In a hydrogen oxygen fuel cell combustion of hydrogen occurs to

When one looks at various applications, fuel cells have a number of other attributes that makes them more suitable or more desirable for many applications. If one thinks of an automobile, fuel cells are solid state devices, they don't have any moving parts in the fuel cell themselves, therefore, they are inherently a low vibration, low noise device. So it quite obvious that for a number of other reasons besides just environmental reasons that fuel cell powered products will not just be cleaner products but it will ultimately be better ones. Fuel cells are primary energy producers, not just like batteries that are storage devices, that store energy that was produced elsewhere. In other words, fuel cells take up fuel (H) and produce the energy from that fuel. The key issue is fuel infrastructure: Fuel cells are going to use a different fuel (H-gas) than conventional fossil fuel. So the issue of determining what that fuel is going to be and ensuring that when these technologies are in the market place, is something that is very important. The infrastructure of production and distribution will be provided by the energy companies. As H-fuel is still expensive and difficult to transport and store; therefore, the introduction of the H-society will be still a matter of patience, it maybe not before the year 2005. In the meantime, it is much more likely to utilize a hydrocarbon like natural gas or methanol. These would then be treated in a process called "steam reforming"; this releases H which is then used in the fuel cell. What we need is a cheap, clean and sustainable method of separating H from a compound molecule. A team at the University of NSW may have an answer. They found a way of speeding up the water splitting reaction first describe 30yrs ago that uses the mineral "rutile" to decompose water. Rutile is found in sandy beaches and it is another main component in titanium dioxide (TiO_2) or titania. A fuel cell is a device that generates electricity by a chemical reaction. Every fuel cell has two electrodes called, respectively, the anode and cathode. The reactions that produce electricity take place at the electrodes. Every fuel cell also has an electrolyte, which carries electrically charged particles from one electrode to the other, and a catalyst, which speeds the reactions at the electrodes. Hydrogen is the basic fuel, but fuel cells also require oxygen. One great appeal of fuel cells is that they generate electricity with very little pollution–much of the hydrogen and oxygen used in generating electricity ultimately combine to form a harmless byproduct, namely water. One detail of terminology: a single fuel cell generates a tiny amount of direct current (DC) electricity. In practice, many fuel cells are usually assembled into a stack. Cell or stack, the principles are the same. Top How do fuel cells work? The purpose of a fuel cell is to produce an electrical current that can be directed outside the cell to do work, such as powering an electric motor or illuminating a light bulb or a city. Because of the way electricity behaves, this current returns to the fuel cell, completing an electrical circuit. (To learn more about electricity and electric power, visit "Throw The Switch" on the Smithsonian website Powering a Generation of Change.) The chemical reactions that produce this current are the key to how a fuel cell works. There are several kinds of fuel cells, and each operates a bit differently. But in general terms, hydrogen atoms enter a fuel cell at the anode where a chemical reaction strips them of their electrons. The hydrogen atoms are now "ionized," and carry a positive electrical charge. The negatively charged electrons provide the current through wires to do work. If alternating current (AC) is needed, the DC output of the fuel cell must be routed through a conversion device called an inverter. Graphic by Marc Marshall, Schatz Energy Research Center Oxygen enters the fuel cell at the cathode and, in some cell types (like the one illustrated above), it there combines with electrons returning from the electrical circuit and hydrogen ions that have traveled through the electrolyte from the anode. In other cell types the oxygen picks up electrons and then travels through the electrolyte to the anode, where it combines with hydrogen ions. The electrolyte plays a key role. It must permit only the appropriate ions to pass between the anode and cathode. If free electrons or other substances could travel through the electrolyte, they would disrupt the chemical reaction. Whether they combine at anode or cathode, together hydrogen and oxygen form water, which drains from the cell. As long as a fuel cell is supplied with hydrogen and oxygen, it will generate electricity. Even better, since fuel cells create electricity chemically, rather than by combustion, they are not subject to the thermodynamic laws that limit a conventional power plant (see "Carnot Limit" in the glossary). Therefore, fuel cells are more efficient in extracting energy from a fuel. Waste heat from some cells can also be harnessed, boosting system efficiency still further. Top So why can't I go out and buy a fuel cell? The basic workings of a fuel cell may not be difficult to illustrate. But building inexpensive, efficient, reliable fuel cells is a far more complicated business. Scientists and inventors have designed many different types and sizes of fuel cells in the search for greater efficiency, and the technical details of each kind vary. Many of the choices facing fuel cell developers are constrained by the choice of electrolyte. The design of electrodes, for example, and the materials used to make them depend on the electrolyte. Today, the main electrolyte types are alkali, molten carbonate, phosphoric acid, proton exchange membrane (PEM) and solid oxide. The first three are liquid electrolytes; the last two are solids. The type of fuel also depends on the electrolyte. Some cells need pure hydrogen, and therefore demand extra equipment such as a "reformer" to purify the fuel. Other cells can tolerate some impurities, but might need higher temperatures to run efficiently. Liquid electrolytes circulate in some cells, which requires pumps. The type of electrolyte also dictates a cell's operating temperature–"molten" carbonate cells run hot, just as the name implies. Each type of fuel cell has advantages and drawbacks compared to the others, and none is yet cheap and efficient enough to widely replace traditional ways of generating power, such coal-fired, hydroelectric, or even nuclear power plants. The following list describes the five main types of fuel cells. More detailed information can be found in those specific areas of this site. Top Different types of fuel cells. Drawing of an alkali cell. Alkali fuel cells operate on compressed hydrogen and oxygen. They generally use a solution of potassium hydroxide (chemically, KOH) in water as their electrolyte. Efficiency is about 70 percent, and operating temperature is 150 to 200 degrees C, (about 300 to 400 degrees F). Cell output ranges from 300 watts (W) to 5 kilowatts (kW). Alkali cells were used in Apollo spacecraft to provide both electricity and drinking water. They require pure hydrogen fuel, however, and their platinum electrode catalysts are expensive. And like any container filled with liquid, they can leak. Drawing of a molten carbonate cell Molten Carbonate fuel cells (MCFC) use high-temperature compounds of salt (like sodium or magnesium) carbonates (chemically, CO_3) as the electrolyte. Efficiency ranges from 60 to 80 percent, and operating temperature is about 650 degrees C (1,200 degrees F). Units with output up to 2 megawatts (MW) have been constructed, and designs exist for units up to 100 MW. The high temperature limits damage from carbon monoxide "poisoning" of the cell and waste heat can be recycled to make additional electricity. Their nickel electrode-catalysts are inexpensive compared to the platinum used in other cells. But the high temperature also limits the materials and safe uses of MCFCs–they would probably be too hot for home use. Also, carbonate ions from the electrolyte are used up in the reactions, making it necessary to inject carbon dioxide to compensate. Phosphoric Acid fuel cells (PAFC) use phosphoric acid as the electrolyte. Efficiency ranges from 40 to 80 percent, and operating temperature is between 150 to 200 degrees C (about 300 to 400 degrees F). Existing phosphoric acid cells have outputs up to 200 kW, and 11 MW units have been tested. PAFCs tolerate a carbon monoxide concentration of about 1.5 percent, which broadens the choice of fuels they can use. If gasoline is used, the sulfur must be removed. Platinum electrode-catalysts are needed, and internal parts must be able to withstand the corrosive acid. Drawing of how both phosphoric acid and PEM fuel cells operate. Proton Exchange Membrane (PEM) fuel cells work with a polymer electrolyte in the form of a thin, permeable sheet. Efficiency is about 40 to 50 percent, and operating temperature is about 80 degrees C (about 175 degrees F). Cell outputs generally range from 50 to 250 kW. The solid, flexible electrolyte will not leak or crack, and these cells operate at a low enough temperature to make them suitable for homes and cars. But their fuels must be purified, and a platinum catalyst is used on both sides of the membrane, raising costs. Drawing of a solid oxide cell Solid Oxide fuel cells (SOFC) use a hard, ceramic compound of metal (like calcium or zirconium) oxides (chemically, O_2) as electrolyte. Efficiency is about 60 percent, and operating temperatures are about 1,000 degrees C (about 1,800 degrees F). Cells output is up to 100 kW. At such high temperatures a reformer is not required to extract hydrogen from the fuel, and waste heat can be recycled to make additional electricity. However, the high temperature limits applications of SOFC units and they tend to be rather large. While solid electrolytes cannot leak, they can crack. More detailed information about each fuel cell type, including histories and current applications, can be found on their specific parts of this site. We have also provided a glossary of technical terms–a link is provided at the top of each technology page. Top ©2017 Smithsonian Institution (Copyright Statement) You will find out: > about the chemical reaction that takes place in a fuel cell > about exothermic reactions > about energy-level diagrams Why are fuel cells less polluting? Petrol, used in a car engine, comes from a fossil fuel. It burns in oxygen to make carbon dioxide. Increased carbon dioxide levels have been linked with climate change. It is thought to contribute to global warming. Fuel cells use hydrogen as a fuel. Water is made as the only product. Hydrogen reacts with oxygen to make water. In this reaction, the reactants are hydrogen and oxygen. When they react, the product is water. The word equation for this reaction is: hydrogen + oxygen → water The reaction between hydrogen and oxygen is exothermic. This means that energy is given out. The hydrogen-oxygen fuel cell uses the energy released from the reaction to produce electrical energy efficiently. You may remember the reaction between hydrogen and oxygen that you have tested before. Look at Figure 4. Do you remember the squeaky pop? In a fuel cell, this reaction takes place in a sealed chamber. The waste gas is water vapour. Figure 4: The exothermic reaction between hydrogen and oxygen. Questions 13. Why is oxygen gas needed in the fuel cell? 14. What type of reaction happens when hydrogen gas and oxygen react. 15. In a fuel cell, what type of energy is transferred out of the cell? 16. Why is a fuel cell less polluting than an engine burning petrol? A fuel on its own will not make a fuel cell work. The energy is only released when the fuel reacts with oxygen in air. A reaction which gives out energy is exothermic. If the fuel cell uses hydrogen, the reaction is: hydrogen + oxygen → water When hydrogen reacts with oxygen by burning, the chemical energy is given out as heat. A fuel cell converts chemical energy directly into electrical energy – there is no heat. $2H_2 + O_2 \rightarrow 2H_2O$ with electrons being exchanged from the cathode to the anode. Other fuels, such as methanol, are also being tried. Figure 5: Fuel cells come in different sizes. Some are small, some much bigger. Questions 17. What does the fuel react with in a fuel cell? 18. What is the name for chemical reactions that give out energy? 19. Methanol is a liquid. Suggest one advantage of using liquid fuels to recharge the batteries in laptop computers. 20. Methanol contains carbon. Suggest one disadvantage of using methanol as a large-scale fuel. The fuel and oxygen have chemical energy inside them. When the fuels react, some of the chemical energy is given out. This leaves less chemical energy inside the chemicals. This is shown in an energy-level diagram. > The hydrogen forms an H^+ ion at the catalyst releasing an electron at the negative electrode. This is the reaction: This is an oxidation reaction. The electrons move through the wire, while the ions travel through the electrolyte. > The ions are reduced while reacting with oxygen, the positive electrode in the fuel cell takes in the electrons: This is a reduction reaction. A reaction where electrons are gained and lost is called a redox reaction. Figure 6: A simple energy-level diagram. What type of energy change is shown in this diagram? Figure 7: Diagram of a fuel cell. What happens at the negative and positive electrodes? Questions 21. Draw a labelled energy-level diagram for the combustion of hydrogen. 22. What happens to the amount of chemical energy in a reaction that gives out heat? 23. Why should the electrodes be made from metal? 24. The fuel in a fuel cell is oxidised. Use one of the half equations to explain why. Used in fuel cells or internal combustion engines Hydrogen fuel is a zero carbon fuel burned with oxygen. It can be used in fuel cells or internal combustion engines (see HICEV). Regarding hydrogen vehicles, hydrogen has begun to be used in commercial fuel cell vehicles, such as passenger cars, and has been used in fuel cell buses for many years. It is also used as a fuel for spacecraft propulsion. In the early 2020s, most hydrogen is produced by steam methane reforming of fossil gas. Only a small quantity is made by alternative routes such as biomass gasification or electrolysis of water[1][2] or solar thermochemistry,[3] a solar fuel with no carbon emissions. Hydrogen is found in the first group and first period in the periodic table, i.e. it is the lightest and first element of all. Since the weight of hydrogen is less than air, it rises in the atmosphere and is therefore rarely found in its pure form, H_2.[4] In a flame of pure hydrogen gas, burning in air, the hydrogen (H_2) reacts with oxygen (O_2) to form water (H_2O) and releases energy. $2H_2 (g) + O_2 (g) \rightarrow 2H_2O (g) + energy$ If carried out in atmospheric air instead of pure oxygen, as is usually the case, hydrogen combustion may yield small amounts of nitrogen oxides, along with the water vapor. The energy released enables hydrogen to act as a fuel. In an electrochemical cell, that energy can be used with relatively high efficiency. If it is used simply for heat, the usual thermodynamics limits on the thermal efficiency apply. Hydrogen is usually considered an energy carrier, like electricity, as it must be produced from a primary energy source such as solar energy, biomass, electricity (e.g. in the form of solar PV or via wind turbines), or hydrocarbons such as natural gas or coal.[5] Conventional hydrogen production using natural gas induces significant environmental impacts; as with the use of any hydrocarbon, carbon dioxide is emitted.[6] At the same time, the addition of 20% of hydrogen (an optimal share that does not affect gas pipes and appliances) to natural gas can reduce CO_2 emissions caused by heating and cooking.[7] Production Main article: Hydrogen production Because pure hydrogen does not occur naturally on Earth in large quantities, it usually requires a primary energy input to produce on an industrial scale.[8] Hydrogen fuel can be produced from methane or by electrolysis of water.[9] As of 2020, the majority of hydrogen (~95%) is produced from fossil fuels by steam reforming or partial oxidation of methane and coal gasification with only a small quantity by other routes such as biomass gasification or electrolysis of water.[1][2][10] Steam-methane reforming, the current leading technology for producing hydrogen in large quantities,[11] extracts hydrogen from methane. However, this reaction releases fossil carbon dioxide and carbon monoxide into the atmosphere which are greenhouse gases exogenous to the natural carbon cycle, and thus contribute to climate change.[4] In electrolysis, electricity is run through water to separate the hydrogen and oxygen atoms. This method can use wind, solar, geothermal, hydro, fossil fuels, biomass, nuclear, and many other energy sources.[5] Obtaining hydrogen from this process is being studied as a viable way to produce it domestically at a low cost. Shinzo Abe tours the FH2R facility in March 2020 The world's largest facility for producing hydrogen fuel is claimed[12] to be the Fukushima Hydrogen Energy Research Field (FH2R), a 10MW-class hydrogen production unit, inaugurated on 7 March 2020, in Namie, Fukushima Prefecture.[13] The site occupies 180,000 square meters of land, much of which is occupied by a solar array; but power from the grid is also used to conduct electrolysis of water to produce hydrogen fuel.[12] Production is usually classed in terms of colour; 'grey hydrogen' is produced as a by-product of an industrial process, 'blue hydrogen' is produced through a production process where CO_2 is also produced then subsequently captured via CCS, and finally 'green hydrogen' is produced entirely from renewable sources. Energy Hydrogen is locked up in enormous quantities in water, hydrocarbons, and other organic matter. One of the challenges of using hydrogen as a fuel comes from being able to extract hydrogen efficiently from these compounds. Now, steam reforming, which combines high-temperature steam with natural gas, accounts for the majority of the hydrogen produced.[14] This method of hydrogen production occurs at temperatures between 700-1100 °C, and has a resultant efficiency of between 60-75%.[15] Hydrogen can also be produced from water through electrolysis, which is less carbon intensive if the electricity used to drive the reaction does not come from fossil-fuel power plants but rather renewable or nuclear energy instead. The efficiency of water electrolysis is between about 70-80%,[16][17] with a goal set to reach 82-86% efficiency by 2030 using proton exchange membrane (PEM) electrolyzers.[18] Once produced, hydrogen can be used in much the same way as natural gas - it can be delivered to fuel cells to generate electricity and heat, used in a combined cycle gas turbine to produce larger quantities of centrally produced electricity or burned to run a combustion engine; all methods producing no carbon or methane emissions.[19] In each case hydrogen is combined with oxygen to form water. This is also one of its most important advantages as hydrogen fuel is environmentally friendly. The heat in a hydrogen flame is a radiant emission from the newly formed water molecules. The water molecules are in an excited state on initial formation and then transition to a ground state; the transition releasing thermal radiation. When burning in air, the temperature is roughly 2000 °C (the same as natural gas). Historically, carbon has been the most practical carrier of energy, as hydrogen and carbon combined are more volumetrically dense, although hydrogen itself has three times the energy density per mass as methane or gasoline. Although hydrogen is the smallest element and thus has a slightly higher propensity to leak from venerable natural gas pipes such as those made from iron, leakage from plastic (polyethylene PE100) pipes is expected to be very low at about 0.001%.[20][21] The reason steam methane reforming has traditionally been favoured over electrolysis is because whereas methane reforming directly uses natural gas, electrolysis requires electricity. As the cost of producing electricity (via wind turbines and solar PV) falls below the cost of natural gas, electrolysis becomes cheaper than SMR.[22] Uses Main article: Hydrogen economy Hydrogen fuel can provide motive power for liquid-propellant rockets, cars, trucks, trains, boats and airplanes, portable fuel cell applications or stationary fuel cell applications, which can power an electric motor.[23] The problems of using hydrogen fuel in cars arise from the fact that hydrogen is difficult to store in either a high pressure tank or a cryogenic tank.[24] Alternative storage media such as within complex metal hydrides are in development. In general batteries are more suitable for vehicles the size of cars or smaller, but hydrogen may be better for larger vehicles such as heavy lorries.[25] Hydrogen fuel can also be used to power stationary power generation plants, or provide an alternative to natural gas for heating applications. Fuel cells Main article: Fuel cell vehicle Fuel cells present the most attractive choice for energy conversion from hydrogen directly towards electricity, due to their high efficiency, low noise, and limited number of moving parts. Fuel cells are of interest for both stationary and mobile power generation from hydrogen. Fuel cells are often considered as part of a vehicle propulsion system. Using a fuel cell to power an electrified powertrain including a battery and an electric motor is two to three times more efficient than using a combustion engine, although some of this benefit is related to the electrified powertrain (i.e. Including regenerative braking). This means that much greater fuel economy is available using hydrogen in a fuel cell, compared to that of a hydrogen combustion engine. Internal combustion engine conversions to hydrogen Main article: Hydrogen internal combustion engine vehicle Alongside mono-fuel hydrogen combustion, combustion engines in commercial vehicles have the potential to be converted to run on a hydrogen-diesel mix. This has been demonstrated in prototypes in the UK, where up to 40% of CO_2 emissions have been reduced during normal driving conditions.[26] This dual-fuel flexibility eliminates range anxiety as the vehicles can alternatively fill up only on diesel, when no hydrogen refuelling is available. Relatively minor modifications are needed to the engines, as well as the addition of hydrogen tanks at a compression of 350 bars.[27] Trials are also underway to test the efficiency of the 100% conversion of a Volvo FH16 heavy-duty truck to use only hydrogen. The range is expected to be 300 km/17 kg;[28] which means an efficiency better than a standard diesel engine[29] (where the embodied energy of 1 gallon of gasoline is equal to 1 kilogram of hydrogen). Compared to conventional fuels, if a low cost price for hydrogen (€5/kg),[30] significant fuel savings could be made via such a conversion in Europe or the UK. A lower price would be needed to compete with diesel/gasoline in the US, since these fuels are not exposed to high taxes at the pump. Combustion engines using hydrogen are of interest since the technology offers a less substantial change to the automotive industry, and potentially a lower up-front cost of the vehicle compared to fully electric or fuel cell alternatives. However, the non -zero emission nature of the engine means it will not be able to operate in city zero emission zones, unless part of a hybrid powertrain.[citation needed] Drawbacks Although hydrogen has a high energy content per unit mass, at room temperature and atmospheric pressure it has a very low energy content per unit volume, compared to liquid fuels or even to natural gas. For this reason it is usually either compressed or liquefied by lowering its temperature to less than 33 K. High-pressure tanks weigh much more than the hydrogen they can hold. For example in the 2014 Toyota Mirai, a full tank contains only 5.7% hydrogen, the rest of the weight being the tank.[31] Hydrogen fuel is hazardous because of the low ignition energy and high combustion energy of hydrogen, and because it tends to leak easily from tanks.[32] Explosions at hydrogen filling stations have been reported.[33] Hydrogen fuelling stations generally receive deliveries of hydrogen by truck from hydrogen suppliers. An interruption at a hydrogen supply facility can shut down multiple hydrogen fuelling stations.[34] See also Fuel cell vehicle HCNG Hydrogen compressor Hydrogen safety Hydrogen storage Hydrogen technologies Hydrogen vehicle Oxyhydrogen flame Photocatalytic water splitting to isolate hydrogen Synthetic fuel References Notes ^ a b Roberts, David (2018-02-16). "This company may have solved one of the hardest problems in clean energy". Vox. Retrieved 2019-10-30. ^ a b Ogden, J.M. (1999). "Prospects for building a hydrogen energy infrastructure". 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