Hydrogen Initiatives

"As a future clean transport alternative, hydrogen and fuel-cell technology have huge potential. Hydrogen is potentially a game-changing transportation fuel,"

Hydrogen is colorless as a liquid. Its vapors are colorless, odorless, tasteless, and highly flammable. Liquid hydrogen is non-corrosive. Special materials of construction are not required to prevent corrosion. However, because of its extremely cold temperature, equipment must be designed and manufactured of material, which is suitable for extremely low temperature operation.

Flammability

The wide flammability range, 4% to 74% in air, and the small amount of energy required for ignition necessitate special handling to prevent the inadvertent mixing of hydrogen with air. Care should be taken to eliminate sources of ignition, such as sparks from electrical equipment, static electricity sparks, open flames or any extremely hot objects. Hydrogen and air mixtures within the flammable range can explode and may burn with a pale blue, almost invisible flame.

Physical Properties

- **Molecular Weight:** 2.016
- **Boiling Point @ 1 atm:** -423.0°F (-252.8°C, 20^{o}K)
- **Freezing Point @ 1 atm:** -434.5°F (-259.2°C, 14^{o}K)
- **Critical Temperature:** -399.8°F (-239.9°C)
- **Critical Pressure:** 188 psia (12.9 atm)
- **Density, Liquid @ B.P., 1 atm:** 4.23 lb./cu.ft.
- **Density, Gas @ 68°F (20°C), 1 atm:** 0.005229 lb./cu.ft.
- **Specific Gravity, Gas (Air = 1) @ 68°F (20°C), 1 atm:** 0.0696
- **Specific Gravity, Liquid @ B.P., 1 atm:** 0.0710
- **Specific Volume @ 68°F (20°C), 1 atm:** 192 cu. ft./lb.
- **Latent Heat of Vaporization:** 389 Btu/lb. mole
- **Flammable Limits @ 1 atm in air 4.00%:** -74.2% (by Volume)
- **Flammable Limits @ 1 atm in oxygen 4.65%:** -93.9% (by Volume)
- **Detonable Limits @ 1 atm in air 18.2%:** -58.9% (by Volume)
- **Detonable Limits @ 1 atm in oxygen 15%:** -90% (by Volume)
- **Autoignition Temperature @ 1 atm:** 1060°F (571°C)
- **Expansion Ratio, Liquid to Gas, B.P. to 68°F (20°C):** 1 to 848

Safety Considerations

The hazards associated with handling liquid hydrogen are fire, explosion, asphyxiation, and exposure to extremely low temperatures. Consult the Air Products Material Safety Data Sheet (MSDS) for safety information on the gases and equipment you will be using. The potential for forming and igniting flammable mixtures containing hydrogen may be higher than for other flammable gases because:

1. Hydrogen migrates quickly through small openings.
2. The minimum ignition energy for flammable mixtures containing hydrogen is extremely low. Burns may result from unknowingly walking into a hydrogen fire. The fire and explosion hazards can be controlled by appropriate design and operating procedures. Preventing the formation of combustible fuel-oxidant mixtures and removing or otherwise inerting potential sources of ignition (electric spark, static electricity, open flames, etc.) in areas where the hydrogen will be used is

essential. Careful evacuation and purge operations should be used to prevent the formation of flammable or explosive mixtures. Adequate ventilation will help reduce the possible formation of flammable mixtures in the event of a hydrogen leak or spill and will also eliminate the potential hazard of asphyxiation. Protective clothing should be worn to prevent exposure to extremely cold liquid and cold hydrogen vapors.

3. Cold burns may occur from short contact with frosted lines, liquid air that may be dripping from cold lines or vent stacks, vaporizer fins, and vapor leaks. Air will condense at liquid hydrogen temperatures and can become an oxygen-enriched liquid due to the vaporization of nitrogen. Oxygen-enriched air increases the combustion rate of flammable and combustible materials.

Purging

Gaseous and liquid hydrogen systems must be purged of air, oxygen, or other oxidizers prior to admitting hydrogen to the systems, and purged of hydrogen before opening the system to the atmosphere. Purging should be done to prevent the formation of flammable mixtures and can be accomplished in several ways. Piping systems and vessels intended for gaseous hydrogen service should be inerted by suitable purging or evacuation procedures. If the piping systems are extensive or complicated, successive evacuations broken first by an inert gas and finally with hydrogen are most reliable. Evacuating and purging of equipment in gaseous hydrogen service should include the following considerations:

1. Evacuate the equipment and break vacuum with an inert gas, such as nitrogen. Purge with an inert gas if equipment design does not permit evacuation.
2. Repeat step 1 at least three times. If analytical equipment is available, purge system until oxygen content of residual gas is either less than or meets the process specification impurity level.
3. Hydrogen may now be introduced to the equipment.
4. Flush system with hydrogen until required purity is reached. Vent all waste hydrogen through a flue or flare stack. Any purge method should be repeated as often as required to be certain a flammable mixture cannot be formed upon introducing hydrogen or air to the system.

Fire Fighting

Heat, open flames, electrical sparks, and static electricity easily ignite hydrogen. It will burn with a pale blue, almost invisible flame. Most hydrogen fires will have the flame characteristic of a torch or jet and will originate at the point where the hydrogen is discharging. If a leak is suspected in any part of a system, a hydrogen flame can be detected by cautiously approaching with an outstretched broom, lifting it up and down. The most effective way to fight a hydrogen fire is to shut off the flow of gas. If it is necessary to extinguish the flame in order to get to a place where the flow of hydrogen can be shut off, a dry powder extinguisher is recommended. However, if the fire is extinguished without stopping the flow of gas, an explosive mixture may form, creating a more serious hazard than the fire itself should re-ignition occur from the hot surfaces or other sources. The usual fire fighting practice is to prevent the fire from spreading and let it burn until the hydrogen is consumed. Dry powder fire extinguishers should be available in the area. A fire blanket should be conveniently located. An adequate water supply should be available to keep surrounding equipment cool in the event of a hydrogen fire. The local fire department should be advised of the nature of the products handled and made aware of the best known methods for combating hydrogen fires.

A hydrogen economy seems to be evolving as we adapt to the challenges of global warming. Such an economy appears to promise energy with a price less than that from oil.

- John O'M. Bockris (Haile Plantation, Gainesville, Florida, USA) proposes three new low-cost methods of obtaining clean hydrogen in massive amounts.

In the first method, new technology for converting solar energy and water to hydrogen at a price of $2.50 for an amount of hydrogen equal in first law energy to that in a gallon of gasoline seems to follow from a company's announcement of their new technology, already working, in one fully industrialized plant, producing electricity at a price corresponding to that from coal.

In the second method, pure hydrogen (no accompanying CO_2) can be obtained from natural gas and heat. The cost would be a little less than that of the low-cost hydrogen from water decomposition. It would also avoid storage of hydrogen for the up to 18 h/day of zero solar light.

In the third method, CO_2 is extracted from the atmosphere and combined chemically with low-cost hydrogen to produce methanol. On being used to produce heat or electricity (fuel cell), CO_2 is left over. However, the amount of CO_2 thus added to the atmosphere is just equivalent to that removed.

The presence of low-cost hydrogen from water means that the resulting methanol will also be inexpensive and combat global warming without requiring a radical change in the method of distribution.

- An international team of researchers has created a catalyst which produces hydrogen from bioethanol under 'realistic conditions.'

  Comprising nanoparticles of rhodium and palladium, supported by larger particles of cerium oxide, the catalyst allows the reaction to occur at a temperature of around 500 degrees Celsius. Hicham Idriss of the University of Aberdeen, who led the group, says that the trial reactor operated successfully for three weeks with no apparent deactivation of the catalyst or carbon deposition.

  The hydrogen produced is reported to be pure enough for use in fuel cells and, unlike current production methods which are 90 per cent reliant on natural gas and emit large quantities of carbon dioxide the fuel source is renewable.

  "As with traditional methods of hydrogen production, carbon dioxide is still created during the process we have developed. However unlike fossil fuels which are underground we are using ethanol generated from an above-the-ground source – plants or crops. This means that any carbon dioxide created during the process is assimilated back into the environment," said Idriss.

- **Young company is developing equipment that extracts hydrogen from ethanol and natural gas; technology is strategic for Brazil**

A company that bets on the use of ethanol and natural gas as sources of hydrogen to supply future fuel cells was born at the Hydrogen Laboratory (Laboratório de Hidrogênio) of the State University of Campinas (Universidade Estadual de Campinas, Unicamp)'s Physics Institute (Instituto de Física). HyTron Tecnologia em Hidrogênio (or HyTron Technology in Hydrogen), supported by the Technological Innovation in Small Businesses Program (Programa Inovação Tecnológica em Pequenas Empresas, PIPE) of the State of São Paulo Research Foundation (Fundação de Amparo à Pesquisa do Estado de São Paulo, Fapesp), was founded in March of 2005 by a group of 12 researchers, some of them very young, just graduated or finishing their Master's Degrees or PhDs. The company's objective is to develop and manufacture ethanol and natural gas reformers – a reformer being the equipment that "reforms" ethanol or natural gas chemically in order to extract hydrogen. A series of reactions take place within the reformer to break up the molecules and separate, among them, the molecules of hydrogen.

Fuel cells, which use hydrogen as fuel, pollute little, are already being tested by large manufacturers for use in automobiles and may be used in places where there's no electricity. But they still have a disadvantage: it's very expensive to produce them.

Looking for technologies for obtaining hydrogen from ethanol is strategic for Brazil. Throughout the world there are large investments in research and development for making fuel cells feasible – because they generate clean energy, there's hope that they may become a significant energy source in the future, especially for ending pollution caused by vehicles. Ethanol is already becoming an alternative fuel; if it could also be used as an energy source in the future, the market perspectives for Brazil's production will gain longevity and relevance.

"Alcohol is the most important bio-fuel today, but we have to think in the long run, in technologies that could be cheaper and more interesting for the market, such as the case of the fuel cells and of the future hydrogen era," says agronomy engineer **Heloisa Burnquist**, who is a researcher at the Department of Economics, Administration and Sociology (Departamento de Economia, Administração e Sociologia) of the Luiz de Queiroz Agricultural School (Escola Superior de Agricultura Luiz de Queiroz, Esalq), of the University of São Paulo (Universidade de São Paulo, USP). "We can think in technological eras, and currently Brazil has a privileged situation concerning ethanol. We have to continue thinking in ways for adding more advantages to that potential and to new technologies," she argues.

Prototypes

HyTron is being incubated at the Campinas High Technology Hub Development Company (Companhia de Desenvolvimento do Pólo de Alta Tecnologia de Campinas, Ciatec) and has picked as its focus small customers. So far, the company has made three prototypes, two for ethanol and one for natural gas. One of the ethanol reformers was ordered by Spain's Air and Space Technical Institute, which should receive it by January of 2007. The other, that also uses ethanol, is being developed in partnership with Petrobras' Research Center (Centro de Pesquisas, Cenpes) – Petrobras is Brazil's State oil company. The reformer that uses natural gas has the participation of CPFL, a power company that operates in the State of São Paulo.

The order from Spain came because Unicamp's Hydrogen Laboratory has had contacts with the Spanish institution's Renewable Energies Laboratory since 1992. With the Vega project, an automobile that runs on hydrogen developed at Unicamp's laboratory, both worked together in the question of hydrogen storage. HyTron is not allowed to say what the Spanish are going to do with the reformer they have bought from Brazil because the Air and Space Technical Institute is engaged in military research and thus its activities are related to national security.

The incubated company uses equipment from Unicamp's Hydrogen Laboratory to carry out the reformers' prototype's daily tests. For its research activities, in addition to the support from Fapesp's PIPE, it has also received funding from the Brazilian Innovation Agency/Research and Projects Financing (Financiadora de Estudos e Projetos, Finep) and from the National Council for Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico, CNPq); and from the companies associated with the project – a total of approximately US$ 182,000 until December of 2006.

How a reformer works

The operation of ethanol and natural gas reformers are similar, in spite of the fact that they run on different fuels. On the day ***Unicamp Innovation*** visited the laboratory, HyTron tested the ethanol reformer Spain has ordered. João Carlos Camargo, an electric engineer with a degree from the Federal University of Santa Maria (Universidade Federal de Santa Maria, UFSM) and one of HyTron's founding partners, explains the process that takes place within the reformer while showing the equipment being tested. Camargo has a Master's Degree and a PhD in energy systems planning.

The reformer's heart is the reform reactor, where a mixture comprised of 50% water and 50% ethanol is heated to a temperature of around 700°C (1,292º F). The high temperature breaks the ethanol molecules; catalysts hasten the process. In this phase is produced a synthesis gas, comprised mostly of hydrogen, carbon monoxide and carbon dioxide. That gas goes to a sequence of smaller reactors that extract all the hydrogen until only carbon dioxide is left (and it then is let outo into the atmosphere). The hydrogen the reformer produces is applied directly to the fuel cell; there's only a small low pressure reservoir between both.

The ethanol HyTron is using in the tests has been donated by the Sugar and Alcohol Technology Center (Centro de Tecnologia Canavieira, CTC). "We're producing reformers to supply fuel cells that generate 5 kilowatts and require 5 cubic meters [176 cubic feet] of hydrogen per hour. In order to produce that amount of hydrogen we need between 3 and 4 liters (between .8 and 1.0 gallon] of ethanol per hour," says Camargo. The company intends to make reformers for fuel cells of up to 100 kW.

The ethanol reformer runs on ethanol, and the natural gas' on natural gas – thus part of the ethanol or the gas used in the reform process is burned in order to provide the energy for the reform process proper. Camargo explains that the reform reaction is endothermal, that is, it consumes heat in order to take place. "The amount of gas used to supply heat for the reaction runs from 16% to 20% of the energy available in the ethanol or in the gas," he continues. "By and large, we could say that 80% of the fuel's energy is available for hydrogen production," he says.

Make them small

"The challenge for those devices is making them small. In large refineries there are already equipments such as these, but they're very large," explains Camargo. HyTron plans to produce smaller ones for the government and for power companies. Its prototypes are 1.9 meters high by 60 centimeters wide and 1.2 meters deep (6.2 feet by 1.9 feet by 3.9 feet). "In the Unite States companies are testing prototypes in customers' houses," he says. Besides the U.S., Japan and Germany are we ll advanced in the technology of reformers. "The electric power companies in Brazil are interested in those devices because of a new niche in the market, the distributed generation, which has been growing in other countries and is expected to grow here as well," he adds. In the distributed generation system, natural gas and fuel residues are used to generate electric power close to where it's consumed. In this model, energy distributors sell or rent small generators to consumers.

The company has one more year left for incubation. That's why it's working on its business plan, in which it will define, with figures, its potential market, how much investment it will need to produce reformers, potential investors, where the plant is going to be located, how much it will produce, etc. One of the ideas is to go to the **Campinas Technology Park**, which is being set up. Camargo says that it's still very difficult to get resources for the research.

The cost of the final product hasn't been estimated yet. In order to make a prototype that produces around 10 cubic meters (353 cubic feet) of hydrogen per hour, the costs today amount to around US$ 113,000, according to Camargo.

The challenges

"Brazil doesn't have a basic development in that area of vital components. We need to import catalysts and some of the materials we need in order to operate in high temperatures, such as special steel and interface components," lists Camargo. Red tape for importing inputs causes delays in the chronogram of tests. HyTron strives to nationalize its technology as much as possible. "Almost 90% of our technology is Brazilian; many of our solutions were developed ourselves in order to nationalize as many items as possible," he comments. But the company can't manufacture internally inputs such as catalysts, which it has to import.

Another critical aspect is to make the company economically viable once it leaves incubation. "The challenge is to make this system feasible to compete with diesel in the future. We'll need to invest in order to gain scale," says Camargo. A policy of government purchases, such as the one United States has, would help. "There the government buys so that the company gains production scale and is able to continue in the market," he points out.

Strategic technology and market on the rise

To become really commercially viable, ethanol reformers depend on the evolution and on the increase in the demand for fuel cells. Doesn't that make HyTron's business unfeasible in the short run? "No, because, in the first place, we believe that the technology of fuel cells is here to stay. And, second, we have the possibility of using ethanol and natural gas reformers to extract other inputs, such as acetic acid and carbon monoxide, which have applications in the chemical sector," answers the physicist and researcher Antônio José Marin Neto, another HyTron partner.

- **The Indian government has announced an ambitious plan to phase in a million hydrogen-fuelled vehicles by 2020. Seventy-five per cent of these vehicles will be two- and three-wheelers, according to the Union ministry of new and renewable energy (mnre). A hydrogen-based power-generating capacity of 1,000 mw and Rs 25,000 crore worth of hydrogen supply infrastructure has been planned to support this plan.**

A steering group of the national hydrogen energy board, set up by the ministry in 2003, drew up the roadmap. It was headed by Ratan Tata, chairperson of the Tata Group, who said, "The national economy could be built on hydrogen as an alternative to fossil fuel. However, it may remain illusive for long-term because there are challenges to generate, store and deliver it."He was optimistic, though, that Indias strength in scientists and humanpower would make the clean fuel a reality, and the group focused on the need for research to make hydrogen viable.

CNG is the bridge India is investigating the potential of running internal combustion (ic) engines on hydrogen as opposed to fuel cell technology (fct) favoured in the West, which Indian industry believes will take longer to develop. M Raja of Tata Motors says that hydrogen can be used sooner in ic engines through adaptation of existing infrastructure.

- **The compressed natural gas (cng) programme in Delhi provides the immediate bridge for transitioning to hydrogen in India. A commercial hydrogen dispensing station will be commissioned in Delhi by March 2009 as a joint project of mnre and Indian Oil Corporation Ltd, dispensing neat hydrogen and cng-blended hydrogen as vehicular fuels for modified cng vehicles. The station will also have hydrogen generation capacity.**

Another jointly-planned two-year project by the ministry and the Society of Indian Automobile Manufacturers will allow introduction of h-cng blends on a trial basis in existing cng vehicles.

Currently, hydrogen use in vehicles is at the demonstration stage, and the industry faces a skills shortage. While several new hydrogen energy and fuel cell r&d projects have been sanctioned, automobile experts are worried about intellectual property rights around the jointly-developed technologies. "Where do we draw the line?" asks Arun Jaura, who heads r&d at Mahindra and Mahindra.

Constraints Hydrogen is expensive to produce because it does not exist freely like other fossil fuels. Production in India is currently limited to the captive requirement of some industries and as a by-product in some chemical industries, and hydrogen production techniques from non-fossil fuels are still being developed. According to V Raghuraman, principal advisor at the Confederation of Indian Industries, "Hydrogen is a non-carbon fuel but it currently comes from carbon-based sources. We need a breakthrough in its production to meet the estimated demand by 2020."

Once hydrogen is produced, vehicles will need effective on-board storage. According to O N Srivastava, coordinator of the Centre of Advance Studies and Hydrogen Energy Center at Benaras Hindu University, "Hydrogen can be stored in gaseous form, as liquid or in the solid state metal hydride form, which acts as a sponge that soaks hydrogen." Srivastava has developed two-wheeler models in which hydrogen is stored in the form of metal hydride, which is safer and non-explosive at room temperature, but this method has poor capacity, making long-distance travel impossible. Other storage methods also have flaws; gas cylinders have poor efficiency, as hydrogen requires large storage volumes at very high pressure (400 atmospheric pressure or more), creating safety concerns. Liquid hydrogen requires cryogenic temperatures (below 150 degrees c) and is currently not viable for road transport.

Cost barrier The present cost of hydrogen is about Rs 240 per kg, which must come down by a factor of three or four for viability, according to the plan, while noting that the sharp rise in petrol prices would make hydrogen more attractive.

While industry has appealed for fiscal incentives, Montek Singh Ahluwalia, deputy chairperson, Planning Commission, is sceptical about subsidy-based programmes."Hydrogen is unlikely to become a plausible solution in energy security if it continues to be subsidised perpetually," he said. Experts say the government should aid the development of a market for hydrogen fuel and also support r&d.

Creating a market for these vehicles will be difficult. Regulatory interventions such as zero-emission laws will be needed. Given the dismal progress of conventional vehicle technology in India, the roadmap for a million hydrogen vehicles in 12 years brings little cheer. Concrete policy initiatives are needed; else, hydrogen vehicles will remain a pipe dream.

India will ply fuel cell (ZEV-Zero Emission Vehicle) buses in coming years. Indian government already proposed 1 million vehicles running on alterante fules in 2020. Taking the initiative forward, Tata Motors and ISRO(Indian Space Research Organisation) plans to build a hydrogen bus by 2010(possibly before the commonwealth games). Tata and ISRO is already working on the project and a prototype is expected to be ready by December 2008. Tata Motors has contributed Rs5 crore to the project, while Isro is spending Rs1 crore in building the prototype. Tata Motors will build the frame and chassis while ISRO will provide expertise for handling(storing) liquid hydrogen. Fuel cell will be imported from canadian firm(possibly Ballard Systems).

India's first hydrogen bus will be a 60-seater proto-model. The bus will roughly cost Rs 80 lakh with per kg of hydrogen gas that will run it costing around Rs 120 per kg or more. A 40-kg cylinder will allow the bus to run 560 km, ie an entire day for a typical metro bus. "In short run it may be costly, but in long run when we are on the verge of hydrocarbon extinction, people will be willing to pay anything. We are working on a bus now because that will be more economical than a car as it would carry 60 people. In Phase II we will come out with a car with lower cost of hydrogen gas. Technological challenge of conversion of gas to electricity is immediate for ISRO now,'' architect of the bus, V Vnanagandhi, programme director, ISRO, Ahmedabad, said.

- Mazda will be leasing its hydrogen-based RX-8 model in Norway from this summer onwards. Norway is a frontrunner with respect to HyNor, a network of H2 refuelling stations. Over the 580 km route between Stavenger and Oslo there are sufficient refuelling stations to allow motorists to commute between these two cities. Mazda has been a partner in the HyNor project since 2007.

The HyNor Partnership and StatoilHydro announced the official opening of the Norwegian hydrogen highway. Since 2003, StatoilHydro has been the driving force behind HyNor's goal to establish a hydrogen transportation infrastructure along the nearly 600 kilometre route between Oslo and Stavanger. The first hydrogen station was opened at Forus in Stavanger in 2006, the second in

Porsgrunn in 2007, and now two new stations have been opened in Oslo and Lier. HyNor has some 50 partners and manages a fleet of more than 50 hydrogen vehicles made by Mazda, Toyota and Think. "As a future clean transport alternative, hydrogen and fuel-cell technology have huge potential. Hydrogen is potentially a game-changing transportation fuel," says Ms Hansen.

- Teams of researchers and scientists in New Mexico are exploring the possibility of using biofuels such as ethanol for fuel cells.

A grant from the Department of Energy's (DoE) EPSCoR programme has brought together research faculties from the University of New Mexico, New Mexico State University, New Mexico Tech and Eastern New Mexico University as well as researchers from Los Alamos National Laboratory and Sandia National Labs to explore the possibility of making usable fuel cells from ethanol.

The grant amounts to US$750,000 per year for up to six years for the research groups, which wish to find out whether ethanol can be reformed to produce hydrogen. If possible, they will build on the results to explore how direct electrochemical oxidation of ethanol might work. The research is expected to result in a new family of materials.

Fuel cells that convert the chemical bonds between hydrogen atoms to energy are about three times more efficient than combustion engines that burn hydrocarbons. And fuel cells powered with pure hydrogen carry out the conversion cleanly.

The trick is finding a cost-effective way to produce hydrogen without polluting the environment.

Researchers from the University of Minnesota and the University of Patras in Greece have devised a way to extract hydrogen directly from ethanol, which would make for a renewable energy cycle. Ethanol is produced by converting biomass like cornstarch to sugar, then fermenting it.

The researchers' method is relatively simple, and an ethanol-to-hydrogen converter designed for home use would be not much larger than a coffee mug, according to Lanny Schmidt, a professor of chemical engineering and materials science at the University of Minnesota.

Historically, there have been two major stumbling blocks to using ethanol as a source for hydrogen. Ethanol is fairly flammable, and the process of extracting hydrogen from ethanol destroys the catalyst traditionally used to extract hydrogen from hydrocarbons like oil.

The University of Minnesota researchers were looking to find a good way to convert ethanol because it packs a lot of energy -- 80 percent that of gasoline -- and is a renewable fuel source. "We tried ethanol," said Schmidt. "And it didn't work for two years."

The researchers eventually solved the flammability problem by using an automotive fuel injector, said Schmidt. "It rapidly vaporizes ethanol water and mixes [it] with air and does this so fast that there's no time for flames to start," he said.

They solved the catalyst problem accidentally, said Schmidt. At first the researchers were using the same rhodium catalyst they'd had success with in extracting hydrogen from diesel fuel and natural gas. This, "forms carbon on the surface and otherwise makes a mess out of things," which destroyed the catalyst within a few hours, said Schmidt. "We... discovered serendipitously that rhodium-ceria as the catalyst had a long life," he said. The researchers are still investigating exactly why the new catalyst works so much better.

The gasoline sold by many service stations around the country is really a mix of ethanol and gasoline, but fuel ethanol must be refined so that it contains no water. The researchers' method not only allows for water to be mixed with ethanol, it extracts some of the hydrogen from the water as well, said Schmidt. This makes producing ethanol for hydrogen potentially cheaper. Ethanol is currently more expensive than gasoline, but the two fuels are in the same realm -- wholesale prices are about $1.10 a gallon versus 70 cents for gasoline, he said.

The researchers' method is relatively simple. "You feed ethanol plus water into the top of a reactor," said Schmidt. The fuel injector vaporizes the fuel and sprays the drops onto a hot surface to make a mixture of mostly ethanol with a little air and water, which hits a catalyst that's glowing bright orange from the heat of the chemical reaction. "That makes hydrogen form very quickly... and that feeds into the fuel cell," he said.

The reactor could be any size depending on the application, said Schmidt. A reactor large enough to extract hydrogen for a washing machine-sized fuel cell designed to power a house could be made as small as a coffee mug, said Schmidt.

The method could be used in practical applications now, said Schmidt. "We'll have the technical capability to switch to a significant extent away from fossil fuels toward renewable fuels, but whether we do... is a political question and an economic question," he said. "It's not cheaper than natural gas or coal... but it's cleaner, and renewable."

Although extracting hydrogen from ethanol produces carbon dioxide, the carbon dioxide is reclaimed by the next year's crop, making for a renewable energy cycle. "If you use biomass as your source of energy instead of fossil fuels, carbon dioxide gets sequestered back into next year's crop," said Schmidt.

Eventually waste products like wood chips, grass clippings and crop wastes could be used to make lower-cost ethanol, said Schmidt. How far down the road this is depends on "when we want to switch to renewable fuels," he said. "Technically we could do it in 10 years."

- The production of hydrogen from biomass by fermentation is one of the routes that can contribute to a future sustainable hydrogen economy. Lignocellulosic biomass is an attractive feedstock because of its abundance, low production costs and high polysaccharide content.

Batch cultures of Caldicellulosiruptor saccharolyticus and Thermotoga neapolitana produced hydrogen, carbon dioxide and acetic acid as the main products from soluble saccharides in Miscanthus hydrolysate. The presence of fermentation inhibitors, such as furfural and 5-hydroxylmethyl furfural, in this lignocellulosic hydrolysate was avoided by the mild alkaline-pretreatment conditions at a low temperature of 75degreesC. Both microorganisms simultaneously and completely utilized all pentoses, hexoses and oligomeric saccharides up to a total concentration of 17 g l-1 in pH-controlled batch cultures. T. neapolitana showed a preference for glucose over xylose, which are the main sugars in the hydrolysate. Hydrogen yields of 2.9 to 3.4 mol H2 per mol of hexose, corresponding to 74 to 85% of the theoretical yield, were obtained in these batch fermentations. The yields were higher with cultures of C. saccharolyticus compared to T. neapolitana. In contrast, the rate of substrate consumption and hydrogen production was higher with T. neapolitana. At substrate concentrations exceeding 30 g l-1, sugar consumption was incomplete, and lower hydrogen yields of 2.0 to 2.4 mol per mol of consumed hexose were obtained.

Efficient hydrogen production in combination with simultaneous and complete utilization of all saccharides has been obtained during the growth of thermophilic bacteria on hydrolysate of the lignocellulosic feedstock Miscanthus. The use of thermophilic bacteria will therefore significantly contribute to the energy efficiency of a bioprocess for hydrogen production from biomass.

- The UN Development Programme , through the Global Environment Facility , the Brazilian Mines and Energy Ministry and the city of São Paulo's Urban Transportation Company, has introduced the first hydrogen-powered bus in São Paulo, one of the world's largest cities. The bus is fueled by water and exudes clean vapor instead of fumes.

The hydrogen-fueled bus technology is already available in four other countries: China, the Netherlands, Japan and the US. Due to the initial investments associated with the technology and the production of hydrogen, this pilot project will not seek to replace the entire fleet, but to assess the hydrogen production infrastructure and the effectiveness of such buses as public transport for large cities.

This first water-powered bus prototype was the result of four years of research and collaboration by a consortium of national and international partners, involving: Brazilian energy companies AES Eletropaulo and Petrobras; bus manufacturers Marcopolo and Tuttotrasporti; Ballard Power Systems and Hydrogenics from Canada; Epri International from the US; and Nucellsys from Germany. The consortium expects to make the technology available to other developing countries.

- Siemens is producing an energy storage system for light rail vehicles that is said to reduce carbon emissions by up to 80 metric tons a year.
  The development is called the Sitras HES, for "hybrid energy storage," intended for trams.

Siemens Mobility's development manager for the new system, Michael Meinert, said trams with so-called hybrid energy storage systems can operate without connecting with the overhead electricity supply wires for up to 2,500 meters. Aside from being aesthetically more promising for the city, Meinert said the trams are more environment-friendly and energy-efficient.

This is because vehicles equipped with an energy storage system can consume up to 30% less energy per year, resulting in a significant reduction in carbon emissions compared with vehicles not using them.

The Sitras HES system consists of two energy-storing components: the Sitras MES unit, for "mobile energy storage," and a nickel-metal hydride battery. The systems are mounted on unused roof surfaces of a tram and electrically connected to the feed-in point of the vehicle. Using a new "autonomous connection" concept, the energy storage system can be directly integrated into new vehicles or built into ones that already exist.

Last year, Siemens Mobility installed a Sitras HES in a tram belonging to the Portuguese company Metro Transportes do Sul S.A. Since November, 2008, the system has been used in passenger service and has proved to be highly successful, the company said.

The redesigned Combino vehicles now operating between Almada and Seixal, two cities to the south of Lisbon, are not only able to travel over distances without being supplied with overhead power, but are also saving energy at the same time, Siemens said.

- National Hydrogen Propulsion Programme (NHPP) is hanging fire. This Rs 700 crore project was to have brought together Tata Motors, Ashok Leyland, M&M, Eicher Motors, Bajaj Auto and TVS Motor Company besides members of the academia and research professionals. But after more than a year of talks, the NHPP is still pending since the Department of Science and Technology is unwilling to give its go ahead. This, despite 50%, or Rs 350 crore, corpus for development of hybrids and fuel cells being borne by the industry.

Another ambitious proposal which seeks to provide 50% subsidy for indigenous development of hybrid technologies is similarly biting dust with the Ministry of New & Renewable Energy (MNRE) for the last three years.

Even some smaller amounts sought by the industry for funding smaller projects to develop hybrids and fuel cells have also been rejected. The Society of Indian Automobile Manufacturers had sought a meagre Rs 5 crore for development of hybrid four-wheelers and another Rs 4 crore for developing hybrid two-wheelers but the government has not agreed to either proposal. Another demand for just Rs 1.5 crore to develop hydrogen fuel cells has also been similarly rejected.

The only projects where government and industry have begun working together are the likes of the 'Hithane' project, which seeks to develop an ideal mix of hydrogen and CNG and do not need any large scale investment from the government's end.

- Team with support of IIMA is working on Technology for hydrogen from Ethanol / CNG / LPG using an auto thermal reforming catalytic converter. This technology is cheapest so far for hydrogen production, apart from power generation, which is long term focus. Undoubtedly there is a vast hydrogen usage in edible oils, sorbitol, hydrogen peroxide, Fertilizers, steel industry, etc apart to Transportation needs which is hung on GOI policy.

Author: Phani Mohan Kancharla
e-mail: phanis.kancharla@gmail.com
Year: 2009