CTIM (The Buffett Center for Technology & Innovation Management at Northwestern University), and GATIC (The Global Advanced Technology & Innovation Consortium), in collaboration with ACNG (American Compressed Natural Gas) Consortium

Report on an Exploratory “Action” Workshop with Follow-up and Next Steps
held March 17, 2011 at the Northwestern University
Kellogg School of Management
Evanston, Illinois

Compressed Natural Gas for Automotive Applications

For further information contact:
Jeffrey Strauss, Northwestern University
847-491-5145
Email: j-strauss@northwestern.edu
OVERVIEW

1. Introductory Notes

- The need for vigorous pursuit of the development and application of CNG as a vital component of the local, national and global transportation equation is becoming increasingly self-evident. That this can be achieved with the needed rapidity, scope and effectiveness is less obvious. Much needs to be developed and proven in practice in developing and managing the enabling technologies, systems and the required physical and social infrastructures as well as public perceptions. Severe performance requirements, complex and dynamic drivers and numerous inhibitors produce a “wicked” innovation challenge with an unclear path forward. Strategy must align with Game-changing vision, inform policy, and be pursued adaptively in a well-managed approach that is global, rich in intelligence, and guided by appropriate metrics.

- Roadmapping, in conjunction with other tools and carried out at both the operational technology product and broader strategic and mind-set changing levels can help ensure robust identification of full balance of system costs and “what needs to be achieved, when, how, by whom, and the dangers and (often hidden) risks”. The associated tools could include mindmapping, scenario change impact assessment, portfolio management, patent mapping, stage-gate controls, simulations, business/economic modeling.

2. The Workshop

With the above thinking in mind a Workshop was organized by Northwestern University’s Buffett Center for International & Comparative Studies (BCICS) through its Center for Technology & Innovation Management (CTIM) and that organization’s close collaborator the Global Advanced Technology & Innovation Consortium (GATIC), working in collaboration with the American Compressed Natural Gas Consortium (ACNG) consortium (see appended descriptions.) BCICS strongly emphasizes interdisciplinary applied research and a close connection with industry; CTIM has worked on research and consulting projects for a variety of US and International agencies as well as for many private firms. ACNG was formed to encourage collaboration within the industry and works to ameliorate public opinion of CNG.

The meeting took place on March 17, 2011 when 28 industry, government and academic experts and support people gathered to discuss issues and strategies related to the use of compressed natural gas as an alternative automotive fuel. The workshop was intended to explore potential that could be achieved through collaboration including the formation of a working “community” and the application of tools, with particular attention to roadmapping. Viewed as a preliminary meeting, the audience was deliberately kept small to encourage discussion and explore potential for larger events and networking, with the expectation that this will be the first of a series of workshops and initiatives covering a range of potential fuels that might be applied individually or in combination to address needs. Planned discussion and input continued beyond the workshop through interaction with individual participants and via evaluation forms. This added input is incorporated in this report. As part of the Workshop Follow-up with participants described below, new
initiatives have already launched focused on solar enabled liquid automotive fuel and electric vehicles. Also, in discussion stimulated by this workshop is the formation of a roadmapping center that might address the key issues, requirements and opportunities across alternative fuels.

There was a general recognition by participants in the conference that this was the time to tackle the called-for challenges for progress in the development and application of CNG for national security, sustainability and economic reasons. It was noted that CNG is potentially a “virtuous fuel” – it is abundant, with the US discovering reserves that will last 70 to 200 years at current usage with new acquisition technologies adding to the potential. This abundance can contribute the US independence and security in the face of wars and rebellions in the Middle East and rising oil prices, especially with respect to use for certain categories of heavy and short-range municipal vehicles (and possibly beyond with technological/gas storage advancement.)

It was also emphasized that advancement in meeting the challenge would not be easy given the many uncertainties and complexities to be overcome but with the potential already becoming visible, success was now becoming attainable. The challenge exemplifies the growing class of “wicked” technology and business innovation problems that have no easy answers or solutions. It was also agreed that any steps taken must take account of global dimensions and opportunities. Other countries have already tapped the potential of CNG far beyond what is to be seen in the US and some technologies necessary for the expansion of CNG discussed at the meeting may be better found outside this country. It was also recognized that CNG may not be a fuels solution in isolation but rather in combination and, potentially, as a bridge to other evolving fuels. The possibility of forming a roadmapping/knowledge center that was both nationally but also internationally centered was explored.

While other CNG events have been held, this one differed in its broader cross-disciplinary and cross university-industry representation and its practical focus on applying a roadmapping mindset that included defining sequenced steps and specific actions to achieve agreed-upon goals. Especially valuable was participation in the workshop of two representatives with industry and academic experience from Japan including the leader of GATIC-Japan. Having such a wide variety of voices - from industry to academic, lawyers to automotive experts and from abroad, allowed brainstorming through roadmapping and scenario planning exercises for what will advance (and constrain) the use of CNG. In this spirit, in addition to plenary presentations and discussions, participants also broke off into smaller groups to address three specific problem areas:

- Infrastructure,
- Vehicle systems and components, and
- Building a consortium or knowledge center.

These focus areas were selected based on options as set out in the following table.
<table>
<thead>
<tr>
<th>CNG Product</th>
<th>CNG Refueling</th>
<th>CNG Consortium</th>
<th>Overall Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop opportunity space options for vehicle installation (OEM/after-market); identify novel approaches</td>
<td>Explore market potential; regulatory considerations</td>
<td>Make vision and activities for group and individual participants explicit. Expand the make-up and perspectives</td>
<td>Evolution of market &amp; tech. solutions, partners, resources</td>
</tr>
<tr>
<td>Illustrate selected alternatives, timing, alliances, etc.</td>
<td>Identify required research/solutions timing; new areas to incorporate</td>
<td>Identify areas for tech. &amp; business model innovation partners/suppliers</td>
<td>Solutions that are for total business model vs. individual technologies/systems</td>
</tr>
<tr>
<td>Carry out a small and rapid roadmapping capability, efficiency &amp; effectiveness demonstration</td>
<td>Build alliances &amp; players; opponents; hidden risks</td>
<td>Increase engagement of members; determine areas of interest</td>
<td>Visual strategic plan to be internalized by customers, providers, government, media</td>
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By the end of the day, the workshop’s goal was to lay the foundation for how to move forward with sustaining activity and address specific challenges.

#### ATTENDEES

Attendees at the conference were selected from a variety of fields and backgrounds but with the common goal of advancing the inclusion of CNG in the automotive sector in America. A brief overview is provided here but a complete listing of participants with short bios is appended.

**Academic attendees** included: A Northwestern (NU) engineering professor who directs a Sustainable Energy Center in addition to working with MIT and U. of Illinois and leads a new automotive engine program; a leading Chemist who also directs the multi-million dollar Argonne-NU Solar Energy Research and is senior scientist of Nanoscale Materials at Argonne; a leader of NU's Transportation Research Center and head of its Commercialization of Innovative Transportation Technology program (a person with long industry experience); and, the director of the Illinois Institute of Technology's Institute of Sustainability and Energy Research. From Japan came a professor of Knowledge Science who had spent 24 years in R&D with Toshiba and is also the leader of GATIC-Japan, accompanied by his university's Director of International Programs. The technology management side coming from the Kellogg School was represented by an expert in technology innovation (Director of CTIM and co-director of the Workshop), with strong academic technology and management background & industry experience. These were complemented with several other staff persons and graduate students.

**Scientists and industry experts**: A strong practitioner group also offered their input on ways to make CNG a viable fuel source for the American automobile industry. Included were two from Argonne National Labs who brought extensive engine, combustion and transportation experience gained from Industrial and Research Institute backgrounds in the US and abroad; a representative of the National Renewable Energy Laboratory with expertise on
the use of CNG on municipal and other transport fleets; a very experienced international technology sourcing expert who had also filled the top Industrial Research Institute position; and a former member of the technical staff at Motorola Labs with over 30 years experience on systems engineering, decision management and architectures as well as strategic roadmapping. Coming specifically from the CNG injection field was a specialist with 35 years at Ford including 28 in global leadership in alternative fuels and vehicles and who was a representative for Ford in the US Department of Energy's Freedom CAR program. Other practitioners included two from Bosch - its marketing manager in the gasoline fuel injection division responsible for sale of power-train components, controllers and sensors and a second who is director of project management and global technical manager for gasoline systems, coordinating OEM system projects and opening of technical windows to key customers on a global basis. A 32 year veteran GM director of global technology strategy (also a GATIC specialist in roadmapping and other tools) complemented the automobile industry expertise; together with three consultants specializing in the direct automotive field. The IP legal side included an internationally known legal authority on intellectual property law, with more than 25 years of experience. The City of Chicago sent a senior automotive equipment analyst responsible for the purchase of alternative-fuel, hybrid and electric vehicles - he oversees the implementation of diesel-emissions-retrofit, idle-reduction and other programs meant to reduce petroleum usage and emissions from the city-wide fleet. The American CNG consortium (ACNG is a Workshop co-sponsor) was represented by its founder & leader - an entrepreneur and owner of a CNG fuel station, responsible for the technical collaboration for a CNG conversion system for trucks. Members of a leading Publishing House also participated.

WORKSHOP CONTENT AND DISCUSSION

1. Introduction: Co-directors of the Workshop, Herring and Radnor led the opening session, which addressed the big questions facing CNG - why compressed natural gas and why now? They posited the virtuous fuel as offering potential to improve the quality of life for all Americans. The presentation began with a section on roadmapping as a way to answer these questions. They asked who and what would be needed in order to take big steps forward. The presence of risks was addressed, including hidden risks often evident in such projects. A global perspective was emphasized, since some technologies or experts might be located in foreign countries and also, potentially, markets. The workshop was intended to enumerate the priorities and what should be done first.

CNG is important to expand on now in order to give national independence and security in the face of rising oil prices and the crisis in the Middle East. There are also environmental sustainability advantages of CNG although concerns have been raised about possible methane release, required significant water usage and potential contamination from chemicals used in the fracking process even as improvements provide access to greater stores of NG. But this is also a field of business and there is money to be made in the emerging field. While it was thought to be too early to involve PR representatives or journalists, the public needs to be aware of this exciting new fuel source. At this planning
stage it will be vital to learn what users want and need. This will "stimulate interest away from the backburner," according to Radnor, who emphasized the need to create a community where knowledge is stored and information can be sought out. Once that is ready, promotion can start, as well as searching for investors and funding.

Herring then highlighted great quotes from past and current American leaders about our reliance as a country on foreign oil for energy. He emphasized the oft-cited shocking statistic: Daily, America sends $1 billion of its wealth to foreign countries for oil. The use of CNG in important parts of the automotive world can at least reduce that problem. America is discovering volumes of natural gas that could sustain the country for 70-200 years at our current usage. In addition to being more abundant and easier to access, CNG is also 30% better for the environment.

Herring made a strong case for the need for government support of CNG research. “If the government doesn’t do something to help the private sector with fuel, they’re not going to get the private sector’s support,” he said. He also pointed out the expanding conversion kit market. While many conversion kits function decently, a next generation conversion kit (e.g., as had been engineered with Ford for the Mustang) has attracted potential NASCAR interest and could contribute to the reimagining of CNG to the public. The Consortium shares information such as this among CNG groups, since their main goal is not to corner the CNG market but rather to expand it. After these introductory remarks, speakers and participants were introduced. But before formal presentations began, a moment of silence was taken for the victims of the earthquake in Japan. The Japanese attendees, Ikawa and Kawanishi, spoke about their personal experience and what the earthquake was doing to their country.

2. Examples of CNG applications.

- John Lapetz spoke first about his experiences at Ford and Westport-Juniper.

  Lapetz joined the alternative fuel team at Ford in 1980 and experimented with many types of alternative fuel, including ethanol, methanol, natural gas, propane and hydrogen. He saw much interest in both methanol and ethanol. While the public was interested in these alternatives, they were concerned about infrastructure and where these new fuels could be obtained.

  In his presentation, Lapetz discussed the history of energy reforms in the United States and why some failed. The Energy Policy Act in 1992 required a certain percentage of fleets to run on alternative fuel. Companies, like Ford, responded to this act by investing in alternative fuel research since organizations would be required to purchase alternative fuel vehicles. Basically, a law was put in place that required commercial consumers to buy a product that car companies, including Ford, did not make at that time. Ford sold 30% of its vehicles to fleets, so they expected to make back the money they invested in research.

  When Ford invested, it seemed like the biggest development would be in natural gas because it would provide the largest payback. Since there was no cost per mile penalty, purchasers could capture the incremental cost of a CNG vehicle if they drove it long enough. Ultimately, Ford spent $150 million to give customers a transparent experience.
In the 11 different models running on CNG or LPG, customers would not see any difference from a traditional gasoline fueled car.

However, there was no one to enforce the Energy Policy Act mandate. With organizations not following the rules about how many cars had to run on alternative fuels, car companies were not selling the cars to offset their millions of dollars invested in research.

Lapetz encouraged investors to stay the course and continue investing in research, even when fluctuating prices made gas the cheaper solution. He emphasized that an investment in CNG and alternative energy must be long-term, since a return on money spent today may not be seen for three to five years.

- Matt Stewart from the City of Chicago’s department of fleet management spoke next about the use of CNG in Chicago’s fleet and plans for the future.

The City has not been a very heavy user of CNG - some 50,000GTE. The City’s early activity largely ended when US based automotive companies dropped CNG vehicle in the early 2000’s. Recovery Act funding has enabled a significant resurgence. There are now six CNG stations owned by the city of Chicago with plans for a seventh to be built this year. About 100 City fleet vehicles run on CNG now with plans to expand the number of vehicles substantially this year. Stewart also credits the city’s ability to expand their CNG use to large fleets, particularly, AT&T, whose commitment to adding CNG vehicles to their fleet has encouraged Ford and GM to bring back their alternative energy offerings. Recovery Act money is also going toward the building of two CNG stations in the area which will be the first truly open to the public. This initiative is being implemented jointly with Clean Energy (T. Boone Pickens) and Yellow Cab, which is buying 100 CNG vehicles. The major Waste Management firm is building a station for its own use.

The public stations will help with what Stewart calls the public’s biggest issue with CNG: infrastructure. Right now, CNG is not as convenient or as easily accessible as gasoline or diesel. The other issue is that the cost of buying or converting a vehicle to CNG has skyrocketed. Until use picks up, the cost of maintaining a compressor station is also significant. Although nominally CNG may be available for $1 per gas gallon equivalent, adding the station cost with limited use may make the real cost closer to $2.50.

Stewart emphasized that CNG is only one of several strategies being used by the city in its commitment to cleaning up their fleet. Stewart does not see CNG as the "savior" solution, noting it can have its own negative environmental impact.

- Caley Johnson spoke next about municipal fleets’ business case findings. His slides are appended to this report.

Similarly to Stewart, he emphasized that CNG is not the “silver bullet,” and that using a combination of technologies would be the best solution.

Johnson began by explaining why municipal fleets are an obvious choice for CNG conversion. This category includes vehicles such as transit buses, refuse trucks and school buses. The first reason these types of vehicles are well suited for CNG use is that they travel in circular routes. This means that as long as a CNG station is built along one
of these routes, these vehicles will be guaranteed to go by the stations to refuel very often. This not only makes it far more convenient for the driver to use CNG, it also reduces infrastructure costs since fewer stations would need to be built. Another reason municipal vehicles are well suited to CNG is that, where most businesses are primarily concerned with profits, governments can look at and value long term effectiveness to improve the standard of living in their community. Governments value consistent operating costs and energy and climate security. Because of this, CNG may also be a viable fuel source for delivery trucks and taxis.

Johnson next presented the VICE (Vehicle and Infrastructure Cash-flow Evaluation) model, which contrasted cash flow of diesel against cash flow of CNG. Through this he could calculate the payback period, which is the number of years it takes to get money back from the investment. Next he looked at base case parameters for both fleets and CNG refueling stations. A base-case is an average or common value. It can be used as a benchmark to see how much changing one parameter will change the entire value. Using this model, a business or government can see how their total costs for the year will change depending on how many cars they have or how many miles these cars drive.

One consideration in base-case parameters for refueling stations is how quickly vehicles can refuel. Johnson used transit buses and school buses as an example. Transit buses must be refueled quickly so they can get back on the streets to transport people, meaning the pressure needs to be higher. School buses, on the other hand, can sit and refuel all day while kids are in school or overnight when they are not needed.

An important consideration according to Johnson is that while variables can be changed, one benefit to CNG is that while oil prices fluctuate, the cost of CNG remains relatively consistent (see discussion this point below.)

The main question being answered by changing base case parameters is how many vehicles a fleet needs in order to make the project profitable. This includes concern over whether or not the organization will receive a tax incentive. In terms of profitability, there are three different kinds of fleets: resilient fleets, which have more than 75 vehicles and can remain profitable even with changes in number of miles driven, marginal fleets, which have less than 75 vehicles and are primarily made of school buses that are not as adaptable to change, and fleets with no CNG vehicles.

Following Johnson’s presentation, workshop attendees raised some issues, including the potential for hybrid/user switchable systems made up of both CNG and electric (or biofuel) technology and what combination of energy sources will be best on a national scale. There was general support for further exploring the comparison between CNG usage and refueling requirement and the experience of using rechargeable electric vehicles.

Discussion also clarified projections of flat pricing of CNG at least for several years. In Michigan, for example, suppliers are offering contract with flat rates for 7 years. The explanation given was that although there are varied assessments of existing CNG supply, technology improvements including in hydraulic fracturing which have, in some cases uncovered gas even in wells thought to be dry, has and is expected to continue to yield supply well in excess of demand.
3. **Introduction to and starting technology roadmapping**: (David Grossman and Jeffrey Strauss.)

This presentation was designed to lay a foundation for Break-out discussions. Key covered issues were skills and mindsets in planning and roadmapping. The presenters also touched on the potential of integrating roadmapping with scenario planning to address CNG’s dynamic evolution.

The most important part of roadmapping is to understand where you are, where you want to be and what series of defined, specific steps will get you from one to the other. Resource requirements and other hurdles at each step need to be identified and addressed (including strategies to develop resources if they are not in place) along with “who needs to do what”, and when - an important element in any roadmap is a timeline, so that anyone who sees the roadmap knows when each specific step will be happening. Roadmapping was also presented as a way to communicate with and among internal and external stakeholders.

Roadmapping needs to be understood and pursued as an ongoing process that dynamically positions an idea within a wider look at the ecosystem, linking the resources available to the goals and objectives. It may be done at the corporate level, or as in this case, at an industry level with a prime example being work carried out by SEMATECH for the semiconductor industry. The attendees were asked to use this strategy to examine uncertainties in CNG use in their break-out groups. It was also suggested to look at what assumptions are being made that may not be true and how these assumptions are affecting or could affect strategy.

**BREAKOUT SESSIONS**

Participants went to one of the three selected break-out sessions: infrastructure, vehicle systems and components, and building a consortium or knowledge center. Participants reconvened to present their findings to the entire group for general discussion.

1. **Infrastructure group**: The discussion included consideration of:

   - Logistical issues such as the potential of shared public/private fueling facilities, for example, at airports (noting the need to be within the security fence) to maximize utility and initiatives to foster collaboration between fleets and designating shifts to minimize waits for fueling.

   - The need for education to help the public see CNG value such as less exhaust, quieter engines, potential – if calibrated correctly – of cleaner fuel burning. A likely initial education media is signs on public CNG using vehicles.

   - The need for a clear and strong policy at Federal and state levels; need for standards. Currently there is variation in quality and required/available pressure across stations. There are standards in Europe such as NGV 3.1. but it was also suggested
the European (and other countries/regions using CNG extensively) and US markets are different along multiple dimensions worth studying. Bosch injectors are well suited for North American requirements including low leakage and cold start ability. Regulations are also unclear related to CNG conversion with constraints on tampering with emission systems, variations by age of vehicle, etc.

- Recognition that a key motivator for CNG use is the potential to migrate from CNG to other alternative fuels, particularly biogas. One participant noted that at “optimal” use levels, currently identified CNG supply in the US might last only 20-25 years. Vehicles allowing switching between CNG and other fuels could also be viable.

- A sense that CNG evolution parallels that of electric vehicles and lessons could be learned from exploring that similarity.

- A case was made of value in a (currently lacking) better collected and shared information, clearinghouse. This should include better tracking of who the stakeholders are and how they are interrelated, who is using injectors. Particularly as availability and infrastructure vary significantly across the US and a concern for drivers is the ability to refuel en route, a regularly updated and available mapping of CNG stations and their characteristics (including pressure level) would be useful. In California, natural gas corridors exist where its is possible to plan point-to-point travel.

- A potential game-changer raised by several participants could be the development and dissemination of inexpensive home natural gas compressing stations. Relatedly, “clubs" of CNG vehicle users could evolve in which CNG home (or other private location) stations are shared.

Task force participants also raised the need to involve the Department of Energy but noted that DOE responds to varying political pressures with current focus on electric vehicles (previously it was hydrogen and then ethanol.) Utilities should also be invited although it seems they do not yet see a significant market in CNG and they, like those who actually install CNG fueling stations (mostly small companies) rarely come to CNG meetings.

From a roadmapping perspective, early tasks would include:

- Exploration of public-private shared stations
- Support for collaboration between fleets
- Development of standards
- Educational initiatives (ongoing)
- Establishment of information clearinghouses with dynamic mapping of available stations
- Policy promotion.

Intermediate steps could include research into in-home fueling, formation of clubs and exploration of migration paths to other fuels. A key risk pointing to a scenario variation
would be AT&T moving away from CNG and emergence of new complementary or competing technologies. Fracking is currently minimally regulated. Public concerns over potential negative environmental effects from the process could push regulations which might alter cost and gas access calculations. Finally, the pace of increase in CNG use could impact on how long CNG is available.

2. **Vehicle systems and components:**

- This group was concerned first with safety. They emphasized the need to convince the public that CNG fueled cars are safe to drive by reducing the stigma of explosion linked with gas. They also looked at energy storage and availability, compression and fuel composition, environmental benefits and how the fuel would be packaged to consumers.

- Like the infrastructure group, the vehicle systems group emphasized the need to rethink social and government policy, including tax issues and incentives for users of CNG. They identified several risks associated with CNG, including competing technology and lack of research funding. Another difficulty is the complicated nature of converting vehicles from either diesel or gasoline to CNG.

- In order to better organize the movement to increase CNG use in automobiles, this group looked at getting together a supply base that has a global reach. Ultimately, the most important thing is to bring people together rather than setting up competing groups.

- The discussion group emphasized that the main assumption driving research into CNG is that the price of oil and pressure to find better fuel alternatives (along multiple dimensions) will continue to rise. CNG is assumed to be, either alone or, more likely in combination with other strategies, a source of energy that will give us financial and national independence from foreign oil.

- Looking to the future, this group also emphasized the need to talk with the consumer. By understanding his or her needs, those involved with the CNG industry can figure out how best to meet those needs with CNG. They also addressed the need to have people involved in this movement who can propose policy to the government, rather than just reacting to laws that are made without input from those who are knowledgeable in CNG.

- The next step, (with this conference a beginning), is to bring together the various different specialties involved in CNG and start a conversation. This dialogue should include viewpoints from suppliers, national labs, automobile firms, representatives from the Department of Energy, cross university researchers, manufacturers, engineers and users of the product.

3. **Building an Automotive CNG Knowledge Consortium Center:** The third group looked at the need for such a currently unavailable knowledge and roadmapping center where concerned and involved people and other stakeholders could collaborate and go for answers about the application of CNG in the automotive world. Discussion included:
• If CNG is to become a meaningful part of the automotive fuel spectrum, the initiative has to go beyond sporadic and item-by-item activity. Robust programs will need to be pursued that address the intersecting technology, business case and political advancement dimensions. This calls for global early identified and applied knowledge, targeted/focused programs, and a foundation for cooperation across a currently very fragmented industry. It also needs to be able to function in collaboration with local and central government and with the investing communities. A private sector based and government assisted consortium with national and international reach is needed that can provide the on-going roadmapping, scenario and development monitoring, training and, most important information processing and exchange within the industry and to associated other sectors (other new fuels, materials, etc.) - nothing like this exists for this sector. But such model endeavors as SEMATECH do exist – we can learn from these.

• There was also discussion around the issue of whether any such consortium should be focused only on CNG for automotive use or, and it was generally concluded it would be better, if it should span the broader field of fuel diversity. Especially in the case of different energy forms, there is not much dialogue among experts in the fields and this knowledge center could be the conversation starter.

• The group also saw the consortium as a way to educate people about the benefits of CNG and to dispel the stereotype of explosions and danger often connected with natural gas. While they saw a need for a knowledge center, they questioned what would make a group like this a legitimate source for information. They also saw this group as a place for legislation to be drafted and sent to lobbyists, as well as a place for standards to be put in place.

• In addition to bringing together experts who may not previously have had a place to discuss ideas, the consortium’s main role would be to have good data and do consumer surveys to gauge interest and needs. The group could hold workshops and seminars to educate the public.

• The next steps would be a series of small projects that could be implemented successfully with the plan to build off those successes in the future.

WRAP-UP DISCUSSION

Closing discussion raised the point that a challenge for CNG is lack of scale. Infrastructure is characterized by low capitalization, little automation and amortized pricing including certification and engineering remains high. Maintenance costs for both suppliers and end users needs to also be considered. In general, it was pointed out, planning and discussion including in this workshop fails to consider the impact of potentially significant changes in technology.

Louis Herring gave the workshop’s final comments. He said that addressing problems and spreading the word is not a job for one person alone and encouraged those in the room to join the cause.
"I don’t have a problem carrying the flag for the cause. But at the same time, I’m going to extend a battle cry and say ‘Ladies and gentleman, the cause is appropriate and the time is now.’ It is a matter of great urgency."

**FOLLOW UP, EXTENSION AND NEXT STEPS**

1. **Workshop evaluations**: As completed by attendees the following observations and recommendations were made.

   - 85% of respondents felt that participation in the Workshop had been valuable to them. There was uniform strong interest in attending future events and it was recommended meetings should be held regularly to maintain momentum. With respect to the holding of future events, the top ranked choices for an organizing entity were industry (meetings at firms) and via a university-industry consortium.

   - Agreement was expressed with the need for continued collaboration and further activity, building on the Workshop program. All respondents saw the need for a knowledge/roadmapping center and all but one committed to participation in such an initiative.

   - Respondents encouraged inviting existing associations such as ANGA (invited to this workshop but unable to attend), legislators, CNG station owners, utility companies, natural gas suppliers, infrastructure companies, and “Clean Cities” representatives to future events.

2. **Evolving Plans**: Based on both direct Workshop outcomes and pre and post event initiatives.

   - **Future and follow-up meetings/community building:**
     - The holding of an ongoing series of taskforce roadmapping workshops focused on specific CNG system components & aspects (compression, injection, storage tanks, infrastructure, etc.) is under discussion.
     - Responding to specific inquiry by two participants and building on the consensus noted that CNG must be viewed in conjunction with other alternative fuels and for lessons learned (whether as competitors and in combination or as a bridge to emerging), a roadmapping based cross alternative fuels meeting is being considered.
     - Preliminary discussions have also been held for formulating a second and larger scale meeting (possibly at Conference scale) to involve individuals and groups not yet represented as well as those who did. Such a meeting might be CNG focused or more broadly defined as implied above. One suggestion involves a combination conference-trade show event over the coming winter in Florida with ACNG acting as the “hosting” organization.
     - We are also following up with individuals and groups who, for a variety of reasons were unable to attend the March CNG program. This includes key
individuals from the Department of Energy with whom Michael Radnor will meet in Washington in mid May. Discussion may focus on potential interest in supporting a cross-alternative fuel roadmapping center.

- Early stage planning for a website has begun. Relatedly, discussions with the Emerald Publishing House (which was represented in the CNG workshop) and potentially IBM, a series of GATIC-related publications, meetings and other activities that will include new energy (fuels, CNG, etc.) has been launched.

- The Consortium/Fuels Knowledge Center: Initial discussions and funding requirements and sources has begun.

- New initiatives

  - CTIM has begun work on roadmapping and workshop support effort for a major multi-year emerging Northwestern development and commercialization program to be carried out in collaboration with several top energy and related sector firms with additional private investment, targeting solar enabled liquid automotive fuel. An August NU meeting is planned. Students have been identified to carry out background research and to help in laying out related roadmap parameters; funding appears very likely. A second nascent effort is focused on the potential of new electric car technology with a Workshop tentatively scheduled for late Fall at Northwestern.

- International

  I. Explorations are underway with the support of GATIC-Japan based on earlier ACNG expressed interest to identify small-scale (home level) gas compressor technology.

  II. As part of new worldwide CNG technology sourcing is being initiated (initially in South Asia.)

  III. Israel; Meetings have been scheduled to explore the investment and technical cooperation potential of automotive CNG in the country, related to Israel’s new off-shore access to natural gas.

- Finally, we are exploring new energy/fuels skills training - an important area less covered in this Workshop and are in discussion with IBM, which has relevant ongoing activity and software. Funding from the US Department of Education and National Science Foundation is possible. Partnerships with community colleges to evolve training simulations/serious games and teaching modules for technical as well as management and engineering education will be another aspect.

**APPENDIX**

1. Attendees List with short bios.
2. Workshop Agenda
3. Selected Caley Johnson NREL slides
4. Descriptions of Workshop organizers (GATIC, CTIM and ACNG)
<table>
<thead>
<tr>
<th>Attendee Brief Bios for CNG Workshop (in alphabetical order)</th>
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<tr>
<td><strong>Hamid Arastoopour:</strong> Illinois Institute of Technology. Professor of Energy &amp; Director Wagner Institute of Sustainability and Energy Research; transport research. Ph.D. Gas Engineering IIT.</td>
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<td><strong>Gary DeGregorio:</strong> Decision Innovation, Inc.; was Distinguished Member of Technical Staff, Motorola Labs. Over 30 years with Motorola, focus included systems engineering, decision management, decision-related processes, knowledge foundation and architectures as well as strategic roadmapping. MSEE, University of Illinois-Urbana. (GATIC).</td>
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<tr>
<td><strong>Shaun Denman:</strong> Bosch. Marketing Manager, Gasoline Fuel Injection. Manage planning/pricing of component/systems; previously during 9 years with Bosch, responsible for sale of powertrain components, controllers and sensors.</td>
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<tr>
<td><strong>James De Wolf:</strong> Emerald Publishing (UK); Vice-President Academic Publishing, head Boston Office.</td>
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<tr>
<td><strong>Mike Duoba:</strong> Argonne National Labs. Center for Transportation Research, Energy Systems Div., Worked with many leading automobile firms; major role in support of Student programs. MS &amp; BS Mechanical Engineering.</td>
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<tr>
<td><strong>Susan Gaud:</strong> Former Senior Director External Technology Sourcing, Kraft; President, Industrial Research Institute. Ph.D. Physical Chemistry, Northwestern University (GATIC).</td>
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<tr>
<td><strong>David Grossman:</strong> President, Dynamic Strategy Group. Director Global Technology Strategy, General Motors (32 years with GM in planning, engineering and international executive positions); Roadmapping specialist and consultant. Trained small businesses in mapping tools with Michigan Small Business and Technology Development Center (GATIC).</td>
</tr>
<tr>
<td><strong>Mark Hellmann:</strong> An internationally known legal authority on intellectual property law, with over 25 years of experience in copyright matters spanning print media, electronic media, computer software, computer hardware, internet, video media, and design. Head of two firms (GATIC).</td>
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<tr>
<td><strong>Louis Herring:</strong> American CNG Consortium Leader, entrepreneur, responsible, with technical collaboration, for CNG conversion system for trucks. Former military.</td>
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<tr>
<td><strong>Vince Higgs:</strong> co-creator, Visto, LLC (CNG auto conversion).</td>
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<tr>
<td><strong>Yasuo Ikawa:</strong> Professor, School of Knowledge Science, Japan Advanced Institute of Science &amp; Technology (JAIST). 24 years in R&amp;D with Toshiba Corporation. PhD. Engineering, Tokyo Institute of Technology; Leader GATIC-Japan. (GATIC)</td>
</tr>
<tr>
<td><strong>Bret Johnson:</strong> Assoc. Director, NU Transportation Research, Director, Center for Commercialization of Innovative Transportation Technology. Earlier engineering &amp; project management positions at 3COM, Northrop-Grumman, GE Astropace, and Grayhill, Inc.</td>
</tr>
<tr>
<td><strong>Caley Johnson:</strong> National Renewable Energy Laboratory; Studies on Business Case for Use of Compressed Natural Gas on Municipal &amp; other transport fleets.</td>
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</tbody>
</table>
Shungo Kawanishi: Professor, Japan Advanced Institute of Science & Technology; Director Int’l Programs. VP & Professor, Trans-Pacific Hawaii College. Ph.D. University of Georgia (GATIC).

Diego Klabjan: Associate Professor Industrial Engineering & Management Science, NU McCormick School of Engineering, Director, Sustainable Energy Center Ph.D. Georgia Institute of Technology (Transportation Industry Dissertation prize winner). Also with MIT & University of Illinois.

Jeff Lassaline: President, J. Lassaline & Associates, over 30 years in marketing and business development in OEM Automotive industry.

John Lapetz Jr.: Juniper Engines; 35 years with Ford motor including 28 in global leadership in Alternative Fuels and Vehicles, rep Ford in US Dept. of Energy Freedom CAR program; also Director of Technology, Clean Vehicle Education Foundation.

Diane Lawniczak: Bosch. Director of Project Management and Global Technical Manager for Gasoline System. Responsible for OEM system projects and technical window to key customers on a global basis. With Bosch for 13 years.

Rebecca Marsh: Publishing Director, Emerald Publishing (UK); University of Sterling.

John Perles: Global manufacturer; start-up firms in solar & CNG automotive conversion.

Michael Radnor: Professor, Kellogg School of Management, Northwestern; founder & Chair of Organization & Management Department. Director, Center for Technology & Innovation Management (CTIM); Co-founder & President of GATIC. Worked for Westinghouse, Lucas Industries, Israel Aircraft Industries, & Tann Controls. Ph.D. Industrial Eng., Northwestern University (GATIC)


Matt Stewart: Senior Automotive Equipment Analyst, City of Chicago. Responsible for the purchase of alternative-fuel, hybrid and electric vehicles as well as implementation of diesel-emissions-retrofit, idle-reduction and other programs that reduce petroleum usage and emissions from the city-wide fleet, including police, fire, airports and sanitation.

Jeffrey Strauss: 35 years experience in cross-cultural service management; innovation, strategic planning and marketing; Associate Director, Northwestern CTIM (GATIC.)


Michael Wasielewski: Clare Hamilton Hall Professor of Chemistry, Northwestern, Director, Argonne -Northwestern Solar Energy Research (ANSER) and concurrent position as Senior Scientist Nanoscale Materials at Argonne; Fellow of American Association for the Advancement of Science. Currently heads over $40million in energy funded research projects. Ph.D. University of Chicago.
Jeff Wyatt: President, Venchurs, Inc – packaging and logistics; 15 years in strategy development and process roadmapping.

Northwestern Students

Anup P. Dhalwani: Kellogg MBA student, Investment Banking with focus on automotive industry

David Morse: Kellogg MBA student, management consulting and sustainability; joining Accenture’s clean energy practice. As an Accenture intern, contributed to a just published report on alternative transportation fuels in the US and China.

Ian Murray: Ph.D. student, McCormick School of Engineering, with extensive experience in advanced organic photovoltaics and other energy sources as well as materials; also owns high tech start-up.

Owen Worley: Ph.D. student, McCormick School of Engineering - Sustainable Energy Center.


Agenda

9:00AM  Registration and coffee (Room 101, Leverone Hall)

9:30AM  Setting the stage (Radnor, Herring)
- Workshop introductions and overview
- The shifting CNG business case? Drivers, constraints goals, strategies and timing?
- What we can already see happening; and need to see
- The Global Potential: Imperatives/threats/opportunities?
- Impact of changing scenarios and what we need to know/do/prepare for?
- Building the knowledge and support bases.

10:00AM  Participant identification

10:10AM  CNG Application Examples
- Westport-Juniper (and Ford) experiences (Lapetz)
- City of Chicago CNG initiatives and perspectives (Stewart)
- Municipal Fleets Business Case findings (C. Johnson)

10:55AM  Open Discussion

11:15AM  Break

11:30AM  Introduction to Roadmapping/Scenario Planning and Task Force charge (Grossman, Strauss)

Noon  Lunch Break (Food may be purchased in Kellogg basement level Cafeteria)

1:00PM  Split into Roadmap Input Taskforces – breakouts will be given discussion guides on: Achievement metrics; drivers & constraints; political/economic/policy issues, risks and key uncertainties; action requirements; roles; timing; and, research implications.)
Taskforces:
- Infrastructure (drilling, distribution, refueling)
- Vehicles Systems/Components
- Building National Consortia; National & Global Promotion; Establishing a CNG Knowledge Center; Building a local (Chicago/Midwest) consortium as an example (needs, key participants, roles, and how to implement?)

2:45PM  Break

3:00PM  Taskforce Reports (10 minutes each)

4:00PM  “How to Refine and Achieve the Vision?” Next steps for individuals and groups. (Complete the Evaluation and Action form during the discussion.)

5:00PM  Close
Selected Caley Johnson NREL slides

**Business Case for CNG in Municipal Fleets**

Northwestern University
CNG Workshop
Caley Johnson
Transportation Market Analyst
NREL
March 17, 2011

How many miles per year do I need to drive my vehicles to break even?

**Profitability of Base Case**

![Graph: Profitability of Base Case](image)

- Payback Period by Fleet Size
- Minimum Number of Vehicles to Have a Positive NPV or 6% ROR

<table>
<thead>
<tr>
<th>Type of Vehicle</th>
<th># of Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 Pass, 200-Mile</td>
<td>100</td>
</tr>
<tr>
<td>12 Pass, 300-Mile</td>
<td>50</td>
</tr>
<tr>
<td>15 Pass, 200-Mile</td>
<td>25</td>
</tr>
<tr>
<td>15 Pass, 300-Mile</td>
<td>12</td>
</tr>
<tr>
<td>15 Pass, 400-Mile</td>
<td>6</td>
</tr>
</tbody>
</table>

**What if I don’t get the tax incentives?**

- Vehicle tax credit has expired, and station tax credit reduced to $30K
- Tax incentives need to be passed along to municipal governments—an uncertain proposition

**Payback Period (Years) with Various Tax Credits Missing**

<table>
<thead>
<tr>
<th>Fleet (100 Vehicles)</th>
<th>All Credits</th>
<th>No Fuel Credit</th>
<th>No No Station Credit</th>
<th>No No Diesel Credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit Buses</td>
<td>3.6</td>
<td>5.6</td>
<td>5.6</td>
<td>9.6</td>
</tr>
<tr>
<td>School Buses</td>
<td>11.9</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Single-Unit Trucks</td>
<td>2.8</td>
<td>4.0</td>
<td>4.0</td>
<td>7.0</td>
</tr>
</tbody>
</table>

- Fuel ($0.55/gal diesel) and vehicle (<$32K/vehicle) credits make a big difference
- Station tax credit ($50K) is less significant
- There are synergies between the three credits

**Conclusion**

- Very Profitable
  - Large (>75 vehicle) transit or refuse fleets
  - Diesel drops below $2.25/gal
  - CNG vehicle maintenance costs increase 30%
  - VMT drops below 26,000 miles per year (transit) or 14,000 miles per year (refuse)
  - Vehicle incremental costs double
  - Various combinations of the above

- Profitable
  - Small (<75 vehicle) transit or refuse fleets

- Marginal Fleets
  - All school bus fleets
  - Small (<75 vehicle) transit or refuse fleets

- No-CNG Fleets
  - Low annual fuel use
  - Access to unusually inexpensive diesel
  - Exceptionally high CNG vehicle and infrastructure costs

- Not Profitable
  - Precipitous drop in profitability:
    - Transit or refuse fleets below 10 vehicles
    - School bus with VMT drops below 10,000 miles per bus

**Update with New Tax Incentives (March 2011)**

![Graph: Relationship Between Diesel Prices and Payback Period](image)

Collaborating Workshop Organizers

1. **CTIM** (the Center for Technology & Innovation Management) that is based in the Buffett Center for International and Comparative Studies at Northwestern University is located in the university’s Kellogg School of Management. It was launched as a National Science Foundation University-Industry Cooperative Research Center at the initiative of GATIC affiliated firms (including Baxter, DuPont, General Motors, IBM, IMS, Intel, Kodak, Kraft, Lockheed Martin, Lucent, Ford, Material Sciences, Motorola, Rockwell Automation, Roche, Siemens Westinghouse, Tripod, and United Technologies.) Together with its IBD forerunner it has carried out funded research and consulting projects totaling approximately $50 Million for companies, US and International government agencies (including the Department of Commerce, US Trade & Development Agency, NASA, USAID, World Bank, UN and various foundations) across the country and worldwide. It co-founded GATIC.

2. **GATIC** (Global Advanced Technology & Innovation Consortium) works with experts from top universities and firms on the increasingly challenging techno-innovation demands by bringing better management tools, models and new types of organization into practice. Launched by CTIM-Northwestern University, the Japan Advanced Institute of Science and Technology and ETH-Zurich in 2002, it was joined by universities worldwide. Fittingly, GATIC operates through virtual regional “hubs” truly driven by industry practice and research ("industry-driven and academically informed"). It provides the infrastructure and stimulus for the exchange of pointed practical intelligence on strategic implications of emerging conditions and threats and the development of creative solutions. This is accomplished through regional and global meetings and with customized research, clinics, training, guidance in developing in-house capability and structure, and early “weak-signal” monitoring. Recognized for such techno-innovation management support processes as roadmapping and scenario planning & services management, GATIC introduced these processes into Japan, including their National Energy Development Organization – NEDO.

3. **ACNG** (American CNG) **Consortium** is an inclusive community of participants drawn from across the spectrum of the CNG enterprise who recognize the national economic, environmental, and security interests at stake and that the United States offers the largest untapped market in the world for CNG as a transportation fuel. By listening to our members, clients, industry leaders, academic and research institutions, as well as the marketplace, the Consortium applies the iconic American values of entrepreneurial self-interest in the service of the American public. The Consortium advocates for a realignment within the industry, and a re-imaging of CNG to help public recognition of CNG as an attractive fuel option for the near-term and foreseeable future. Launching a dynamic CNG “Knowledge Center” that will inform strategic planning and cultivate and attract the intellectual leadership in relevant fields needed to meet the challenges that impede expansion of domestic CNG use is an important goal of the Consortium. The Consortium identifies innovative technologies, management practices, and products and seeks ways to incentivize the application of innovation both to improve quality and performance, and to, combined with group purchasing power, reduce pricing. Acknowledging that the foreign CNG market is far more robust than the fledgling U.S. market, and that a globally integrated CNG market will benefit the American marketplace, the Consortium is evolving as a globally linked enterprise.