

# The Undeniable Realities of the Hydrogen Economy in the United States

## Index

### A

ammonia, 5  
author, 1  
    howard@fuelcell-info.com, 1, 34, 38

### B

balance of payments, 29  
biomass, 10

### C

California Fuel Cell Partnership, 27, 38  
captive hydrogen, 6, 22, 24  
carbon dioxide, 16, 27, 28, 30  
carbon nano structures, 19, 20, 32, 36  
    nano applications, 20, 36  
    nano fibers, 19  
    nano powders, 19  
    nano structures glossary, 20, 36  
    nano tubes, 19  
carbon sequestration, 28, 30, 31, 38  
chemical hydride, 19, 20  
coal, 10, 27, 28, 30, 34, 38  
commentary, 33  
commodity, 22, 32  
conclusions, 29  
contracts, 6, 13, 22, 24, 32  
cost competitive, 30, 32, 33  
cost structure, 22  
cradle-to-grave, 33  
crude oil, 17

### D

defense, 29  
delivery cost, 24  
DoE, 19, 23, 26, 28, 29, 30, 31, 34, 36, 38

### E

electricity, 11, 12, 13, 14, 15, 18, 23, 25, 27,  
    30, 31, 32, 33, 34  
electrolysis, 5, 11, 12, 13, 15, 18, 29, 30, 32,  
    34, 35  
electrolyzer, 12, 13  
    PEM, 12  
    Proton Energy HOGEN H2 Generator, 12, 35  
    proton exchange membrane, 12  
    Stuart Energy Electrolyzer Platforms, 12, 35  
    United Technologies SPE H2 Generator, 12, 35  
    Vandenborre H2 Generator, 12, 35  
    Water2Fire H2 Generator, 12, 35  
Energy Vision, 26, 38  
environmental, 6, 14, 30, 31, 33  
EU, 25, 27  
European initiatives, 25

### F

feedstock, 10, 11, 23, 24, 27, 29, 32, 34  
Figures  
    Figure\_01 H2 Industrial Uses, 5  
    Figure\_02 H2 Specification Summary, 5  
    Figure\_03 H2 Distribution Model, 6, 7  
    Figure\_04 H2 MSDS, 8  
    Figure\_05 H2 Production & Distribution Model,  
        8, 9  
    Figure\_06 H2 Production Methods &  
        Feedstocks, 10  
    Figure\_07 H2 Product Grade and Use, 10, 24  
    Figure\_08 Electrolyzer Manufacturers and  
        Products, 12  
    Figure\_09 H2 Storage Technologies & Their  
        Applications, 19  
    Figure\_10 Natural Gas Production 1970-2001,  
        22  
    Figure\_11 Natural Gas Annual Energy Outlook  
        2003, 23, 24  
    Figure\_12 European Initiatives, 25  
    Figure\_13 American Initiatives, 26  
    Figure\_14 State Initiatives, 27  
    Figure\_15 National Hydrogen Vision – Key  
        Driver Analysis, 27, 29, 30  
    Figure\_16 The Undeniable Realities of the  
        Hydrogen Economy, 29, 31, 32  
foreign oil, 17  
fossil fuel, 5, 28, 30, 31, 33, 34  
fossil fuels, 5, 30, 31, 33, 34  
fuel cell, 4, 13, 17, 24, 25, 26, 27, 31, 37, 38  
fuel oil, 6, 32

### G

gas quality see product grade, 10  
gasification, 13, 30, 35  
    hyperlinks, 13, 35  
gasoline, 6, 17, 31, 32  
geo-terror, 31, 33  
global warming, 27, 29  
greenhouse gases, 17

### H

high sulfur crude oil, 17  
hydrogen consumer, 7  
hydrogen cost factors, 24  
hydrogen demand, 6  
    market, 6  
hydrogen distribution, 6, 7  
hydrogen distributor, 7  
hydrogen economy, 6, 27, 28, 29, 31, 33  
hydrogen feedstocks, 8, 31  
    biomass, 10  
    coal, 10, 27, 28, 30, 34, 38  
    crude oil, 17  
    gasoline, 6, 17, 31, 32

# The Undeniable Realities of the Hydrogen Economy in the United States

- high sulfur crude oil, 17
- high sulfur fuel oil, 10
- LLMW, 15, 36
- low level mixed waste, 10, 15, 36
- methanol, 5, 10, 16, 26, 38
- municipal waste, 10, 15
- natural gas, 6, 10, 14, 16, 17, 22, 23, 24, 27, 28, 30, 31, 32, 33, 34
- petroleum coke, 10
- propane, 10, 16
- water, 5, 11, 12, 13, 14, 15, 16, 17, 18, 21, 32, 34
- hydrogen fuels
  - compressed hydrogen, 8, 19, 20, 35
  - hydrogen slurry, 19, 20
  - liquid hydrogen, 19, 21, 24, 32
- hydrogen gas, 12, 16, 20
- hydrogen internal combustion engine, 27
- hydrogen price, 22, 24
- hydrogen pricing, 14
- hydrogen producer, 8, 22
- hydrogen production, 8, 10, 13, 18, 22, 24, 26, 27, 32
  - electrolysis, 5, 11, 12, 13, 15, 18, 29, 30, 32, 34, 35
  - gasification, 13, 30, 35
  - natural gas, 6, 10, 14, 16, 17, 22, 23, 24, 27, 28, 30, 31, 32, 33, 34
  - photocatalytic, 17, 18
  - pyrolysis, 14, 34
  - steam reforming, 16
  - thermochemical water splitting, 18
- hydrogen purification, 11, 35
  - pressure swing adsorption (PSA), 11
  - QuestAir, 11, 35
- hydrogen purity
  - see product grade, 35
- hydrogen roadmap
  - Europe, 19, 25, 27, 31, 33, 37
  - hydrogen infrastructure, 27
  - national energy vision, 26, 38
  - state initiatives, 25, 26, 27
- hydrogen safety, 7
  - Material Safety Data Sheets, 7, 8
  - MSDS, 5, 8
- hydrogen specification, 5, 35
- hydrogen storage, 19, 20, 21, 25, 29, 32, 33, 34, 36
  - canisters, 7
  - carbon nano structures, 19
  - chemical hydride, 19, 20
  - compressed gas, 7
  - compressed hydrogen, 8, 19, 20, 35
  - cylinder, 22, 24
  - liquid hydrogen, 19, 21, 24, 32
  - metal hydride, 19, 21, 32, 36
  - water, 5, 11, 12, 13, 14, 15, 16, 17, 18, 21, 32, 34
- hydrogen transport, 21
  - pipeline, 7, 10, 21, 22, 24, 27, 32
  - railcar, 10, 21, 24
  - ship, 10, 24, 28
  - truck, 7, 10, 21, 24
  - tube trailer, 24, 33
- hydrogen uses
  - ammonia production, 5
  - detergent production, 5
  - explosives production, 5
  - fertilizer production, 5
  - food processing, 5
  - gasoline production, 6, 17, 31, 32
  - glass production, 5
  - hydrogenated oils production, 5
  - lacquer production, 5
  - lubricant production, 5, 8
  - metallurgy, 5
  - methanol production, 5, 10, 16, 26, 38
  - paint production, 5
  - pharmaceuticals, 5
  - refrigeration, 5
  - semiconductor processing, 5
  - solvent production, 5, 8
  - space flight, 5
  - welding, 5
- Hyperlink Directory, 4, 29, 34, 35
- hyperlinks, 4, 25
  - Air Gas, 8, 35
  - Air Liquide, 8, 35
  - Air Products, 8, 35
  - author howard@fuelcell-info.com, 4, 6, 38
  - BCC Hydrogen Market Report, 6, 35
  - BOC, 8, 35
  - Breakthrough Technologies, 37
  - California Fuel Cell Partnership, 27, 38
  - Carbon Sequestration, 28, 38
  - Congressional Email Addresses, 38
  - Connecticut Innovations, 27, 38
  - Days of Shock and Awe About to Hit the Natural Gas and Power Markets Part 1, 23, 37
  - Discussion Group, 38
  - DoE Task 17, 19, 36
  - Energy Conversion Devices, 21, 36
  - European Commission Interim Report, 37
  - European Fuel Cell Group Ltd, 25, 37
  - European Union, 25, 31, 33, 37
  - EyeForFuels Cells, 25, 37
  - FIBA H2 Storage & Transportation Equipment, 22, 37
  - FuelCell-info Publishing, 1, 37
  - FuelCellPath, 26, 38
  - FuelCellToday, 25, 37
  - Gasification Industry Organization, 13, 35
  - General Atomic Presentation on Nuclear Hydrogen, 18, 36
  - General Hydrogen, 21, 36
  - Governors of the United States, 38
  - H2 Production as Nuclear Energy Application, 18, 36
  - Historical Natural Gas Data, 22, 37
  - Hydrogen Energy Center, 26, 38
  - Hydrogen Political Action Committee, 5, 35
  - Hydrogen Supply Cost Estimate for Hydrogen Pathways, 24, 37

# The Undeniable Realities of the Hydrogen Economy in the United States

IEA Hydrogen Program Publications, 25, 37  
International Carbon, Inc., 19, 36  
International Energy Agency (IEA), 37  
Linde Gas Group, 8, 35  
Low Level Mixed Waste, 15, 36  
Massachusetts Technology Collaborative, 27, 38  
Matheson Tri-Gas, 8, 35  
Metal Hydride Database, 21, 36  
Methanol Institute, 38  
Millennium Cell, 21, 36  
Nano Structures Glossary, 20, 36  
National Hydrogen Association, 38  
Natural Gas Annual Energy Outlook 2003, 23, 37  
NETL Gasification Technologies, 13, 35  
New Mexico Solar Assn, 11, 35  
nexAir Gas Technologies, 22, 37  
Praxair Compressed Hydrogen MSDS, 8, 35  
Praxair H2 Purity & Specifications, 10, 35  
Praxair Hydrogen Specification Sheet, 5, 35  
Praxair Liquid Hydrogen MSDS, 8, 35  
Properties and Perspectives Of Nano Applications, 20, 36  
Proton Energy HOGEN H2 Generator, 12, 35  
Proton Energy Systems, 12, 35  
Pyrolysis Information, 10, 14, 35  
QuestAir H2 Purification Devices, 11, 35  
Remco Engineering, 13, 35  
Safe Hydrogen, 21, 36  
Senate Committee on Energy and Natural Resources, 38  
Solar Hydrogen Production, 19, 36  
State Agencies and Organizations, 27, 38  
Steam Reforming of Natural Gas, 16, 36  
Stuart Energy Electrolyzer Platforms, 12, 35  
Survey of the Economics of Hydrogen Technologies Report, 20, 24, 36, 37  
Terrorism and Oil, 29, 38  
The Chemistry Behind Combustion, 16, 36  
The Michigan Renewables Energy Program, 27, 38  
Total Economic Impact Analysis, 24, 28  
United States Department of Energy, 19, 26, 38  
United Technologies SPE H2 Generator, 12, 35  
Vandenborre H2 Generator, 12, 35  
Water2Fire H2 Generator, 12, 35  
World Fuel Cell Council, 37

## I

IEA, 25, 37  
industrial consumption, 22  
infrastructure, 13, 20, 21, 22, 24, 26, 27, 31, 32  
International Energy Agency, 37  
introduction, 4, 5, 11, 35

## L

liquid hydrogen, 19, 21, 24, 32

long term contracts, 22  
low level mixed waste, 10, 15, 36

## M

Material Safety Data Sheets, 7, 8  
merchant hydrogen, 6, 7, 24  
metal hydride, 19, 21, 32, 36  
methanol, 5, 10, 16, 26, 38  
MSDS, 5, 8  
municipal waste, 10, 15

## N

National Energy Roadmap, 31, 33, 38  
National Energy Vision, 4, 25, 26, 31, 33, 38  
natural gas, 6, 10, 14, 16, 17, 22, 23, 24, 27, 28, 30, 31, 32, 33, 34  
nuclear energy, 18  
nuclear reactors, 18, 31, 32

## O

Ocean Thermal Energy Conversion, 15, 36  
oil, 10, 14, 17, 23, 27, 28, 30, 31  
open source, 33, 34  
OTEC, 15, 32  
outreach organizations  
Breakthrough Technologies, 37  
California Fuel Cell Partnership, 27, 38  
Connecticut Innovations, 27, 38  
European Fuel Cell Group Ltd, 25, 37  
European Union, 25, 31, 33, 37  
EyeForFuels Cells, 25, 37  
FuelCell-info Publishing, 1, 37  
FuelCellPath, 26, 38  
FuelCellToday, 25, 37  
Hydrogen Energy Center, 26, 38  
International Energy Agency, 37  
Methanol Institute, 38  
National Hydrogen Association, 38  
State Agencies and Organizations, 27, 38  
United States Department of Energy, 19, 26, 38  
World Fuel Cell Council, 37

## P

paradigm shift, 33  
PEM, 12  
petroleum coke, 10  
photocatalytic, 17, 18  
photos of storage & transportation equipment, 22, 37  
planning, 28, 33, 34  
planning models, 34  
pressure swing adsorption (psa), 11  
price, 6, 22, 24, 26, 30, 31, 32, 33, 38  
product grade, 10  
3.0 Industrial Use, 10  
4.5 Total Organic Carbon, 10

# The Undeniable Realities of the Hydrogen Economy in the United States

4.5 Zero, 10  
5.0 Semiconductor Process Gas, 10  
5.0 Ultra High Purity, 10  
5.5 Research, 10, 15, 16, 36  
5.5 Semiconductor Process Gas, 10  
6.0 Semiconductor Process Gas, 10  
propane, 10, 16, 27  
proton exchange membrane, 12  
purity level  
    see product grade, 10, 11  
pyrolysis, 14, 34

## R

renewable energy, 6, 14, 16, 25, 26, 27, 29, 33, 38  
renewable energy economy, 33  
renewable hydrogen, 5, 26  
renewable resources, 33  
    reverse osmosis, 13, 35  
    Remco Engineering, 13, 35  
Roadmap, 26, 29, 30, 31, 38

## S

see carbon sequestration, 28, 29, 38  
solar, 14, 15, 17, 18, 30, 32, 33, 34  
solar energy, 17, 18, 34  
stakeholders  
    California Fuel Cell Partnership, 27, 38  
    Congressional Email Addresses, 38  
    Department of Transportation, 8  
    DoE, 19, 23, 26, 28, 29, 30, 31, 34, 36, 38  
    DOT, 5, 8  
    Environmental Protection Agency, 8  
    EPA, 5, 6, 8

Governors of the United States, 38  
House Committee on Energy and Commerce, 38  
hydrogen consumer, 7  
IEA, 25, 37  
International Energy Agency, 37  
Occupational Safety and Health Administration, 8  
OSHA, 8  
Senate Committee on Energy and Natural Resources, 38  
standard cubic feet (scf), 7, 12, 22, 24, 33  
steam reforming, 16  
syngas, 13  
synthesis gas, 13

## T

thermochemical water splitting, 18  
traded commodity, 24  
tube trailers, 21, 24

## V

vittrification definition, 15

## W

water, 5, 11, 12, 13, 14, 15, 16, 17, 18, 21, 32, 34  
water purification, 13, 35  
    reverse osmosis, 13, 35  
water splitting, 18, 34  
wind, 14, 15, 30, 32