ANL/ESD/11-10

Checklist for Transition to New Highway Fuel(s)

Energy Systems Division

About Argonne National Laboratory

Argonne is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC under contract DE-AC02-06CH11357. The Laboratory's main facility is outside Chicago, at 9700 South Cass Avenue, Argonne, Illinois 60439. For information about Argonne and its pioneering science and technology programs, see www.anl.gov.

Availability of This Report

This report is available, at no cost, at http://www.osti.gov/bridge. It is also available on paper to the U.S. Department of Energy and its contractors, for a processing fee, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone (865) 576-8401
fax (865) 576-5728
reports@adonis.osti.gov

ANL/ESD/11-10

Checklist for Transition to New Highway Fuel(s)

by
C. Risch and D.J. Santini
Energy Systems Division, Argonne National Laboratory

September 2011

CONTENTS

ACKNOWLEDGMENTS iv

PROLOGUE 1

1 OVERVIEW 1

2 CHECKLIST 2

2.1 Customers 2
2.2 Government 2
2.3 Fuel Industry 3
2.4 Automotive Industry 3

3 CHECKLIST DISCUSSION 4

3.1 Customers 4
3.2 Government 5
3.3 Fuel Industry 7
3.4 Automotive Industry 9

4 CLOSING COMMENTS 11

APPENDIX A: HISTORICAL HIGHWAY FUEL TRANSITIONS — SUCCESS AND FAILURE ASSESSMENTS 13

APPENDIX B: ABOUT THE AUTHORS 14

ACKNOWLEDGMENTS

The authors are very grateful to colleagues willing to share their time and provide opinions of earlier drafts and ideas. They are responsible for many valuable improvements to this document. We thank them very much.

External reviewers:

- David Thomasson, U.S. Air Force (retired), Technology Advisor, NASA
- David Slocum, Bechtel Corporation (retired), Manager, Process Engineering, Petroleum, and Refinery Division
- Prof. Zac Chambers, Ph.D., Rose-Hulman Institute of Technology, Associate Prof., Mechanical Engineering; Inaugural Director, Advanced Transportation Systems Program
- Dr. Kanehira Maruo (retired), Swedish Country Expert, International Energy Agency HEV & EV Implementing Agreement Task XIV: Lessons Learned in Market Deployment of Hybrid and Electric Vehicles; former staff member, ETC Battery & Fuel Cells, Sweden
- Dr. Philip Patterson (retired), Analyst, Vehicle Technologies Program, Energy Efficiency and Renewable Energy, U.S. Department of Energy
- David Gushee (retired), Section Head, Environment and Natural Resources Policy Division, Congressional Research Service

Internal reviewers, Argonne National Laboratory:

- Steve Plotkin, Transportation Energy and Environmental Systems Analyst, Center for Transportation Research; former staff member of the Office of Technology Assessment, U.S. Congress
- Dr. Mark C. Petri, Technology Development Director, Energy Sciences and Engineering Directorate
- Dr. Larry Johnson, Director, Transportation Technology Research and Development Center

CHECKLIST FOR TRANSITION TO NEW HIGHWAY FUEL(S)

C. Risch and D.J. Santini

PROLOGUE

This Checklist has been jointly prepared by two longtime industry veterans who have seen many failed attempts to introduce alternative fuels for highway vehicle use. Dr. Santini has worked primarily for the government at Argonne National Laboratory, while Mr. Risch has worked at Ford Motor Company (refer to Appendix B: About the Authors). At times, both have been enthusiastic about different alternative fuel options, but neither has seen the desired degree of success. Dr. Santini 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. The intention 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. The enclosed Checklist is 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.

The Checklist has been reviewed by colleagues in industry, government research, and academia. The reviewers have varying degrees of experience with or responsibility for the introduction of alternative fuels. Reactions have ranged from brief statements of approval to comments about an important element that had been neglected. 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.

The support of the U.S. Department of Energy, Office of Vehicle Technologies, and the Argonne National Laboratory Transportation Technology R&D Center are gratefully acknowledged.

1 OVERVIEW

Transportation is vital to the U.S. economy and society. As such, U.S. Presidents have repeatedly stated that the nation needs to reduce dependence on petroleum, especially for the highway transportation sector.

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.

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. While it is tempting to make quick decisions about the new fuel(s) of choice, it is preferable and necessary to analyze all the pertinent criteria to ensure that correct decisions are made. Doing so will reduce the number of changes in highway fuel(s). Obviously, changes may become necessary because of occurrences such as significant technology breakthroughs or major world events. With any and all of the possible transitions to new fuel(s), the total replacement of gasoline and diesel fuels is not expected. These conventional fuels are envisioned to coexist with the new fuel(s) for decades, while the revised fuel and vehicle infrastructures are implemented.

The transition process must analyze the needs of the primary "players," which consist of the customers, the government, the fuel industry, and the automotive industry. To maximize the probability of future successes, the prime considerations of these groups must be addressed.

Section 2 presents a succinct outline of the Checklist. Section 3 provides a brief discussion about the groupings on the Checklist.

2 CHECKLIST

2.1 CUSTOMERS

Customers of both the government (i.e., voters and interest groups) and industry expect that any new product will have an overall advantage relative to the status quo. Areas of special interest include:

- Environmental Impacts (addressed primarily via the government)
- Safety (addressed partly via the government)
- Cost of Ownership
- Vehicle Function
- Refueling
- Unique Purchase Incentives

2.2 GOVERNMENT

The government should implement a consistent long-term approach with special considerations for:

- Environmental Impacts
- Energy Efficiency
- Energy Independence and Energy Security
- Feedstock Adequacy and Reliability
- Taxpayer Affordability
- Policy Continuity

- National Economic Impacts
- International Considerations

2.3 FUEL INDUSTRY

The fuel industry should establish a solid business plan with special considerations for:

- Technical Feasibility, including legal/regulatory compliance
- Transition Plans
- Infrastructure Investment
- Operating Financial Implications
- Competing Actions from the current petroleum industry
- Multi-national Business Strategies
- Corporate Image
- Feedstock Adequacy and Reliability
- Lead Time

2.4 AUTOMOTIVE INDUSTRY

The automotive industry should establish a solid business plan with special considerations for:

- Technical Feasibility, including legal/regulatory compliance
- Transition Plans
- Infrastructure Investment
- Operating Financial Implications
- Competing Actions from current fuel and automotive industries
- Multi-national Business Strategies
- Corporate Image
- Feedstock Adequacy and Reliability
- Lead Time
- Consumer Acceptance

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

3 CHECKLIST DISCUSSION

3.1 CUSTOMERS

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 both direct consumer purchases and indirect interest-group preferences — particularly environmentalists and safety advocates. The latter are customers of the government in the sense that they organize voters to exert pressure to regulate the design of vehicles, the fuel infrastructure, and the highway network. For the consumer of the final product or system design, when the new is radically different, the advantages must be sufficient to overcome the fear of being the "guinea pig" for a transportation service delivery system and associated products that could have early design problems and/or could become obsolete. Areas of special interest include:

- Environmental Impacts: Individuals turn to the government to assure protection of the environment via: (a) provision of clean air and water, (b) solid waste containment or recycling, and (c) preservation of land that supports important habitats. Due to significant and broad demand for environmental protections, modern environmental assessments must now examine these three pollution aspects from the source to final use (also known as well-to-wheels, or WTW). Green images, supported by careful reporting and upheld by government and industry testing, have an effect on both the vehicle and fuel choices made by consumers. Over the years, environmental science has increased the list of by-product substances of concern, in all steps of vehicle and fuel production, and has addressed the use and disposal of vehicles.

- Safety on both real and perceived levels must be equal to or preferably superior to the status quo products. The government is often expected to assure the system-wide implementation of safe designs. Effort must be made jointly by the government, the fuel industry, and the automotive industry to assure 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.

- Cost of Ownership implications for vehicles that use the new fuel(s) 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.

Early in the process of introduction, government incentives can overcome high production costs at low volume.

- Vehicle Function is an obvious determining factor 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 start-up time, acceleration performance, and attainable highway speed); and comfort/utility (including passenger/trunk volume, accessories, and heater warm-up time).

- Refueling must be evaluated for ease of refueling, the time required to refuel, and service station accessibility.

  Consumers expect the refueling time and convenience of the new products to be the same as or better than the petroleum products. Further, they want the connection between the refueling station and the vehicle to be similar to petroleum (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. There should always be confidence that fuel can be located before the tank is empty.

- 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. These considerations have the potential to favorably influence consumer purchases, even when the aggregate of the previously mentioned attributes are unfavorable. Everything depends on the mindset of the marketplace.

3.2 GOVERNMENT

This section presents the Checklist Discussion for the government. Areas of special interest include:

- The Environmental Impacts of pollution are both a local and a global concern. Environmental analyses must consider all pollution aspects from the source to the final use (also known as well-to-wheels, or WTW).

  Frequently, there is a tendency to focus on the automotive criteria pollutants (hydrocarbons, carbon monoxide, and nitrogen oxides) and greenhouse gas emissions (carbon dioxide) from vehicles. However, all environmental aspects must be considered. This includes 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 must be evaluated.

- Energy Efficiency: Similar to the Environmental Impacts discussed above, the entire cycle must be analyzed for energy usage. Doing so will improve the possibility of selecting the correct alternative fuel(s). A generic consideration is that, although an alternative fuel may be very efficient onboard the vehicle, there are often cases where the process for producing and delivering the fuel to the vehicle is very inefficient.

- Energy Independence and Energy Security both have advantages for the nation.

  i. 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).
  ii. 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.
  iii. It is possible that a viable solution will be a combination of these options.

- Feedstock Adequacy and Reliability for the new fuel(s) and special materials (e.g., lithium for batteries, rare earths for 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 consider 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: The period of transition to new fuel(s) will likely require government incentives for the fuel(s) industries, automotive companies, related entities, and consumers. In addition to start-up incentives, ongoing incentives may be needed for operating financial shortfalls. This topic is discussed further in Sections 3.3 and 3.4.

  Incentives must be sufficient to entice the affected parties to make the transition. Eventually, incentives must be reduced to sustainable levels or gradually be eliminated. At the national budget level, the cost of incentives could possibly be partly offset by reducing some of the indirect costs that are necessary to protect the nation's petroleum supply.

  Some of the alternatives for the transportation sector may require an investment for public sector items, such as roadway or rail networks.

- Policy Continuity: Successful transition to new transportation fuel(s) will require as much continuity 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.

- National Economic Impacts: The United States must be competitive in the world market, even with significant shifts in the price of conventional and alternative fuel(s). Alternative fuel selection(s) must not appreciably increase the cost of ownership.

- International Considerations: Shifting the U.S. transportation sector to new fuel(s) may have international implications, depending on the nations involved and the rate of the transition. For example, OPEC could reduce the price of petroleum, which would lead to lower gasoline and diesel prices. This 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. Either would impact the federal budget.

  Another concern is a disruption to the balance of trade among nations, which could result in an array of 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.

3.3 FUEL INDUSTRY

Separate assessments are required for each fuel type, such as petroleum (oil-well derived and new feedstocks) and new fuel(s).

Every major 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 aspects such 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 have been developed or projected to meet customer needs, as well as current and forecasted government requirements (e.g., emissions, safety, and codes/standards) on national, state, and local levels. As future requirements are established, there must be assurance that unnecessary "roadblocks" will not be created.

- 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?

- Infrastructure Investment: Unless initially self-financed, new infrastructure may require significant investments from the fuel industry. This will necessitate start-up government incentives combined with confidence in future free-market customers.

  Displaced portions of the petroleum industry infrastructure (e.g., refineries, distribution systems, filling stations, and feedstock investments) are expected to have notable implications. These must be analyzed. Support for adaptation and phase-out costs may be necessary.

- Operating Financial Implications: Day-to-day operations may necessitate ongoing government incentives for short-term, mid-term, and long-term periods. Long-term incentives must be sustainable or preferably eliminated.

- Competing Actions from the current oil-well-derived petroleum industry must be considered. For example, OPEC and others could reduce their profit margins, which would cause the price of gasoline at the pump to be lower. This would result in the need for costly government actions to promote the new fuel(s). This situation would impact Taxpayer Affordability and Policy Continuity and have National Economic Impacts, as mentioned in Section 3.2.

- 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 has the potential to be enhanced by becoming a leader in alternative fuel(s).

- Feedstock Adequacy and Reliability must be sufficient in the short-term, mid-term, and long-term phases of the transition.

- 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.

3.4 AUTOMOTIVE INDUSTRY

This discussion includes automobile manufacturers, suppliers, and related entities (Note: Individual companies are expected to have differing assessments.)

Every major 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 have been developed or projected to meet geographically varying customer needs, as well as current and future government requirements for vehicles (e.g., emissions, fuel economy, safety, and codes/standards) — primarily on the national level, but also at state and local levels. 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 investment 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 with high-pressure hydrogen fuel cells. In this comparison, the ethanol fuel tank will have minor implications on 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 on vehicle designs and manufacturing facilities.

  The automotive industry will not make major investments in new production capacity unless there are adequate government start-up incentives combined with confidence for future customers.

- Operating Financial Implications may necessitate varying, adaptable government incentives for short-term, mid-term, and long-term periods. Long-term incentives must be sustainable or eliminated.

- Competing Actions from the current fuel and automotive industries must be considered, since the desirability of alternative fuel vehicles would be affected. For example, auto 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(s). This would have an impact on Taxpayer Support, Policy Continuity, and National Economic Impacts, as mentioned in Section 3.2. Also, 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. Increases in the differences between U.S. vehicles and those of the rest of the world have 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.

- Corporate Image has the potential to be enhanced by becoming a leader in alternative fuel(s).

- Feedstock Adequacy and Reliability for the auto 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 electric machinery, and/or platinum for fuel cells.

- The Lead Time for internal company-generated programs is set by each company. In the event of excessively aggressive government regulation 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 all the design considerations and verifications may not be fully performed. This scenario raises the concern for possible product problems that would taint the reputation of the fuel and/or vehicle technology — potentially for a very long time. When standards-setting promotion of alternative fuels is involved, determining the appropriate Lead Time must be a cooperative effort among all parties.

- Consumer Acceptance is an important consideration used by vehicle manufacturers when making program decisions. The key criteria are listed in Section 3.1.

4 CLOSING COMMENTS

Crude oil is a finite and diminishing resource. However, worldwide usage is increasing, especially in third world countries. By all indications, the price of petroleum will continue to rise because of the slower growth (or possible decline) of supply and more rapidly increasing demand. The U.S. dependence on petroleum for its transportation sector causes vulnerability for the economy. Alternative fuel sources must be pursued on a timely basis, since the transition will take many years to accomplish. It is preferable to make fuel transition(s) as infrequently as possible, because the infrastructure change-over expense may be very large. However, there must be a realization that additional fuel shifts may be necessitated by changes in technology, international affairs, world pricing of fuels, and so forth. Analyses for the selection of the new transportation fuel(s) must maximally satisfy the needs of all the affected parties to enhance program success.

APPENDIX A: HISTORICAL HIGHWAY FUEL TRANSITIONS — SUCCESS AND FAILURE ASSESSMENTS

Successes

- Agricultural products (e.g., hay and oats) for animal-drawn carriages to gasoline vehicles
- Gasoline to sugar-cane-based ethanol vehicles in Brazil, in two waves:
  - 1970s and early 1980s
  - Late 1990s to the present
- Gasoline to diesel in heavy-duty vehicles in the United States, 1960s to the present
- Gasoline to diesel in European light-duty vehicles through the 1980s and 1990s
- U.S. switch from leaded to unleaded gasoline in U.S. vehicles during the 1970s and 1980s (and largely worldwide thereafter)
- Low-sulfur diesel fuel in the United States

Successes (partial, limited, temporary, or as yet to be determined)

- Gasoline to propane vehicles in the Netherlands and Japan
- Gasoline to natural gas vehicles in Italy, New Zealand, Argentina, and Egypt
- Gasoline to corn-based ethanol-blended gasoline vehicles in the United States, 1980s to the present
- Gasoline to diesel in light-duty passenger vehicles in the United States

Failures (at this point)

- Gasoline to methanol vehicles in the United States and Germany
- Gasoline to MTBE-blended gasoline vehicles in the United States
- Electric vehicles for horses in the United States, 1895–1930 (gasoline prevailed)
- Gasoline to ethanol vehicles in the United States
- Gasoline to natural gas vehicles in the United States
- Gasoline to LPG vehicles in the United States

Undetermined success or failure assessments (categories currently under development)

- Electric drive powered via grid electricity
- Hydrogen internal combustion engine
- Hydrogen fuel cell
- Cellulosic ethanol

APPENDIX B: ABOUT THE AUTHORS

Mr. Charles Risch holds B.S. and M.S. degrees in Mechanical Engineering. 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). Since retiring, he has been working part-time for Argonne National Laboratory, where he has analyzed alternative fuel programs. He also has served on the management team for the Partnership for a New Generation of Vehicles (PNGV) and FreedomCAR. While Mr. Risch is pleased with the technical progress, he is disappointed with the minimal amount of petroleum that has been displaced by alternative fuels. Of primary concern are the energy security and economic implications that petroleum dependence could pose for the United States.

Dr. Danilo J. Santini earned his Ph.D. in Urban Systems Engineering and Public Policy at Northwestern University. He has worked in the Center for Transportation Research at Argonne National Laboratory since 1982. As a member of the Alternative Fuels Committee of the Transportation Research Board since its founding in 1989, he served as its second chairman from 1996 to 2002. His job has been to conduct technology assessments for advanced highway vehicle technologies and alternatively fueled vehicles. Dr. Santini has studied successful transitions to alternative fuels throughout U.S. history and, for the last few decades, ongoing transportation technology transitions in several countries. Although his historical U.S. studies examined the successes, he has become well aware that the absence of studies to investigate the failures is a shortcoming. By using the methods that he was taught, he has analyzed several options for which his results encouraged abandonment of the technology. However, partly due to the absence of a checklist, some of his analyses promoted alternatives that did not succeed. Dr. Santini is in agreement with the recent wisdom that, since no winning alternative is evident, a portfolio of options should be pursued.

Energy Systems Division
Argonne National Laboratory
9700 South Cass Avenue, Bldg. 362
Argonne, IL 60439-4815

www.anl.gov