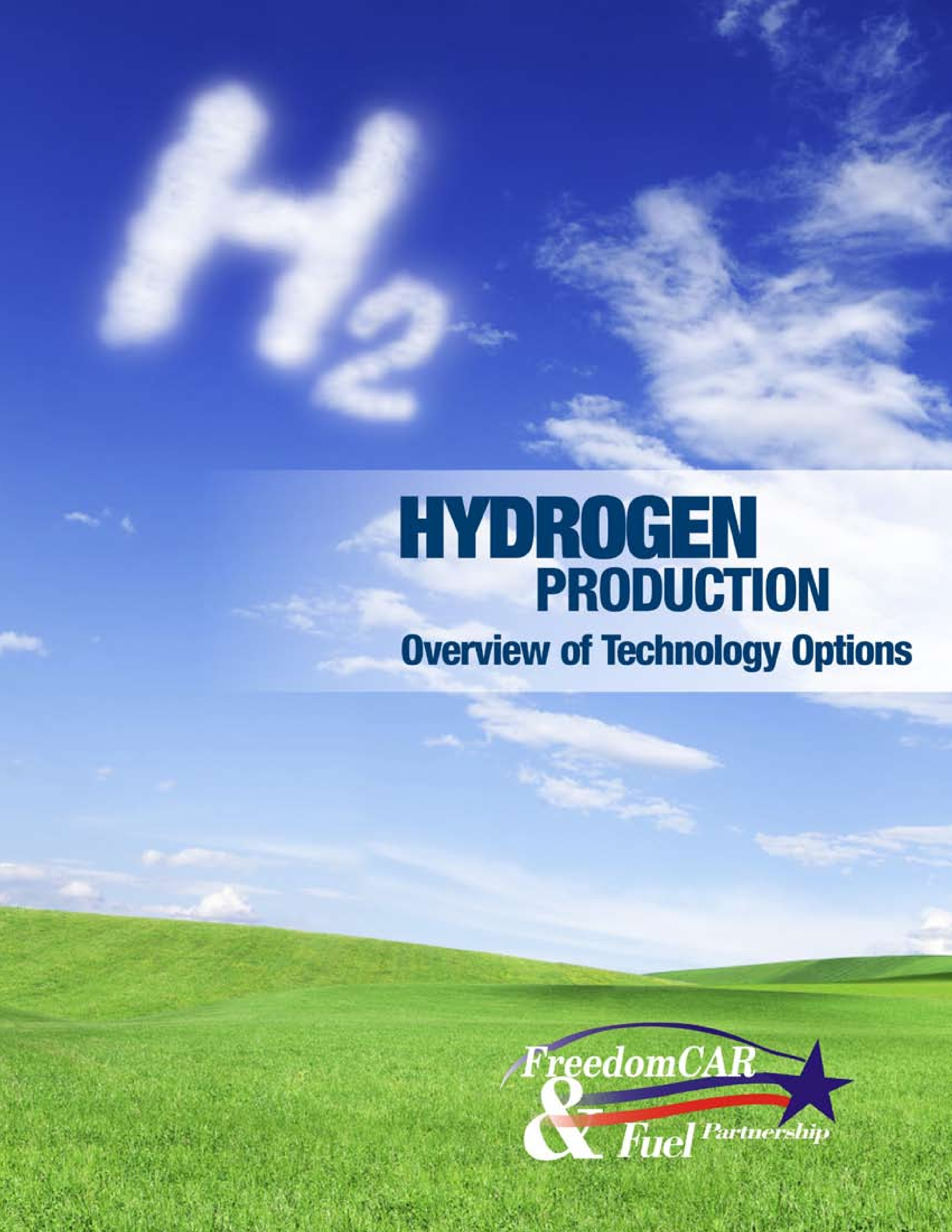

HYDROGEN PRODUCTION

Overview of Technology Options

FreedomCAR & Fuel Partnership

Hydrogen offers sustainable solutions to our nation's energy and climate challenges.

Hydrogen provides a pathway for energy diversity. It can store the energy from diverse domestic resources (including clean coal, nuclear, and intermittently available renewables) for use in mobile applications and more.

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Energy Security

Hydrogen-powered vehicles could significantly reduce imports of foreign oil.

Sustainability

Hydrogen production technologies can potentially take advantage of abundant renewable energy resources (e.g., solar, wind, geothermal, hydroelectric).

Climate Change

Vehicles produce near-zero carbon emissions when operating on hydrogen produced from renewable resources, nuclear energy, or fossil energy with carbon capture and storage.

Urban Air Quality

Hydrogen can reduce or eliminate regulated tailpipe emissions (e.g., hydrocarbons, carbon monoxide, nitrogen oxides).

Economic Vitality

The United States can secure a share of future global energy markets by leading the development and commercialization of hydrogen and fuel cell technology.

Producing Hydrogen

Delivering the potential for clean, safe, affordable, and secure energy from abundant domestic resources*

Hydrogen can increase America's energy security.

Vehicles operating on hydrogen can dramatically reduce our nation's dependence on oil and significantly reduce tailpipe emissions. Hydrogen offers a potential means to store and deliver energy from abundant, domestically available resources—while reducing our nation's carbon footprint.

Hydrogen is the most abundant element on Earth.

However, it does not exist naturally in its molecular form. It must be produced from other sources or "feedstocks" such as water, biomass, or fossil fuels. The technologies for producing pure hydrogen from these feedstocks also require energy to power the production process.

Researchers are working to produce hydrogen economically from diverse sources. Sustainable production technologies offer exciting possibilities for the future. Meanwhile, hydrogen produced from fossil fuels (like natural gas) can help to build early markets and infrastructure. The ability to generate hydrogen from a variety of feedstocks using diverse energy sources makes hydrogen a particularly promising energy carrier.

Collaborative partnerships are accelerating technology advances. By working together, government and industry can expedite progress in improving the efficiency and economics of hydrogen production. **The FreedomCAR & Fuel Partnership** brings together the U.S. Department of Energy (DOE), the major U.S. car manufacturers, energy companies, and utilities in advancing research and development (R&D) to enable high-volume production of affordable hydrogen-powered vehicles and their supporting infrastructure. The Partnership's Hydrogen Production Technical Team has identified the R&D needs for seven key hydrogen production technologies in the *Hydrogen Production Roadmap: Technology Pathways to the Future.*

* *Including renewable resources, nuclear energy, and coal with carbon capture and storage.*

Location and scale of production affect consumer cost.

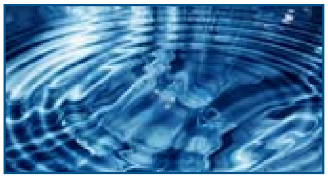
The location and scale of hydrogen production technologies affect hydrogen cost, competitiveness, and timeframe to market.

Distributed Production

Technologies deigned to produce hydrogen on-site at refueling stations will have an economic edge in early markets. Such technologies will use locally available feedstocks and power in compact systems. In the near-term, they may use existing utilities and infrastructure. In remote locations, they may be useful on an ongoing basis.

Central Production

Ultimately, large-scale production at centralized sites will produce the economies of scale needed to achieve low-cost hydrogen. Centralized production, of course, requires an efficient, low-cost delivery infrastructure, which is still in development.



Potential for clean, low-cost hydrogen from a range of domestic resources

Hydrogen Differs from Conventional Fuels

Hydrogen is non-toxic. It is also non-poisonous and will cause no ill effect if inhaled with ambient air.

Hydrogen is odorless, colorless, and tasteless. It is thus undetectable by human senses.

Hydrogen is highly combustible. Leaks are easily ignited yet the hydrogen gas diffuses rapidly into nonflammable concentrations when released to an open environment.

It will not contaminate groundwater. Under normal atmospheric conditions, hydrogen is a gas with a very low solubility in water.

Hydrogen is not a pollutant. A release of hydrogen is not known to contribute to atmospheric or water pollution.

Industry considers these properties when designing structures where hydrogen is used or stored and provides redundant safety systems, including sensors and ventilation.

Hydrogen Production Technologies

The *Hydrogen Production Roadmap* explores **seven promising technology options** for producing hydrogen.

Development of clean, sustainable, and cost-competitive hydrogen production processes is essential to the market success of hydrogen-powered vehicles. The seven key production technologies fall into three broad categories: thermal, electrolytic, and photolytic processes.

Thermal Processes

One type of thermal process uses the energy stored in such resources as coal or biomass to simply release the hydrogen contained within their molecular structures. Another type uses heat in combination with closed chemical cycles to produce hydrogen from feedstocks, such as water; these are known as "thermochemical" processes.

- Distributed Natural Gas Reforming
- Bio-Derived Liquids Reforming
- Coal and Biomass Gasification
- Thermochemical Production
  (Using a Heat-Driven Chemical Reaction to Split Water)

Electrolytic Processes

Water electrolysis uses electricity to split water into hydrogen and oxygen. Hydrogen produced via electrolysis can result in zero greenhouse gas emissions, depending on the source of the electricity used.

- Water Electrolysis
  (Splitting Water Using Electricity)

Photolytic Processes

Photolytic processes use light energy to split water into hydrogen and oxygen. Currently in the very early stages of research, these processes offer long-term potential for sustainable hydrogen production with low environmental impact.

- Photoelectrochemical Hydrogen Production
  (Using Solar Power to Directly Split Water)
- Biological[1] Hydrogen Production
  (Photobiological Water Splitting)

[1] *Includes other biological approaches that are not strictly photolytic*

Technology Summaries

Only by developing and deploying a range of technologies as they move from research into commercial readiness will we ultimately arrive at the sustainable energy solution we seek. This chart provides a broad overview of the challenges and research needed for each of seven hydrogen production technologies. A far more detailed treatment of these topics is available in the *Hydrogen Production Roadmap* produced by the Hydrogen Production Technical Team.

The following pages summarize some of the key challenges common to these technologies and provide a snapshot of each technology today. Further research will help to identify the most sustainable technologies for America's energy future.

	Distributed Natural Gas Reforming	Bio-Derived Liquids Reforming	Coal and Biomass Gasification
Critical Challenges	▪ High capital costs ▪ High operation and maintenance costs ▪ Design for manufacturing	▪ High capital costs ▪ High operation and maintenance costs ▪ Design for manufacturing ▪ Feedstock quantity and quality	▪ High reactor costs ▪ System efficiency ▪ Feedstock impurities ▪ Carbon capture and storage
Major R&D Needs	▪ Improve catalyst efficiency and reduce costs ▪ Develop low-cost, efficient separation/purification ▪ Combine unit operations to increase cost effectiveness ▪ Improve feedstock pre-treatment ▪ Optimize operations to meet variable demand ▪ Develop flexible, modular reformer designs using low-cost materials ▪ Automate process control ▪ Increase equipment reliability ▪ Minimize energy losses and level demand	▪ Increase hydrogen yield and efficiency ▪ Develop catalysts to enable use of low temperatures or the liquid phase ▪ Develop low-cost, efficient separation/purification ▪ Optimize operations to meet variable demand ▪ Develop flexible, modular reformer designs using low-cost materials ▪ Devise economical way to characterize biomass ▪ Identify best feedstock candidates by region ▪ Assure hydrogen quality across feedstocks ▪ Match feedstock pretreatment to required purity	▪ Develop low-cost, efficient separation/purification ▪ Improve catalyst tolerance of impurities ▪ Develop more efficient and robust components for entire system ▪ Reduce cost of biomass feedstock storage, preparation, and handling ▪ Develop effective approaches to carbon capture and storage ▪ Develop economical way to monitor hydrogen quality ▪ Develop biomass/coal co-fed gasifiers ▪ Increase quantity of affordable biomass
Key Benefits	▪ Most viable approach to begin building hydrogen market in near term ▪ Lowest current cost ▪ Existing feedstock infrastructure	▪ Most viable renewable hydrogen pathway in the near term ▪ Existing infrastructure for some feedstocks	▪ Provides low-cost synthetic fuel in addition to hydrogen ▪ Uses abundant and affordable coal feedstock

Hydrogen Production Technologies

Thermochemical

Critical Challenges

- Cost-effective reactor
- Effective and durable materials of construction
- Longer-term technology

Major R&D Needs

- Develop robust, low-cost materials for solar receivers, chemical cycles, reactors, and thermal storage
- Design easy-to-manufacture, low-cost reactors and receivers
- Optimize thermal and chemical storage system designs to address variable solar power availability and lower total costs
- Develop designs for high-volume, low-cost manufacturing of flexible, modular equipment and components
- Develop efficient heat transfer for chemical cycle

Key Benefits

- Produces hydrogen using only water, energy from the sun or nuclear reactors, and chemicals that are recycled.
- Clean and sustainable

Water Electrolysis

Critical Challenges

- Low system efficiency and high capital costs
- Integration with renewable energy sources
- Design for manufacturing

Major R&D Needs

- Develop more durable and less expensive membranes
- Develop long-lasting membranes and corrosion-resistant interconnects
- Develop durable, low-cost, and active catalysts
- Design novel architectures for large-scale production
- Balance storage and production rate capacity for variable demand
- Develop flexible, scalable systems using lower-cost materials
- Increase reliability for high-temperature units
- Develop novel, more efficient drier technologies
- Develop efficient water conditioning systems

Key Benefits

- Produces virtually no pollution with renewable energy sources
- Uses existing infrastructure
- Uses fuel cell advances

Photo-electrochemical

Critical Challenges

- Effective photocatalyst material
- Low system efficiency
- Cost-effective reactor
- Longer-term technology

Major R&D Needs

- Develop durable, effective photocatalysts and electron transfer catalysts
- Develop multifunctional materials available in large quantities at low cost
- Develop highly active, stable, durable materials for supports, coatings, etc.
- Develop manufacturing techniques to assure uniform quality
- Optimize high-volume production design to lower costs
- Automate system control, increase equipment reliability, and minimize energy losses
- Decrease parasitic power losses

Key Benefits

- Operates at low temperatures
- Clean and sustainable — using only water and solar energy

Biological

Critical Challenges

- Efficient microorganisms for sustainable production
- Optimal microorganism functionality in a single organism
- Reactor materials
- Longer-term technology

Major R&D Needs

- Develop microorganism functionality for efficient and sustainable production
- Identify and characterize new microbes
- Develop inexpensive methods to grow and maintain microbes
- Develop low-cost, durable materials with specialized properties for use in bioreactors
- Optimize system to manage variable production and manage diurnal cycles
- Design manufacturing processes for high-volume production at low cost

Key Benefits

- Clean and sustainable
- Tolerant of diverse water conditions
- Self-sustaining

Challenges and Research Needs

Common technical hurdles for most production technologies

While each hydrogen production technology faces specific technical challenges, some common hurdles exist for most of the technology options. Government and industry are investing in research, development, and demonstration activities to address these challenges and pave the way for successful commercialization and widespread use of hydrogen as an energy carrier.

Hydrogen Quality:

Purity is a major issue for any hydrogen intended for use in fuel cells aboard vehicles. The problem arises because the platinum catalysts used in most vehicle fuel cells can be easily "poisoned" by impurities in the hydrogen, ultimately reducing catalyst effectiveness. Hydrogen production technologies must therefore either produce high-purity hydrogen outright or incorporate additional purification processes.

Capital and Operating Costs:

Today's capital costs for many hydrogen production technologies are substantially higher than those for other fuels. Developers are working to reduce these costs by applying the principles of "design for manufacture," identifying better materials, decreasing the number of necessary parts, designing simplified systems, and moving into mass production. Operating costs should also decline as equipment developers identify improved materials, consolidate processing steps, reduce maintenance and labor requirements, and otherwise enhance equipment performance and integration.

Education and Regulatory Issues:

The inspection, testing, certification, and permitting necessary to move new hydrogen production technologies into commercial use will require regulations, codes, and standards to be established or significantly amended at federal, state, and local levels. This process will require extensive outreach to familiarize regulatory agencies with the technologies and to educate the public and local safety officials.

Safety and Control:

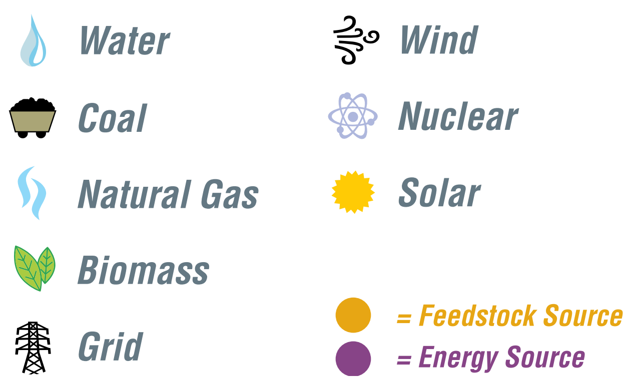
Like gasoline or natural gas, hydrogen must be handled appropriately. The characteristics of hydrogen are different from those of other common fuels, but it can be used as safely when guidelines are observed.

Hydrogen Production Technologies

All hydrogen production technologies will be required to meet the strictest safety requirements. The permitting process demands proven reliability and safeguards. Production units for placement at fueling stations, in particular, must be designed to operate without manual assistance. This capability will require use of back-up and fail-safe modes, remote monitoring capability, exception-based reporting, and infrequent maintenance.

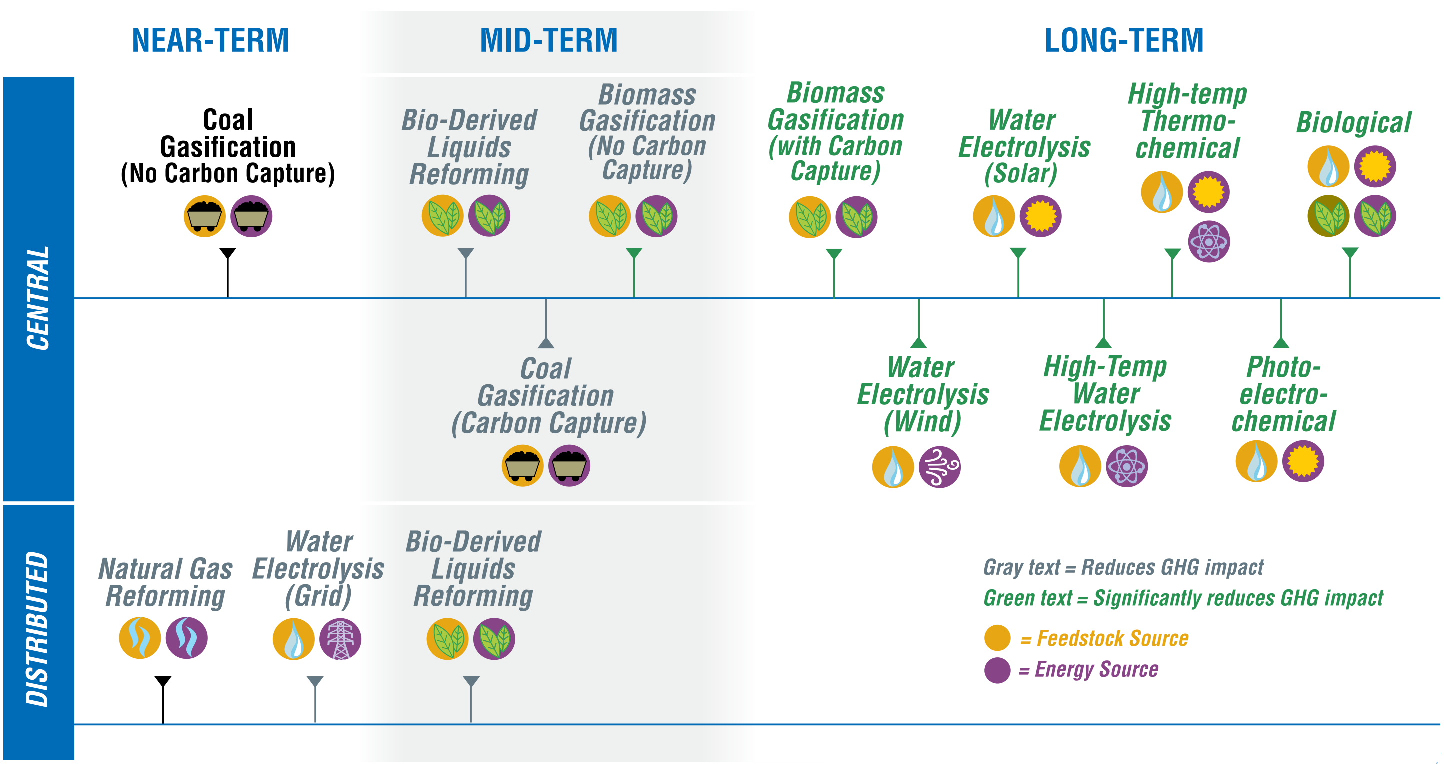
Timing of R&D: The specific challenges for each production technology and the research needed to address them are described in detail in the *Hydrogen Production Roadmap*. The timeline below provides a broad overview of the general timeframe in which these technologies may be expected to move into commercial production.

Production Technology Icon and Color Key:



Timeframes To Market

Some technology options necessarily appear at more than one location along this timeline as market readiness is affected by the specific feedstock, energy source, and production scale.



Distributed Natural Gas Reforming

Near-term energy and carbon advantages

Most hydrogen today is produced through natural gas reforming at large refineries.

Feedstock:	Natural gas
Energy Source:	Natural Gas
Production:	Distributed

Near Term

Mid Term

Long Term

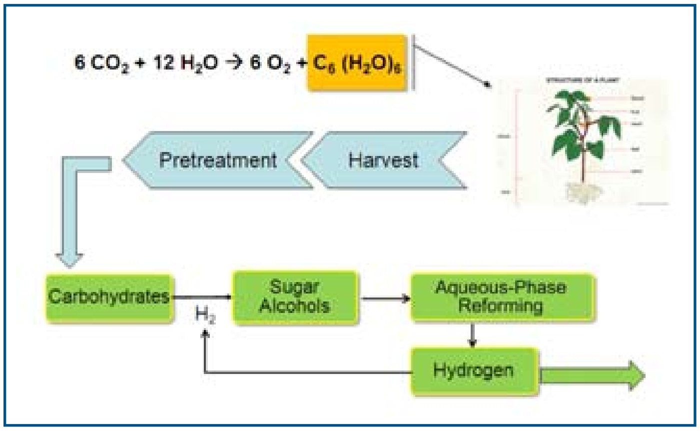
Most viable near-term option: Natural gas reforming at fueling stations offers the most viable approach to moving hydrogen into vehicle markets in the near term. These early markets will help to build the infrastructure needed to expand the use of hydrogen in the United States.

Scale-down of a mature technology: This technology uses high-temperature steam to reform the methane in natural gas into hydrogen and carbon dioxide. Steam reforming of natural gas has been used commercially for many years in large, centralized industrial facilities. The challenge of this option is to scale down the equipment so that it operates cost-effectively in a distributed mode at fueling stations.

An interim solution: The Hydrogen Production Technical Team and DOE consider this production technology as an interim option only because it will raise U.S. demand for natural gas and still release some carbon dioxide. DOE's near-term, technical and projected cost targets for this technology have been met; market success will require the private sector to conduct additional work on system integration, optimization, and technology validation.

Bio-Derived Liquids Reforming

Potential to tap diverse domestic biomass feedstock supply



Aqueous-phase reforming may offer an efficient way to produce hydrogen from sugar alcohols derived from a broad variety of potential biomass feedstocks.

Feedstock:	Biomass
Energy Source:	Biomass
Production:	Distributed Semi-Central

Near Term

Mid Term

Long Term

Reforming with greater efficiency: Liquids derived from biomass can be reformed into hydrogen using high-temperature technologies similar to those used to reform natural gas. However, some bio-derived liquids also offer the potential to use lower-temperature reforming processes, which would greatly improve system efficiency and decrease reformer cost. Researchers are also exploring a variation of this technology known as aqueous-phase reforming.

Improving hydrogen yield: All of these technologies may potentially use a variety of bio-liquid feedstocks, such as sugars, sugar alcohols (like ethanol), bio-oils, and less-refined sugar streams (such as cellulose from non-edible plants). Researchers are trying to find better catalysts to improve the hydrogen yield of these technologies.

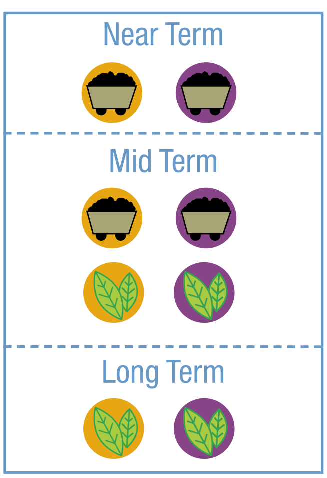
Gateway to wide-ranging biomass feedstocks: For the near term, ethanol may be the most viable bio-liquid for reforming—as it is already widely available. In the long term, reformers may be able to accept a range of biomass resources available in any particular region throughout the year. Eventually, it may be possible to process biomass directly into hydrogen without first converting it to a liquid.

Coal and Biomass Gasification

Combining feedstocks to offset challenges posed by either coal or biomass alone

Some utilities are exploring biomass gasification as a cleaner and more effecient way to meet growing demand for electricity.

Feedstock:	Coal Biomass
Energy Source:	Coal Biomass
Production:	Semi-Central Central



Versatile modern gasifiers: The gasification process can break down almost any carbon-based feedstock into its chemical parts. Modern gasifier systems expose coal or biomass to hot steam and controlled amounts of air or oxygen under high pressures and temperatures. Under these conditions, the molecules break apart, setting off chemical reactions that produce carbon monoxide mixed with smaller amounts of hydrogen and other gaseous compounds. The carbon monoxide can then be subjected to a water-gas shift (WGS) process to produce hydrogen.

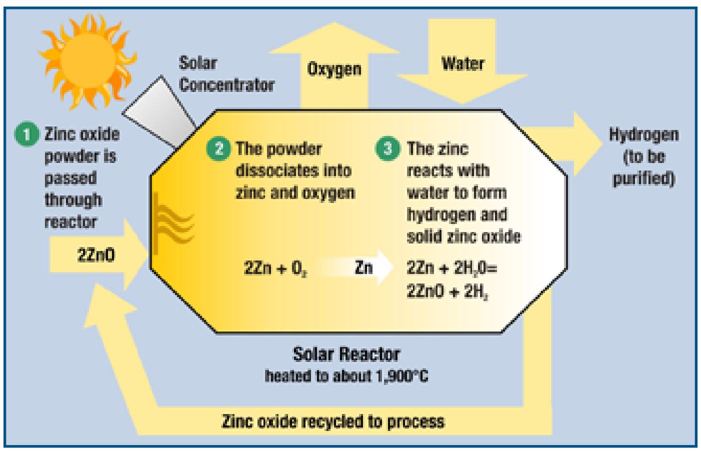
Carbon and productivity vs. cost and supply: Coal gasifiers are now in commercial use to produce power, chemicals, and synthetic fuels, but they generate substantial amounts of carbon dioxide (CO_2). The challenges are to optimize the system for hydrogen production, develop downstream processes, and develop better, lower-cost methods to capture and store the carbon. Gasification of biomass instead of coal would minimize carbon impacts, but biomass cost and supply issues would present other challenges.

Cleaner production through co-gasification: Gasification technologies can use coal or biomass as feedstock, or a combination of the two simultaneously. Co-gasification of coal and biomass helps to address both the carbon issues related to coal and the cost and supply issues related to biomass.

Thermochemical Production

(Using a Heat-Driven Chemical Reaction To Split Water)

Concentrating solar energy to drive an efficient process



One closed chemical cycle uses zinc oxide and solar energy to make hydrogen.

Feedstock:	Water
Energy Source:	Solar Nuclear
Production:	Semi-Central Central

Near Term

Mid Term

Long Term

Sustainable, closed-loop process: Solar energy can be concentrated with mirrors focusing on a special lens to generate temperatures close to 2,000°C. These temperatures can be used to trigger a series of chemical reactions that split water molecules to produce hydrogen without generating any harmful emissions. Since the chemicals used are recycled, this proposed process consumes only water and produces only hydrogen and oxygen. The high temperatures enable extremely fast reaction rates that significantly accelerate production.

Multiple pathways to study: Researchers have identified more than 300 possible chemical reaction cycles for analysis and are in the process of selecting the most promising for further development and demonstration. This technology is relatively immature and requires extensive research in basic chemistry and materials. DOE is also developing similar thermochemical processes designed to use the waste heat from nuclear plants.

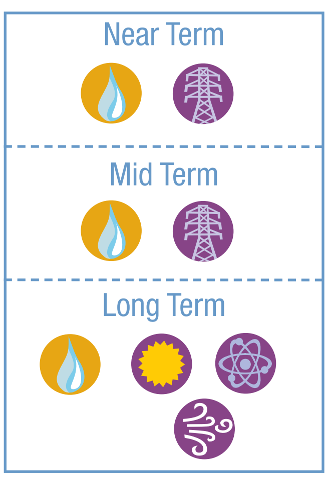
Materials challenge: Many of the chemical reaction cycles under study involve corrosive chemicals at high temperatures. The economic feasibility of this production pathway relies on the identification of materials with sufficient corrosion resistance under these process conditions. Potential candidate classes of materials include refractory metals, reactive metals, super alloys, ceramics, polymers, and coatings.

Water Electrolysis (Splitting Water Using Electricity)

High sustainability potential

Using wind power or waste heat from nuclear reactors would generate hydrogen without emitting greenhouse gases.

Feedstock:	Water
Energy Source:	Grid Wind Solar Nuclear
Production:	Distributed Semi-Central Central



Clean with renewables: A promising way to produce hydrogen is by splitting water using electricity (electrolysis). This involves passing an electric current through the water to split it into hydrogen and oxygen. Electrolysis is less efficient than a direct chemical path but offers virtually no pollution or toxic byproducts if the electric current is generated using renewable energy (including geothermal and hydropower).

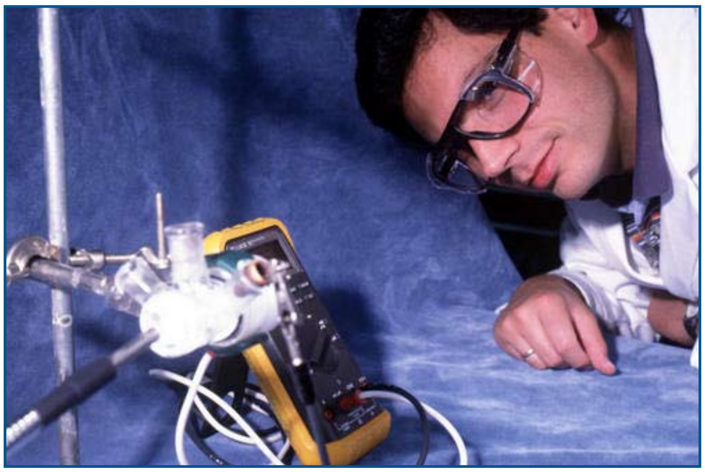
Carbon and cost hurdles: Low-temperature water electrolysis is a process that takes up relatively little space and can use the existing water and electricity infrastructure. For these reasons, this option could be used to make hydrogen on-site at fueling stations in the near term. The major drawbacks to this technology are the cost of electricity and uncertain impacts on carbon emissions, which depend on the energy sources used by the utilities.

Long-term strategy: In the long term, renewable-powered water electrolysis (e.g., wind or solar) at central or semi-central facilities could overcome these challenges. These facilities may take advantage of technology advances or receive cost breaks from the utilities by using "off-peak" power. Water electrolysis facilities at centrally located nuclear plants could produce hydrogen using heat from the reactors. This high-temperature process would require a third less electricity than low-temperature electrolysis.

Photoelectrochemical Hydrogen Production

(Using Solar Power to Directly Split Water)

Direct use of low-temperature solar energy



Researchers focus light on a semiconductor immersed in water to directly split water into hydrogen and oxygen.

Feedstock:	Water
Energy Source:	Solar
Production:	Semi-Central Central

Near Term

Mid Term

Long Term

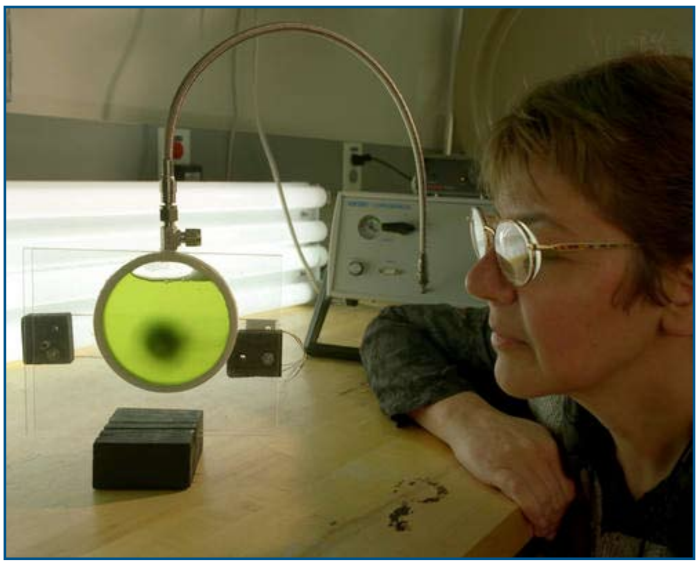
One-step process: Hydrogen can be produced directly from water using sunlight and a special class of semiconductor materials. These highly specialized semiconductors absorb sunlight and use the light energy to completely separate water molecules into hydrogen and oxygen.

Development of high-performance materials: This technology requires a material that is both highly durable and highly efficient at photoelectrochemical hydrogen production. Scientists have identified some materials that split water efficiently and others that offer high durability, but the search continues for a material that meets both of these criteria. Researchers are currently working to discover photoelectrochemical materials and coatings that can efficiently convert a wide spectrum of light—yet remain stable when they come into contact with electrolytes.

Future solutions: Scientists are exploring a range of approaches to solve the materials hurdles, including use of nanomaterial coatings, metal doping, and various hybrid materials. Photoelectrochemical water splitting is in the very early stages of reserach, but offers long-term potential for sustainable hydrogen production with low environmental impact.

Biological Hydrogen Production

Harnessing naturally occurring biological processes



Scientists are pursuing innovative ways to improve photolytic hydrogen production in green algae. Specifically, they are working to increase both the oxygen tolerance of critical enzymes and algae's efficiency at harvesting light.

Feedstock:	Water Biomass
Energy Source:	Solar Biomass
Production:	Semi-Central Central

Near Term

Mid Term

Long Term

Scientists are finding ways to harness natural biological processes that convert and store the energy of sunlight as renewable hydrogen. Metabolic pathways for the generation of hydrogen are found in microorganisms such as unicellular green algae, cyanobacteria, photosynthetic bacteria, and in some forms of dark fermentative bacteria. Optimizing biological hydrogen production requires understanding the enzymatic pathways through which hydrogen is formed at the molecular level. Scientists are exploring four or five main pathways.

Photolytic Biological Production from Water:

This conversion pathway produces hydrogen by using sunlight and specialized microorganisms, such as green algae and cyanobacteria, to split water. Just as plants produce oxygen from photosynthesis, these microbes consume water and produce hydrogen as a byproduct of their natural metabolic processes. Photolytic conversion holds great promise for the long term, but major challenges remain.

A key challenge is that the oxygen produced along with the hydrogen tends to accumulate and impede the work of the hydrogen-evolving enzymes. Researchers are searching for more oxygen-tolerant enzymes and also exploring new genetic forms of the organisms that sustain hydrogen production in the presence of oxygen. An alternative approach uses a metabolic switch (sulfur deprivation) to cycle algal cells back and forth between phases for photosynthetic growth and hydrogen production.

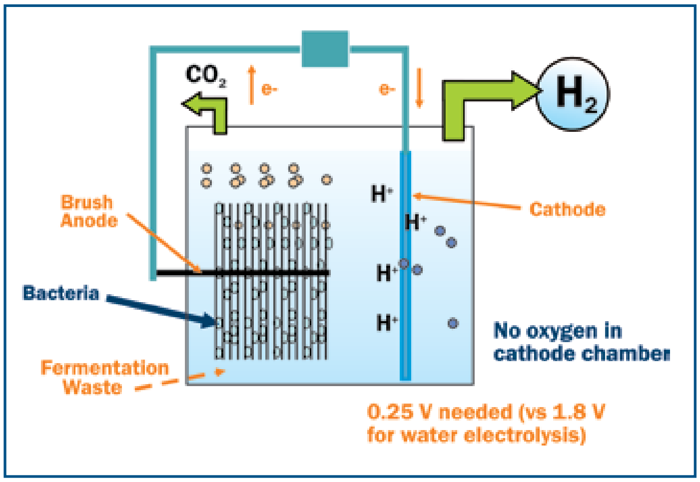
Another challenge is that the chlorophyll in microalgae under bright sunlight absorbs photons at a far faster rate than they can be used in photosynthesis—wasting up to 80% of the photon energy. Researchers are using molecular genetics along with new diagnostic tools to find ways for sunlight to penetrate deeper into the microalgae culture. Success would enable more cells to perform useful photosynthesis—increasing solar conversion efficiency and hydrogen productivity.

Photosynthetic Bacterial Production: Sunlight is the driver for bacteria to break down organic material, thus releasing hydrogen. Purple, non-sulfur bacteria with a specialized enzyme can produce hydrogen gas when exposed to near-infrared light energy.

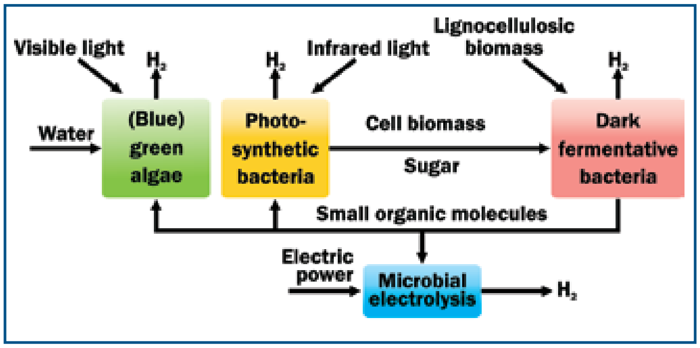
Dark Fermentative Production: Bacteria can act on organic material and decompose it into hydrogen and other byproducts without the aid of sunlight. This process uses anaerobic bacteria that grow in the dark on carbohydrate-rich substrates. These bacteria break down biomass, which is relatively inexpensive, plentiful, and high in carbohydrate content. Researchers are working to identify specific strains of bacteria that can directly and efficiently ferment organic material (or cellulose) to hydrogen. Researchers will then develop mutations that selectively block the generation of waste acids and solvents that reduce ongoing hydrogen productivity.

Microbial-aided Electrolysis: Microbial electrolysis cells use bacteria to efficiently extract energy from organic matter. As the bacteria decompose the organic materials, they produce a low voltage at the anode. Hydrogen is produced at the fully submerged cathode with the input of a tiny amount of additional energy. Optimizing the environment to expedite this natural process could potentially produce hydrogen with much greater efficiency than standard electrolysis.

Combination: Perhaps the most promising biological production pathway incorporates some or all of these technologies into a single system. This integrated approach could alleviate the need to overcome all barriers to individual technologies, as long as the overall system is cost-competitive. Integrated systems may use the byproducts of some production pathways as inputs to others in a nearly closed-loop system that produces hydrogen at each stage.



Microbial electrolysis cells use bacteria to break up acetic acid from plant waste and produce hydrogen gas using a bit of added electricity. The process produces more than 250% more energy than the electricity required to extract it.



A system using multiple biological processes can provide internally generated feedstock and produce hydrogen at each step.

Next Steps

Energy prices, supply uncertainties, and climate concerns are intensifying the need for diverse forms of energy from sustainable domestic resources. Guided by the *Hydrogen Production Roadmap*, the FreedomCAR & Fuel Partnership and the DOE Hydrogen Program are working with researchers in national laboratories, universities, and industry to accelerate the development and commercial readiness of hydrogen production technologies and the supporting infrastructure.

The hydrogen initially available at consumer fueling stations will help to establish the markets, standards, and infrastructure. As research progresses, the technologies used to produce the hydrogen are expected to shift toward those that produce no net greenhouse gas emissions.

While some of the hydrogen production technologies now under development may be supplanted by competing or improved approaches, a variety of production technologies are likely to find long-term use in regions that offer an abundance of their required feedstock and renewable energy resource. Fuel costs to consumers will gradually decrease as these technologies and the delivery infrastructure are optimized and grow to maturity.

Ultimately, hydrogen represents an important component of our national strategy to diversify energy resources. The *Hydrogen Production Roadmap* is helping to align public and private R&D priorities and technology investments to accelerate progress in bringing this clean, domestic energy carrier into widespread use. For more information on the technologies, please visit our website at www.hydrogen.energy.gov

The nozzle used for refueling a hydrogen fuel cell vehicle is designed to form a seal around the filler pipe rather than function as a spout.

Disclaimer

January 2009

The FreedomCAR and Fuel Partnership is a public-private partnership between the U.S. Department of Energy; five major energy producers, including BP America, Chevron Corporation, ConocoPhillips, ExxonMobil Corporation, and Shell Hydrogen LLC; USCAR, whose members include Chrysler, Ford, and General Motors; and two major utilities – DTE Energy and Southern California.

The Partnership envisions a clean and sustainable transportation energy future that reduces our nation's dependence on foreign oil and minimizes regulated emissions and CO_2, yet preserves freedom of mobility and vehicle choice for consumers.

The Partnership's Hydrogen Production Technical Team works closely with the DOE Hydrogen, Fuel Cells & Infrastructure Technologies (HFCIT) Program, which is the lead federal agency for directing and integrating activities in hydrogen production, storage, and delivery with transportation and stationary fuel cell activities. The Hydrogen Production Tech Team provides guidance to DOE's hydrogen production activities:

- Identifying technical goals
- Clarifying R&D needs
- Establishing technical performance targets
- Monitoring progress