehicle, and then complete fleet, change-over; this is equal to the most optimistic projected future technology transition value that Bandivadekar et al. estimated in 2008.

Less significant, but successful, switches of new vehicle engine or transmission technology alone (U.S. Environmental Protection Agency 2015), or regional transport systems (Santini 1989), can be achieved in less time. Bandivadekar et al. (2008) estimated that for both new vehicles and the fleet to transition, the technology with the shortest transition period was gasoline direct injection and turbocharging, an engine technology combination that does not currently require a change of fuels. Aside from the very rapid 5-year U.S. switch from new vehicles with leaded gasoline operability to new vehicles unleaded gasoline operability, the shortest plausible timeframe for a change of new vehicle technology alone (without changing fuel or the entire fleet) is about 10 years (U.S. Environmental Protection Agency 2015, Figure 6.1), which is consistent with Bandivadekar et al.'s (2008) best-case estimates for the period required for new vehicles to change.

When there are significant fleet-wide changes of vehicle powertrains, fuels, and fuels infrastructure to be accomplished, it is expected that the transition time required will increase accordingly. For plug-in hybrids, which require significant changes in powertrains and

changes in final delivery devices for electric fueling (but not in most of the electrical grid and generating system), Bandivadekar et al. (2008) estimate that it will take 35 years to reach maximum attainable share. For hydrogen fuel cell vehicles, which require a completely new powertrain and fuel production and delivery system, the estimate is 50 years.

Historically, gasoline vehicles replaced railroads for intercity travel and horses for local travel; it is estimated that by 1950, there was one gasoline-powered vehicle per household (Tang 2015). This transition took place over 55 years, dating from the creation of the gasoline automobile in 1895. In fact, the transition was still under way in 1950. Tang dated the gasoline vehicle-per-household peak in 1988, after a 1980–1988 plateau. In 1989, Santini retrospectively estimated about five decades would have been necessary for the historical 1900s switch to oil in ground transportation, if a return to coal in World War II had not intervened. In this case, the entire vehicle, the roadway network, and the fuel production and delivery system all had to change dramatically and repeatedly to enable ultimate market success. These examples illustrate best cases for nationally significant switches. Many technology transitions fail, or never attain a large share.

APPENDIX A: HISTORICAL HIGHWAY FUEL TRANSITIONS—GLOBAL SUCCESSES AND FAILURES

There have been many attempts to transition to new highway fuels. As this list shows, the process can be lengthy for the successful ones and even for the relatively modest ones—like switching from leaded to unleaded gasoline. Given the length of time these transitions take, they are also very expensive, *so it pays to get the analysis right*.

SUCCESSES—*A sustained fuel switch for a large portion of the highway fuels market*

- Global: Shift from agricultural products (e.g., hay and oats) for animal-drawn carriages to gasoline vehicles
- Brazil: Shift from gasoline to sugar-cane-based ethanol vehicles, in two waves:
 - 1970s and early 1980s
 - Late 1990s to the present
- Europe: Shift from gasoline to diesel in light-duty vehicles through the 1980s and 1990s
- Germany: Use of synthetic (coal-to-liquid) fuels from the 1930s to 1945
- South Africa: Present-day use of synthetic (coal-to-liquid) fuels
- Armenia and Pakistan: Present day use of natural gas vehicles
- United States:
 - Shift from gasoline to diesel in heavy-duty vehicles, 1960s to the present
 - Switch from unleaded to leaded gasoline during 1920s and 1930s (enabling more automobile power and efficiency and greatly expanded auto use). Global thereafter.
 - For vehicle emissions reduction, a switch from leaded back to unleaded gasoline in the 1970s and 1980s and largely globally thereafter
 - Switch from gasoline to corn-based ethanol-blended (10% volume) gasoline vehicles, 1980s to the present
 - Shift to low-sulfur diesel fuel

PARTIAL SUCCESSES—*The capture and retention of a niche within that market or a small but rising share*

- Global: Nickel-metal-hydride and lithium-ion battery chemistry electric drive vehicles—hybrids, plug-in hybrids, and pure electric vehicles
- Bolivia and Iran: Gasoline to natural gas vehicles
- Turkey, South Korea, Poland, Italy, and Australia: Gasoline to propane vehicles
- United States:
 - Gasoline to diesel in light-duty passenger vehicles
 - Diesel fuel to natural gas for transit buses

FAILURES—*A significant effort to introduce with no success or inability to retain a market niche*

- United States:
 - Gasoline to Methyl-Tertiary-Butyl-Ether (MTBE)-blended gasoline vehicles
 - Lead-acid battery chemistry pure electric vehicles

- In place of horses, 1895–1930 (gasoline prevailed)
 - And again versus gasoline in the 1990s
- Gasoline to natural gas in passenger cars
- Gasoline to propane (liquefied petroleum gas)
- United States and Germany: Gasoline to methanol vehicles
- New Zealand:
 - North Island – Use of compressed natural gas vehicles
 - South Island – Production of gasoline from natural gas

APPENDIX B: ABOUT THE AUTHORS

These checklists were jointly prepared by three longtime industry veterans who have seen many failed attempts to introduce alternative fuels for highway vehicle use. Dr. Santini and Dr. Johnson have worked primarily for the government at Argonne National Laboratory, while Mr. Risch worked at Ford Motor Company. At times, all have been enthusiastic about different alternative fuel options, but none have seen the desired degree of success. Drs. Santini and Johnson and Mr. Risch believe that they now have a much better understanding of the difficulties involved than when they started in this field. As such, they would like convey this knowledge to others who may have just begun and to alternative fuel veterans. The intent is to identify the difficulties in order to enhance the odds of successfully introducing alternative fuels, rather than to discourage those who also would make the attempt. These extensively reviewed checklists are intended to be a quick introduction to the many things that must go right in order to begin a relatively successful transition to new highway fuels and, once begun, to continue the transition process.

Charles (Chuck) Risch holds B.S. and M.S. degrees in Mechanical Engineering from the Rose-Hulman Institute of Technology and the University of Michigan, respectively. While working for Ford Motor Company, he was involved with vehicles that used propane, natural gas, methanol, ethanol, battery electric, and hydrogen internal combustion engines and fuel cells. When he worked on the various Ford alternative fuel programs, he is confident, in retrospect, that he would have welcomed a checklist of any origin and that most of his management would have as well. Since retiring, he has worked part time for Argonne National Laboratory, where he has analyzed alternative fuel programs. He also served on the management team for the Partnership for a New Generation of Vehicles (PNGV) and FreedomCAR. Although Mr. Risch is pleased with the technical progress made in alternative fuels, he is disappointed with the minimal amount of petroleum they have displaced. Of primary concern are missed opportunities for energy security and the environment for the United States.

Danilo J. Santini earned his Ph.D. in Urban Systems Engineering and Public Policy at Northwestern University. A senior economist, Dr. Santini has worked in the Center for Transportation Research at Argonne from 1982 to 2008 and is now a member of the Systems Assessment Group. A founding and continuous member of the Alternative Fuels Committee of the Transportation Research Board since 1989, he served as its chair from 1996 to 2002 and is now an emeritus. His job has been to conduct technology assessments for advanced highway vehicle technologies and alternatively fueled vehicles. Dr. Santini studied successful transitions to alternative fuels throughout U.S. history and, for the last few decades, ongoing transportation technology transitions in several countries. Consistent with standard practice, historical U.S. studies examined successes. An absence of studies that investigate historical failures is a shortcoming. His analyses have encouraged the abandonment of several alternative fuel technologies. However, because of the absence of a checklist and changing scientific knowledge about the consequences of emissions (such as the ones provided in this report), some of his analyses promoted alternatives that did not succeed.

Larry R. Johnson has a Ph.D. in Public Policy Analysis from the University of Illinois, Chicago. He has worked in the field of transportation energy research at Argonne National Laboratory since 1979. In 1997, he became the director of the laboratory-wide Transportation Technology Research and Development Center and was named a Distinguished Fellow, the highest scientific/ engineering rank at the laboratory in 2012. He was a long-time member of the Energy Committee of the Transportation Research Board and its chair from 1990 to 1996. He was also a member of the Society of Automotive Engineers. He was on the Board of Trustees of Kettering University from 2004 to 2012. Although he holds a patent in magnetic levitation, he says a checklist would have been more valuable for the U.S. High-Speed Ground Transportation program in the 1980s. He officially retired in 2013, but he still works part time at Argonne.

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