2010 Hydrogen and Fuel Cell Global Commercialization & Development Update

International Partnership for Hydrogen and Fuel Cells in the Economy

Hydrogen and fuel cell technologies offer a pathway to enable the use of clean energy systems to reduce emissions, enhance energy security, and stimulate the global economy. As part of a portfolio of clean energy technologies, including energy efficiency, renewable energy and fuels, and battery-electric vehicles, employing hydrogen and fuel cells in the economy will help us to achieve these goals. A decade of sustained global research, development and demonstration (RD&D) is now producing the necessary technological breakthroughs for hydrogen and fuel cells to compete in the market. This report offers examples of real-world applications around the world and technical progress of hydrogen and fuel cell technologies, including policies adopted by countries to increase technology development and commercialization.

Hydrogen and fuel cell technologies can use diverse domestic renewable and low-carbon resources and address multiple applications across stationary, transportation, and portable power sectors. The challenges facing full commercialization of hydrogen and fuel cell technologies can be addressed through both, policy mechanisms and technology improvements, which requires consistent and focused international collaboration to increase the incorporation of these technologies in the global energy portfolio.

COMMERCIAL ACTIVITIES

In 2009, Fuel Cell Today estimated more than 22,000 worldwide shipments of fuel cell units, an increase of more than 40% compared to 2008. Increasing performance and decreasing costs, combined with government incentives, are enabling hydrogen and fuel cells to compete successfully with traditional technology areas such as power generation, combined heat and power, materials handling, and backup power.

Power Generation & Electric Grid Support

The demand for multi-megawatt (MW) fuel cell systems for power generation and utility grid support applications is on the rise.

- In Korea, POSCO Power has installed 24 of the planned 68 MW of molten carbonate fuel cells from Fuel Cell Energy (FCE) and Samsung installed 4.8 MW of UTC fuel cells at a power plant outside Seoul.
- In the United States, the State of Ohio utility, First Energy, purchased a 1 MW, polymer electrolyte membrane (PEM) utility-scale distributed generation fuel cell system from Ballard Power Systems Inc. The installation provides feeder peak management, defers distribution system asset upgrades, delivers zero local CO_2 emissions, and provides power conditioning for high quality power.
- Russia has designed and tested 5 MW hydrogen-oxygen steam combustors for demonstration by the Joint Institute for High Temperature and the company JSC "Chemical Automatics Design Bureau."

Benefits of Hydrogen and Fuel Cells as Part of a Portfolio of Clean Energy Technologies

- Hydrogen is a clean fuel. When used in fuel cells, the only byproducts are water and heat.
- Clean hydrogen technology has the potential to strengthen national economies and create high-quality jobs in industries such as fuel cell manufacturing.
- Hydrogen can be derived from renewable sources and is fully interchangeable with electricity – hydrogen can be used to generate electricity, while electricity can be used to produce hydrogen.
- Over 100 years of safe production, transportation and use of hydrogen shows that it carries no more risk than natural gas or gasoline.
- Hydrogen can be produced from diverse domestic sources and processes, freeing it from the political instabilities that affect the world's oil and gas supplies.
- Fuel cells have more than double the energy-efficiency of internal combustion engines.
- Fuel cells have no moving parts – they are silent, vibration-free, and require little to no maintenance.
- Fuel cells provide high-quality, direct-current power that is ideal for many advanced electrical and electronic devices.
- Fuel cells do not require time-consuming recharging and thus have much lower down-time and refueling requirements compared to battery-electric vehicles (BEVs).
- Fuel cells can provide energy at all scales, ranging from micro power sources for small consumer devices to multi-MW power plants.

- An innovative hydrogen-fuelled combined cycle plant launched by Enel in July, 2010 in Fusina, Italy is the first industrial-scale facility of its kind. The 16MW power plant has zero emissions and an overall efficiency of approximately 42%.
- In Canada, Enbridge Inc. and FuelCell Energy Inc. are demonstrating a Hybrid FuelCell power plant - a design specifically for gas utility pressure reduction stations. The plant converts unused pipeline energy, a byproduct of distributing natural gas to customers, and produces enough ultra-clean electricity to serve about 1,700 Canadian homes.

Transportation

The commitment of global automakers to develop and market fuel cell electric vehicles (FCEVs) continues to grow.

- In 2009, seven automakers (Daimler, Ford, GM/Opel, Honda, Hyundai/KIA, Renault/Nissan, and Toyota) signed a letter of understanding to energy companies and government agencies affirming that a "significant number" of hydrogen FCEVs could be commercialized beginning in 2015 onward and urging the development of a supporting hydrogen fuel infrastructure in focused markets like Europe (Germany), the U.S., Japan, and South Korea.
- In 2009, leading auto and energy companies in Germany joined with the government to form the H2 Mobility Initiative. Between 2012 and 2015, this will develop a comprehensive nationwide hydrogen fuelling network to support a complementary incentive program to produce and sell more than 100,000 battery and fuel cell electric cars annually.
- Also in 2009 in Japan, thirteen domestic oil and gas companies announced a collaborative effort to develop hydrogen vehicle fueling infrastructure by 2015. A plan for 1,000 stations and 2 million FECVs by 2025 was announced in 2010.

Combined Heat and Power (CHP)

Japan is rapidly adopting residential fuel cell systems to provide heat and power in homes. A government funded demonstration project installed over 5000 residential fuel cell units. With government incentives and multiple manufacturers such as Panasonic, Toshiba and Eneos now dedicated to supplying the commercial market, thousands of residential fuel cell systems are being sold in Japan. Also, Japan conducts demonstration of solid oxide fuel cell (SOFC) units, provided by Toyota/Aisin, Kyocera, JX Nippon Oil and Energy (formerly Nippon Oil), TOTO and GASTA/Rrinnai.

Retail and manufacturing companies see value in CHP benefits provided by fuel cell systems.

- Multiple companies in the United States, including Whole Foods, Coca-Cola, and Price Chopper, have installed large systems (up to 400 kW) to provide heat and power to their commercial properties.
- In Australia, the SOFC company CFCL is selling to global users. Their systems provide reliable, energy efficient, high quality, and low-emission electricity from natural gas and renewable fuels.

Fuel Cell Energy, United States

Back-up and Remote Power Generation

Back-up and remote power applications provide an important early market for fuel cell systems.

- Wireless TT Info Services Ltd, an arm of a major telecom operator in India, contracted with Plug Power for the purchase of 200 GenSys fuel cell systems to provide continuous power for off-grid cell towers. IdaTech and Ballard are also providing fuel cell systems to Acme Telepower in India.
- Motorola announced that it will use Ballard fuel cells in back-up power systems for 123 base stations in Denmark's public safety communication network.
- In the United States, companies such as Sprint and AT&T are deploying fuel cells for backup power at their cell phone towers. Most recently, he U.S. Department of Energy's (DOE) Recovery Act project deployed 24 fuel cells at cell phone tower sites as of September 2010.
- In Germany, five fuel cell back-up power systems ranging from 5 to 17 kW have been installed in the telecommunications industry, including a project at Deutsche Telekom which uses 100% renewable hydrogen as fuel.
- Beginning in late 2010 the Clean Power Net project in Germany will bring together fuel cell manufacturers and end users to further prepare the fuel cell back-up power market by sharing knowledge, exchanging information, identifying success factors, and working to jointly overcome common challenges.
- Ergon Energy, an Australian electricity distributor, is demonstrating fuel cell systems for distributed generation for its customers in remote areas.

Material Handling Equipment

Governments have emerged as a key early adopter and are helping to establish a clear business case for fuel cell forklifts, and sales are rapidly expanding to commercial facilities. Compared with battery-powered forklifts, fuel cell forklifts have a greater range, take less time to recharge and cool before use, are not prone to voltage drops as power discharges, and do not suffer from downtime due to battery change-outs. Fuel cell systems also require less space for refueling.

  - In the United States, major companies such as FedEx Freight, Coca-Cola, Sysco, and Wegmans are now demonstrating hydrogen powered fuel cells in their fleets.
  - As of September 2010, the DOE's Recovery Act projects have resulted in 276 fuel cell lift trucks delivered to commercial users.

- In Germany, Hoppecke Batteries have set up three fuel cell forklifts as part of a project funded by the state of North Rhine-Westphalia which are now deployed at BASF Coatings in Münster and at Hoppecke in Brilon. A system optimization by Hoppecke is now part of a project funded by the German National Innovation Program (NIP) to prepare a large fleet deployment.

Hoppecke Batterien, Germany

- The United States Department of Defense (DOD) is demonstrating 40 fuel cell forklifts and an indoor hydrogen refueling facility at the nation's largest defense distribution depot in Pennsylvania. The DOD has also initiated the purchase of 40 additional fuel cell forklifts and has received funding for two additional facilities. More than 18,000 fills with H2 have taken place.
- A new Wal-Mart distribution center in Alberta, Canada has invested in a fleet of 75 forklifts resulting in an estimated reduction in greenhouse gas (GHG) emissions by 530 tons/year and saving approximately $2 million in operating costs over seven years.

Energy Storage

Hydrogen systems can serve as viable energy storage options.

- In Canada, a partnership between the Federal Government, BC Hydro, Powertech, and G.E. is converting excess off-peak electricity and storing as hydrogen via an electrolyser, resulting in an estimated decrease in Bella Coola, B.C.'s diesel consumption by 200,000 L/year and 600 tons of GHGs/year.
- Pilot project "Ikebana" in Russia is using hydrogen for energy storage and aims to improve efficiency of power generation with a variety of power sources including renewable energy.
- In Germany, there are several projects underway using hydrogen as an energy storage medium.
  - Germany's Enertrag AG, one of the world's largest wind power companies, is building Germany's first hybrid power plant utilizing hydrogen produced from wind power as energy storage. The 6.7 MW plant will have a hydrogen storage capacity of 1,350 kg and will also produce hydrogen for transport applications.
  - The RH2-WKA project in Mecklenburg-Western Pomerania is developing a 300 bar hydrogen storage system in conjunction with its 180 MW wind park to help balance fluctuating wind energy.

Challenges to Commercialization

- Although hydrogen and fuel cell technologies offer many benefits, their widespread adoption is not without challenges:
- As with several of the other energy alternatives, hydrogen and fuel cell technologies have not developed to the point where they exceed the capabilities of some incumbent technologies. As the technology cost and performance continues to improve, commercialization will increase.
- Safe, lightweight, low-volume hydrogen systems are available now, but their cost remains an issue.
- Public awareness of hydrogen and fuel cell systems is low, and a misconception that hydrogen is unsafe and unreliable is still prevalent. More extensive outreach and better public education will help to remove this barrier.
- Cost-effective, emission-free methods of hydrogen production, including carbon capture and storage systems, are possible today and will continue to improve with further development.
- Current regulations and standards do not reflect real-world use of hydrogen and fuel cell technologies and are not synchronized between countries. This can be mitigated by a strong commitment to international cooperation and coordination.

POLICY DEVELOPMENTS AND PROGRAMS

In addition to supporting basic and applied technology research and development activities, countries around the world are implementing policies*,* including tax incentives and subsidies, to facilitate the adoption of hydrogen and fuel cell technologies into the market. Total government funding is estimated to be more than $1 billion per year for hydrogen and fuel cell research, development, demonstration and deployment activities.

- In Germany, the NIP, a public-private partnership, was launched in 2006 and provides €1.4 billion over ten years (including €700 million in industry funds) to accelerate market entry for hydrogen and fuel cell technologies. The program includes funding for transportation, stationary and special market applications. Germany aims to have 1 million battery-powered vehicles and 500,000 fuel cell vehicles on the road by 2020, and projects the mass marketing of fuel cell powered vehicles to start in 2015. Plans for up to 1,000 hydrogen stations are under way.
- The European Fuel Cell and Hydrogen Joint Technology Initiative (FCHJTI) was launched in 2008 as a public private partnership supporting research, technological development and demonstration (RTD) activities in fuel cells and hydrogen energy technologies in Europe. The objective of the FCHJTI is to significantly accelerate the market introduction of the fuel cells and hydrogen technologies, realizing their potential as an instrument in achieving a carbon-clean energy system. The European Commission funding to the program is € 470 million over the period 2008-2013, which will be roughly € 1billion with the required 50-50 cost share by industry.
- Japan's Large Scale Residential Demonstration Program provides subsidies for producers and users in order to increase deployment of CHP fuel cell systems. As of March 2010, over 5,000 units have been deployed. Government subsidies for stationary fuel cell deployments are estimated at $75 million in 2010.

Ene-farm Residential CHP Fuel Cells, Japan

- In 2009, the United States announced $42 million in Recovery Act funding to accelerate fuel cell commercialization and deployment. With approximately $54 million in cost-share funding from industry participants the new funding will support deployment of up to 1,000 fuel cell systems primarily for emergency backup power and material handling.
- The Australian Association for Hydrogen Energy (AAHE) was founded in September 2010 to advance the knowledge and understanding of production, storage, transport, safe distribution and end use of hydrogen energy.
- The United Kingdom has created a New Automotive Industry Growth Team (NAIGT) and Automotive Council and an Office of the Low Emissions Vehicles as well as a £5 k per car subsidy for electric cars (up to £250 million), plug-in petrol-electric and hydrogen fuel cell powered cars beginning January 2011.

Commercial deployments of CHP are expected to increase as governments increase support for fuel cell technologies. South Korea announced a program starting in 2010 to subsidize 80% of the cost of residential fuel cells for heat and power. The size of the subsidy will fall to 50% from 2013 to 2016 and to 30% from 2017 to 2020. South Korea has also announced an ambitious goal to supply 20% of the worldwide shipments of fuel cells by 2025 and create 560,000 jobs in Korea. A strategic plan for the city of Seoul, includes 47% of renewable energy generation from fuel cells by 2030, more than the power produced by solar, geothermal and all other clean energy technologies combined.

- Denmark announced an ambitious clean vehicle program with the objective that all new vehicles sold after 2025 will be either electric or hydrogen powered.

TECHNOLOGY DEVELOPMENTS

Demonstration projects continue to validate hydrogen and fuel cells technologies. Rapid developments in technology over the last few years have led to announcements by automakers and government agencies throughout the world that suggest commercial introductions of FCEVs and hydrogen fueling infrastructure by 2015.

Hydrogen Infrastructure

Worldwide, there are hundreds of hydrogen fueling stations in operation or in the planning stages. The number of hydrogen refuelings continues to grow at a rapid pace. Germany, Japan, and Korea anticipate having over 300 fueling stations in operation by the 2015 – 2017 timeframe.

- Germany's Clean Energy Partnership (CEP) will deploy a total of 8-10 hydrogen stations (including the largest station in Europe) in its three regions of Berlin, Hamburg, and North Rhine-Westphalia by 2013, and plans to increase the proportion of hydrogen produced from renewable energy at its stations to 50% by 2015. The existing CEP stations have performed over 12,000 refuelings since the program's demonstration activities began in 2005.

- The state of North-Rhine Westphalia in Germany plans to use hydrogen from an existing 220 km industrial pipeline to supply various demonstration and deployment projects in the Rhine-Ruhr area.

TOTAL Deutschland GmbH, Germany

- Japan's Hydrogen and Fuel Cell (JHFC) project is currently operating 14 hydrogen fuelling stations and one hydrogen liquefaction facility in the Tokyo metropolitan, Chubu, Kansai, and Kyushu areas.
- In Norway, new electrolyzers have been developed to help meet demand from Norway's Hydrogen Highway filling stations and for small applications. Development also comprises pressurized electrolyzers and new technologies based on PEM technology. Several production and supply methods are to be tested as more filling stations come into operation.
- In the United States, spurred by the increasing sales of fuel cell forklifts, the number of hydrogen refuelings in the U.S. material handling market reached 120,000 in 2009, up from 20,000 in 2008. Also, the U.S. has over 50 hydrogen fueling stations. The DOE's Technology Validation Program has also demonstrated over 150,000 kilograms hydrogen produced or dispensed for light-duty vehicles.
  - The California Fuel Cell Partnership announced an action plan for deploying over 45 hydrogen fueling stations in California by 2017. Their survey of global automakers estimates more than 4300 FCEVs in California by 2014 and roughly 50,000 FCEVs by 2017.
  - In October 2010, the California Energy Commission announced $19 million, which is expected to fund 11 additional hydrogen fueling stations.
- South Korea continues efforts to develop a Hydrogen Highway, with six stations operating and four planned.
- Two hydrogen refueling stations have opened at Birmingham and Loughborough in the United Kingdom as part of the Midlands Hydrogen Ring, and a depot is planned for London as part of the London Hydrogen Bus and Taxi Demonstration. As many as six refueling stations are planned for use by taxis, busses, and the general public.
- In Canada, Air Liquide Inc. built and operates a hydrogen refueling station capable of dispensing 1,000 kg of hydrogen daily or enough to fill 23 buses each day. The station supports refueling of British Columbia's fleet of 20 zero emission fuel cell buses.

Renewable hydrogen production continues to develop, with the number of demonstration facilities growing each year. In the United States, GM and the State of Hawaii's natural gas company announced their intent to build 20 – 25 hydrogen refueling stations by 2015

- In Hawaii, the U.S. Air Force is demonstrating a hydrogen production and fueling station. The hydrogen is produced by electrolysis using an integrated solar photovoltaic and wind energy system. Hawaii also has a fuel cell shuttle bus demonstration program under development, with the hydrogen to be produced by off-peak geothermal electricity.
- A combined heat, power, and hydrogen generation system based on a molten carbonate fuel cell using wastewater biogas has been factory tested and will be commissioned in Orange County, California in 2010.
- As part of Germany's CEP, the world's first CO_2-free hydrogen fueling station is being built at the Berlin Brandenburg International airport, utilizing wind power from a nearby, purpose-built wind farm to produce renewable hydrogen. Linde is currently putting into service a demonstration plant in Leuna, Germany for production of hydrogen from glycerine, a byproduct of biodiesel production. This process, when optimized, has the potential to reduce CO_2 emissions by 80% compared to SMR (steam methane reforming). Linde is planning to use the hydrogen produced at the Leuna plant to fuel hydrogen buses and passenger vehicles in Berlin and Hamburg, among other applications.
- SunHydro, an effort led by a private investor to build a network of renewable hydrogen refueling stations in the eastern United States, built the first station in the state of Connecticut. The station will initially serve a fleet of 10 Toyota Highlander FCEVs.
- Air Products announced in September 2010 that their partnership with Structural Composites Industries has resulted in the development of a compression-less hydrogen fueling station which will significantly lower the cost of dispensing gaseous hydrogen.

Fuel Cell Vehicles (Cars and Buses)

Next-generation FCEVs show promising test results. Light duty FCEV announcements include Hyundai/KIA's unveiling of its sport utility Borrego FCEV and statement that the company is preparing for initial commercial production of FCEVs to start as soon as 2012, Mercedes-Benz production of a 200 car series of its latest FCEV, the B Class F-Cell; commercial leasing of the Mazda Premacy Hydrogen RE Hybrid; and U.K.-based Riversimple's introduction of a 30-vehicle fleet of small, urban fuel cell car, for a pilot project in Leicester. GM's Project Driveway program, which placed 100 Chevy Equinox FCEVs in consumer hands for real-world driving, achieved over 1.4 million miles in 2010, and GM states that its next-genera-tion fuel cell system is half the size, 220 pounds lighter and uses less than half the precious metal of the current generation Equinox FCEV.

- In the United States, Toyota, Savannah River National Lab, and NREL verified in a road test that the Toyota Highlander Fuel Cell Hybrid Vehicle can achieve an estimated range of 431 miles on a single full tank of compressed hydrogen gas and an average fuel economy of 68.3 miles per gallon of gasoline equivalent.

Government-industry demonstration partnerships continue to tally progress. For the 2010 World Expo in Shanghai, China demonstrated a 196 fuel cell vehicle fleet – the largest single fleet deployed to date. The vehicles included 90 mid-size cars, 100 small sight-seeing carts and 6 full-size city buses. In 2009, a pilot program demonstrating new energy vehicles, including FCEVs, was launched in 13 cities in China. In 2008, a total of 20 Lingyu FCEVs and 3 fuel cell buses successfully provided zero-emission transportation services for the 2008 Beijing Olympic Games. Also, China is planning to convert Chongmin Island to an electric vehicle-only demonstration island in 2011. FCEVs and battery electric vehicles will be used for all transportation on the island.

2010 World Expo, China

- Canada also recently commenced operation of its fleet of 20 hydrogen fuel cell (zero pollution) buses for the 2010 winter Olympics in Whistler, British Columbia. Ford and Daimler have turned to Vancouver's Automotive Fuel Cell Cooperation (AFCC) for fuel cell development. AFCC is the Canada-based successor of the automotive division of Ballard Power Systems and is one of the largest fuel cell development centers in the world.
- In 2009, the European Commission completed the HyFLEET:CUTE project, the world's largest hydrogen-powered bus demonstration project at the time, which included 33 fuel cell and 14 hydrogen ICE vehicles operating in 10 cities on three continents. During the project 10 hydrogen filling stations were in service, six of which had on-site production facilities.
- In the United States, industry is demonstrating 152 FCEVs and 24 hydrogen stations, and has reached more than 2.8 million miles of real-world driving, demonstrating 75,000 miles of on-road durability.. In California, partnerships of auto companies, energy companies, and local, state, and federal government have placed almost 300 FCEVs on the road since 2001, with close to 2.5 million miles traveled.
- In 2010, the European FCHJTI initiated the Clean Energy for European Cities (CHIC) project that will bring learning from all the previous projects together, and integrate and develop it into safe, efficient, commercially viable, technical and human systems.
- Highlights of the CHIC project include:
  - implementing clean urban mobility in 5 major European regions through the deployment of 28 hydrogen fuel cell buses in medium sized fleets, and the enlargement of the hydrogen infrastructure fleets;
  - facilitating the development of clean urban public transport systems and mobility action plans into 14 new European regions;
- The CEP, the largest hydrogen vehicle demonstration project in Europe, has demonstrated up to 47 vehicles and 4 buses in Germany between 2008 and 2010, and plans to enlarge this fleet to 85 vehicles by the end of 2013. Since the demonstration activities began in 2005, CEP vehicles have travelled over 830,000 km.
- A Dutch-German (North Rhine-Westphalian) project consortium will deploy four 18 meter fuel cell buses by the end of 2010 in the cities of Cologne and Amsterdam. The hydrogen infrastructure to support these buses is already in place. Larger fleets are foreseen for the coming years. In addition, the deployment of up to 10 additional vehicles and 1 hydrogen station are planned in North-Rhine Westphalia as part of the Clean Energy Partnership.

- The first "Zemship" (Zero Emission Ship) was launched into regular line service on the Alster River in Hamburg, Germany. The Zemship uses two 48 kW maritime fuel cells and a lead-gel battery in a hybrid system for propulsion. The ship can transport 100 passengers while demonstrating nearly twice the efficiency of a standard diesel vessel.


Hamburger Hochbahn AG, Germany

- In India, a demonstration project of hydrogen / compressed natural gas vehicles is being implemented with the involvement of five major Indian automobile manufacturers. The strategic plan calls for 1 million hydrogen internal combustion vehicles by 2020.
- In Japan about sixty hydrogen-fuelled vehicles are registered in the JHFC demonstration project and 14 hydrogen stations are operating. The top-ranked vehicle in the project has recorded an efficiency of 61.3 percent and a mileage of 159 km/kg of hydrogen.
- In the United Kingdom, at least 20 fuel cell hybrid taxis are being developed in preparation for the 2012 London Olympics as well as 5 fuel cell busesscheduled to run in London.
- The successful launches of a hybrid electric fuel cell urban bus in May 2010 in Rio de Janeiro as well as a refueling station are demonstration highlights for Brazil.

New fuel cell buses recently introduced include the Mercedes Citaro FuelCELL Hybrid and Proton Power's triple-hybrid passenger bus (which does not use a combustion engine, and is powered only by a fuel cell, batteries and ultracapacitors).

Technical and Economic Analysis

A number of significant studies provide much-needed information about the potential costs and contributions of various light duty transportation alternatives to lowering oil imports and reducing GHG.

These independently conducted studies arrived at corroborating conclusions, which, among other things, suggest that hydrogen and fuel cell technologies are likely to be cost competitive with other alternative technologies and that countries should take a portfolio approach to addressing the world's energy, environmental, and economic issues.

- A 2010 study by McKinsey sponsored by a group of over 30 industry stakeholders found that the total cost of ownership of all powertrains may converge in the next 10 to 20 years, and that costs for electrical and hydrogen infrastructures are comparable and affordable. The study concluded that there will be an evolution from today's ICE towards a portfolio of powertrain technologies, in which BEVs are specifically attractive in the small car segments and urban mobility patterns, whereas FCEVs show significant potential in the medium to large car segments with longer driving distances.
- In the United States, the National Research Council has published two studies, one on hydrogen fuel cell vehicles (HFCV) and the other on plug-in hybrid electric vehicles (PHEV). The studies find that the marginal increased costs of HFCVs and PHEVs are likely to be similar.
- The International Energy Agency's "Transport, Energy and CO_2: Moving towards Sustainability.", which predicts hydrogen FCEVs and EVs playing a significant role in reducing petroleum use by 2050.
- The 2009 GermanHy study concluded that mobility based on fuel cells and hydrogen will be possible at today's costs if the development targets for vehicles are met. The study estimates that hydrogen will cost between 4 and 5.5 €/kg in 2020, and between 3.5 and 4.5 €/kg in 2030. Carbon dioxide (CO_2) emissions of cars and light duty vehicles can be drastically reduced to 40g CO_2/km (well to wheel) and 20g CO_2/km (tank to wheel) by 2050 (fleet average).
- The United States organization Fuel Cells 2000 published "The Business Case for Fuel Cells" in September 2010 which showcases successful use of fuel cells by 38 companies.

RESEARCH PROGRESS

The rising levels of investment in developing transformative energy technologies, coupled with broad international cooperation and innovative research and development (R&D), has produced substantial advances in hydrogen and fuel cell technologies and in the production, storage, and transport infrastructure needed to support their growth.

Fuel Cells

Projected fuel cell system costs, using today's best technology, continue to decline. The United States DOE's modeled cost assessment, projected for a manufacturing volume of 500,000 80 kW automotive PEM fuel cell systems per year with today's best technology, has dropped from $275/kW in 2003 to $51/kW in 2010. This brings fuel cell cost into the range of high-end internal combustion systems and suggests that FCEVs can be cost-effective within a few years if produced at high volumes.

Researchers continue to make progress on improving durability and lowering the cost of fuel cells. For PEM fuel cells, lowering platinum (Pt) catalyst loading is a major cost reduction goal. In the U.S., researchers at 3M demonstrated a membrane with 40% lower Pt content than in 2008, and researchers at Los Alamos National Laboratory (LANL) demonstrated non-platinum group metal catalysts that exceed the 2010 DOE research target.

- Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) and the universities of Queensland, Wollongong, South Australia, and the Australian National University, as part of the National Hydrogen Materials Alliance are conducting R&D on new materials for PEFC membranes and catalysts. CSIRO has developed self-breathing PEM fuel stacks and is seeking to commercialize the technology.
- Canada's research efforts have resulted in the development of a low-cost PEM fuel cell humidifier (dPoint Technologies) that drastically reduced cost: from $2,500 to $60 per humidifier. Hydrogenics Corporation also demonstrated a PEM water electrolyzer that can continuously operate 19,800 hours.
- The development of alternative membranes to "Nafion" with the capability to operate at intermediate temperatures, specific anodes for oxidation of ethanol in SOFC, and modifications in the interface of gas diffusion electrodes that increased power density by 85% in small cells are highlights of the robust research effort in Brazil's ProH2 Program.

Hydrogen Production and Distribution

Lower-cost pathways for renewable hydrogen production are being developed. In Production of hydrogen from water using renewable powered electrolyzers is a promising renewable pathway. For example, in the United States, an independent review of on-site, distributed hydrogen production from electrolysis ranges from $4.90/kg to $5.70/kg at high volumes.

- In Australia, R&D on hydrogen production by solar thermal reforming is being carried out by the CSIRO and several university partners and the University of Queensland is leading an international solar biofuels consortium that is coordinating several university projects on the production of hydrogen from biomass.
- In Europe the HYDROSOL project has established a 100 kW scale pilot plant demonstrating that hydrogen production via thermochemical water splitting is possible with concentrated solar radiation under realistic conditions. The most recent phase of the project is focused on building a 1 MW demonstration plant.

Hydrogen Park, Italy

Progress continues on nuclear hydrogen production pathways. Three processes for nuclear hydrogen production were tested in the United States in 2009. An integrated lab-scale high-temperature electrolysis unit was operated for 45 days at Idaho National Laboratory (INL) and achieved a peak output of 5,650 liters of hydrogen per hour. The Savannah River National Laboratory (SRNL) successfully demonstrated operation of a hybrid sulfur electrolyzer without any limitations due to sulfur build-up. The Sulfur-Iodine (SI) thermo-chemical cycle being devel-oped jointly by Sandia National Laboratories, General Atomics and the French Commissariat à l'Energie Atomique (CEA) in France achieved integrated operation, producing about 100 liters of hydrogen per hour.

The projected cost of gaseous and liquid hydrogen delivery pathways continued to decrease. Hydrogen delivery cost reductions are being made possible by R&D on higher-capacity tube trailers and lower-cost pipeline materials, compression and liquefaction technology. The United States, the projected cost of gaseous and liquid hydrogen delivery pathways decreased from 2005 costs by about 15 to 30%.

Byproduct hydrogen from the chemical industry presents a good opportunity for supporting early infrastructure development. A study conducted in North Rhine-Westphalia, Germany, highlights the potential of by-product hydrogen from the chemical industry, suggesting that there is enough by-product hydrogen available in the state of North Rhine-Westphalia to fuel 6000 buses or 300,000 cars (35,000 tons/year). Canada continues to harness industrial by-product streams rich in hydrogen through local electrochemical plants. The development of liquefaction and fuelling facilities will contribute to Canada's Hydrogen Highway initiative and improve the economics and practicality of using locally vented hydrogen as a fuel to reduce the carbon intensity and air contaminants of the transportation sector.

Hydrogen Storage

R&D helps improve technology for compressed and cryogenic tanks. The United States launched a Hydrogen Storage Engineering Center of Excellence (COE) in 2009. This new center will address systems integration and prototype development for on-board vehicular hydrogen storage systems. It is planned as a five-year effort and may produce up to three sub-scale prototype systems as its final output.

- The design of vehicle hydrogen fuel tank systems for 350- and 700-bar compressed gas storage were revised and improved by United States researchers, increasing capacity and reducing incremental cost. Lawrence Livermore National Laboratory (LLNL) also designed and fabricated a cryogenic vessel for cryo-compressed hydrogen storage with promising cost results compared to conventional liquid hydrogen.
- In Australia, significant research programs on hydrogen storage across several universities based on lithium, magnesium and other light metals, carbons, and porous materials is being conducted.
- In Europe, the NessHy project has continued to develop and evaluate solid-state materials for low pressure hydrogen storage. Russia as well continues to focus on advanced hydrogen storage development.

Regulations, Codes and Standards (RCS)

The development of international regulations, codes and standards (RCS) is underway. Standards Development Organizations (SDOs) and international organizations involved in the collaborative and global RCS work include the International Energy Agency (IEA) Hydrogen Implementation Agreement (HIA), the United Nations Economic Commission for Europe (UNECE) Global Technical Regulations (GTR), the International Electrotechnical Commission (IEC), and the International Organization of Standardization (ISO). Notable examples of international collaboration on RCS include:

- IEA HIA Task 19: Collaboration of international experts addressing the safety related barrier to widespread adoption of hydrogen energy. Work includes improving risk analysis methods, closing knowledge gaps and sharing experimental and testing data to achieve a risk informed basis for codes and standards that are not unnecessarily restrictive.
- European Union HySafe Program: Handbook for Approval of Hydrogen Refueling Stations (HyApproval), Hydrogen Installations Permitting Guide (HyPer).
- IEC Technical Committee 105 and ISO Technical Committee 197: Standards for hydrogen and fuel cell technologies.
- Collaborative testing and modeling to establish a scientific foundation for hydrogen fuel quality specifications.
- Near completion of a GTR first draft for hydrogen vehicle systems under UNECE Working Paper 29.

Air Liquide, Canada

Existing hydrogen RCS are based largely on industrial use and experience. However, use of industrial hydrogen does not necessarily reflect the type of requirements for RCS that will be required to govern the safe use of hydrogen and fuel cells in a commercial and consumer friendly environment. International differences in terminology and regulatory approaches present challenges that are being addressed and be overcome with a strong commitment to international cooperation and coordination.

- In Europe, legislation for EU-harmonized type approval of hydrogen vehicles has been approved.
- The Brazilian Association of Technical Standards has developed several regulations and codes in 2010 including regulations helping to: define uniform terminology concerning Fuel Cell Technologies, address basic hydrogen systems security issues, define product specification for hydrogen fuels, use hydrogen generators that utilize fuel processing technologies, use connecting devices for refueling ground vehicles with compressed hydrogen, and general fuel cell technology.

- In the United States, a new draft code, which incorporates critical R&D to reduce separation distances for bulk hydrogen storage, was published in 2010. The code document also consolidates all hydrogen code requirements for the built environment into a single document, which will help to simplify and improve the permitting process and regulation of hydrogen infrastructure. A Technical Reference for Hydrogen Compatibly of Materials, Best Practices Manual, Bibliographic Database, Permitting Compendium, Hydrogen Incidents and Lessons Learned Database, and online courses for emergency responders and code officials are available and used by industry and key stakeholders from around the world.
- In 2007, the Canadian Hydrogen Installation Code (CHIC) was published by the Bureau de normalization du Québec as a National Standard of Canada. It provides Canadian industry and regulatory authorities with guidance for approving hydrogen as an energy carrier and facilitating the approval of hydrogen installations across the country.

HYDROGEN AND FUEL CELLS IN THE GLOBAL ECONOMY

Integrating hydrogen and fuel cells into the global economy offers many opportunities for industrial, economic, environmental, and social progress. Policy makers, local and national government agencies, financial and insurance institutions, and a broad spectrum of industries will be involved. Governments, for their part, can take advantage of the new opportunities by providing dependable, long-lasting incentives, and by promoting coordination of R&D both at home and internationally.

Collaboration will be essential, since this will not only encourage the best use of scarce resources, but will also maintain and increase momentum. There are many actions that can be taken to encourage the widespread adoption of hydrogen and fuel cell technologies.Invest in the RD&D needed to overcome technical barriers.

- Invest in the RD&D needed to overcome technical barriers and reduce costs.
- Promote cooperation in R&D including networks across business, academia, and non-profits.
- Encourage demonstration projects that validate hydrogen and fuel cell technologies, provide real-world feedback on RCS, establish a core base of infrastructure and encourage public acceptance of hydrogen and fuel cell systems.
- Work through existing international agreements to develop, adopt, harmonize, and promote national and international RCS.
- Increase public outreach and education to increase awareness and market uptake.
- Develop methods for creating a skilled workforce that will build, maintain, and manage the hydrogen and fuel cell energy systems of the future.
- Become early adopters of hydrogen and fuel cell technologies yourselves.

The members of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) have been coordinating activities since 2003 to accelerate the adoption of hydrogen and fuel cell technologies into the global economy. The four priority focus areas of the IPHE are: 1) Accelerating the market penetration and early adoption of hydrogen and fuel cell technologies and their supporting infrastructure; 2) Policy and regulatory actions to support widespread deployment; 3) Raising the profile with policy-makers and the public; and 4) Monitoring hydrogen, fuel cell and complementary technology developments. IPHE has 18 member governments, including: Australia, Brazil, Canada, China, the European Commission, France, Germany, Iceland, India, Italy, Japan, the Republic of Korea, New Zealand, Norway, the Russian Federation, the Republic of South Africa, the United Kingdom and the United States. Together, members have a combined population of approximately 3.5 billion people, use three-quarters of all the electricity produced on the planet, and account for two-thirds of global energy consumption and CO_2 emissions.

To learn more about the IPHE and its members, please visit our website at www.iphe.net.