Hydrogen: The Future of Energy?

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Hydrogen Ventures

Whittier Sunrise Rotary

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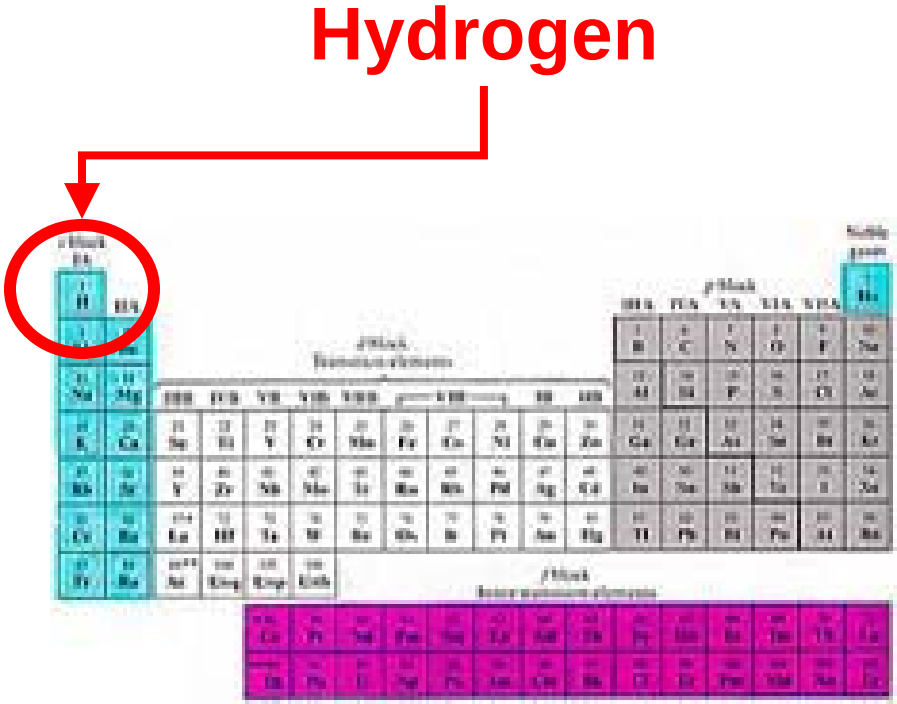
Facts About Hydrogen Today

- **Where does it come from?**
- **Amount Produced**
- **Total Market Value**
- **Key Markets and Uses**



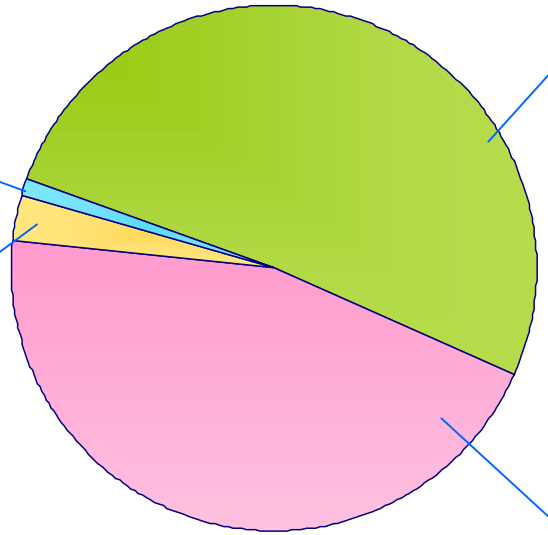
Facts About Hydrogen Today

- ***Where does hydrogen come from?***
- **Hydrogen is abundant**
  - **Accounts for 70 percent of the known universe**
  - **On Earth, however, it is a distant 10th place**
    - **Still, very easy to find!**
  - **Produced mainly from natural gas**
  - **Other sources:**
    - **Electrolysis of water**
    - **Byproduct of chemicals production**

Facts About Hydrogen Today

- ***How much is made?***

- **World production (2001): 540 billion m^3/y**
- **Excluding ammonia production: 260 billion m^3/y**



Ammonia
51%

Others
<1%

Chemicals
3%

Refining
45%

This includes only hydrogen produced for sale

Total production estimated at ten times as much

(*Source: Air Liquide*)

Facts About Hydrogen Today

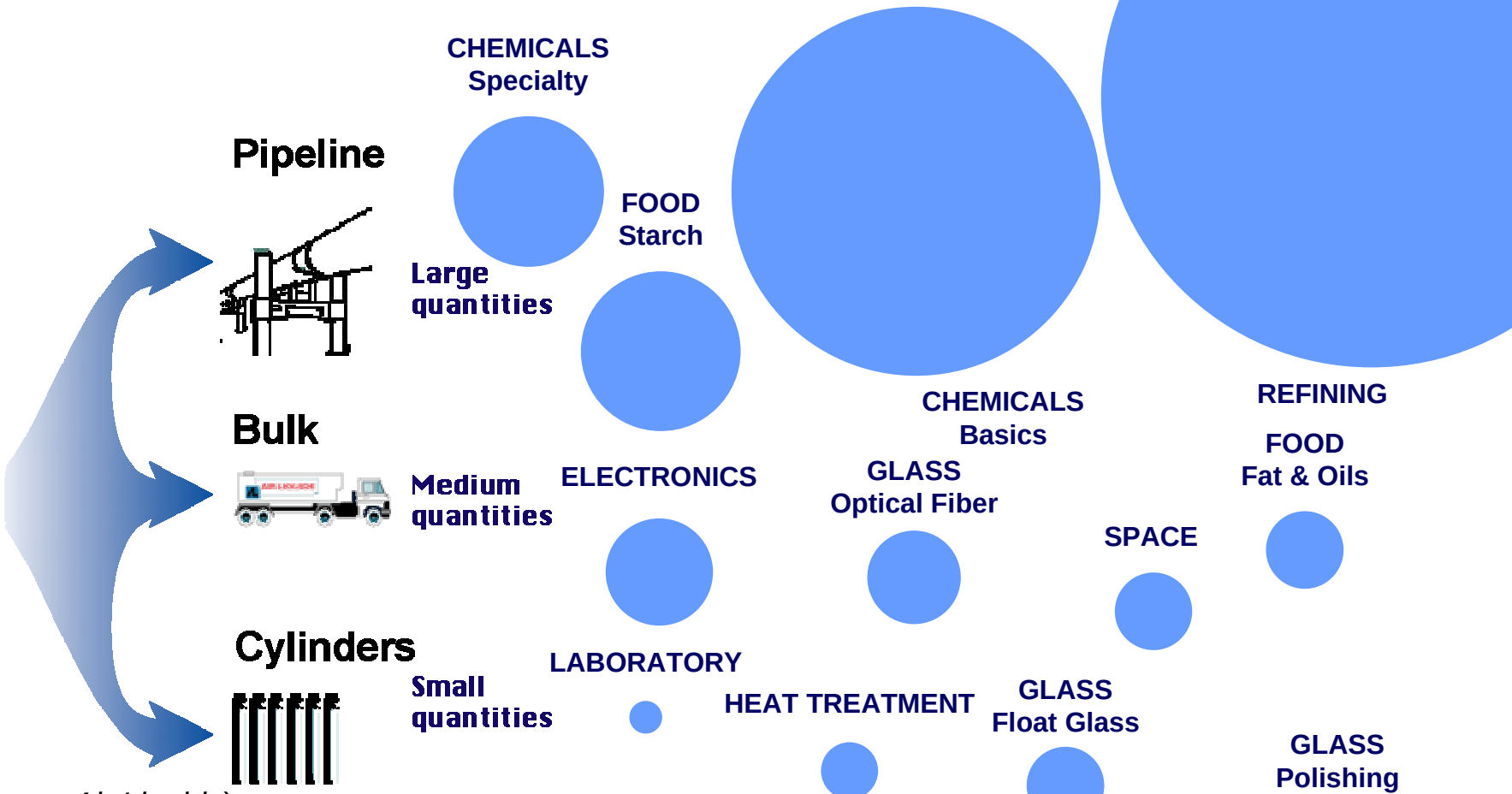
- ***What does it cost?***
- **Production cost**
  - **Typically about 18 – 20 ¢/100 cu. ft.**
- **Delivered costs**
  - **Very large volumes - $0.60 - $0.70/100 cu. ft.**
  - **In smaller volumes easily 10 times as much**
- **World production amounts to about $3 billion**
  - **Point of sale value closer to $10 billion**

Gallon of gasoline equivalents:

Production cost 85 ¢/gal

Delivered cost $2.50 - $3.00/gal

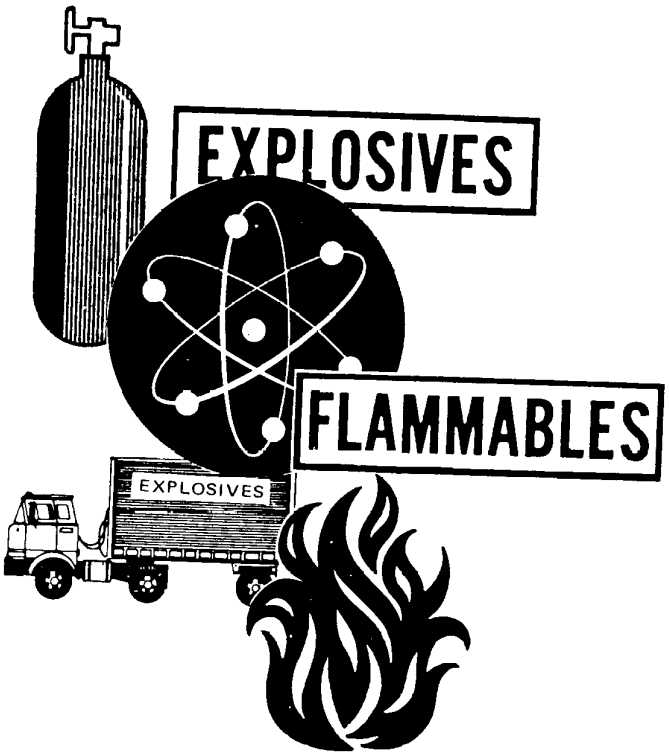
Facts About Hydrogen Today



(*Source: Air Liquide*)

Hydrogen Safety

- Hindenburg Syndrome
- Physical Aspects
  - Confined Space Explosions
  - Comparative Effects – Radiation
  - Smoke, Asphyxiation



Hydrogen Safety

- **The Zeppelin *The Hindenburg***

- **Contained 7 million cu. ft. of hydrogen**
- **Burned and crashed in Lakehurst NJ on 6 May 1937**
- **62 survivors**

- **35 dead**
  - **One was burned**
  - **34 jumped or fell**

Hydrogen Safety

- ***Other Safety Issues***

- **Confined space explosions**
  - **Not as likely with hydrogen**
- **Radiation**
  - **Major source of injury or damage with common fuels**
  - **Virtually non-existent with hydrogen**
- **Smoke, asphyxiation**
  - **No inhalation hazard from hydrogen itself**
  - **Few harmful products of combustion**

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Hydrogen Safety

- ***Comparative flame properties***

Property	Gasoline	Methane	Hydrogen
Flammability Limits In Air (vol %)	1.0 - 7.6	5.3 - 15.0	4.0 - 75.0
Ignition Energy In Air (Mj)	0.24	0.29	0.02
Ignition Temperature (^{o}C)	228 - 471	540	585
Flame Temperature In Air (^{o}C)	2197	1875	2045
Explosion Energy (g-TNT/kJ)	0.25	0.19	0.17
Flame Emissivity (%)	34 - 43	25 - 33	17 - 25

Hydrogen safety issues are *different* than those of other fuels

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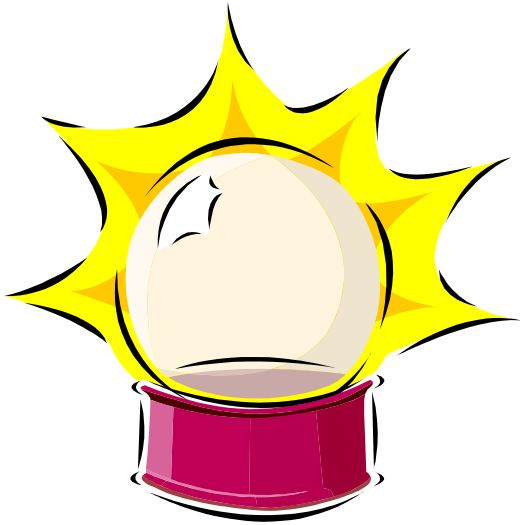
Hydrogen and Fuel Cells

Fuel Cell Type	Fuel Used				
	Hydrogen	Natural Gas	LPG	Syngas	Other
PEM	✓	✗	✗	✗	✗
Metal Air	✗	✗	✗	✗	✓
Direct Methanol	✗	✗	✗	✗	✓
Alkali	✓	✗	✗	✗	✗
Phosphoric Acid	✓	✗	✗	✗	✗
Molten Carbonate	✗	○	✗	✓	○
Solid Oxide	○	○	○	✓	✗

The Future of Hydrogen

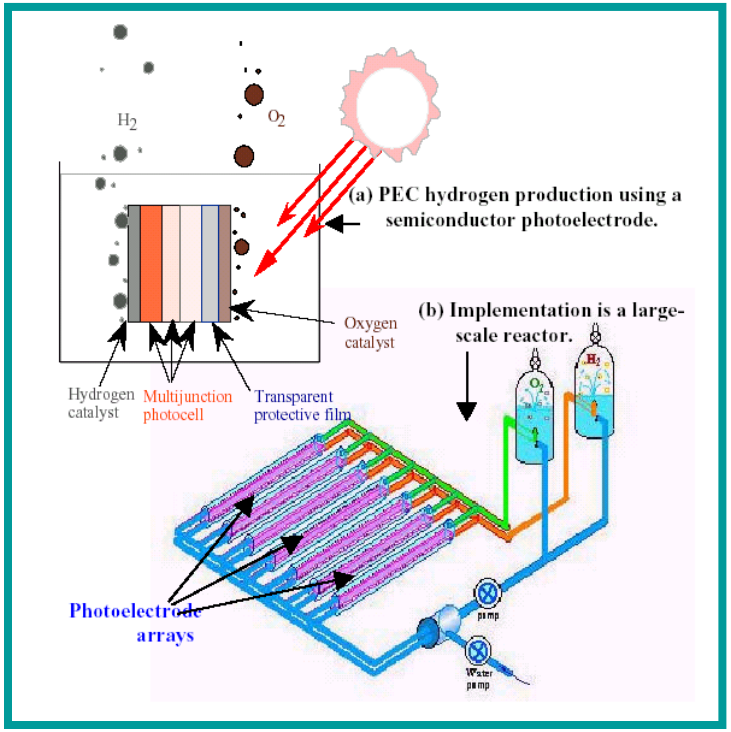
- Where will it come from?
- Renewable Hydrogen?
- Hydrogen as a Fuel
- How Much will be Needed?



The Future of Hydrogen

- ***Where will it come from?***

- **Near term**
  - **Petroleum and natural gas**
  - **Coal – emerging technologies**
- **Mid term (< 50 years)**
  - **Electrolysis**
  - **Biological production**
  - **Other renewable sources**
- **Long term**
  - **Nuclear**
  - **Direct solar photolysis**



(*Source: U.S. DOE*)

The Future of Hydrogen

- ***Renewable Hydrogen***
- **The Goal!**
- **Definition**
  - **Hydrogen produced with no *net* release of carbon dioxide to the atmosphere**
  - **Hydrogen produced from non-fossil resources**
- **Examples**
  - **Electrolysis, photolysis**
  - **Agricultural waste, sewage, biomass**

The Future of Hydrogen

- ***Hydrogen as a fuel***

- **Two modes of use**
  - **Drop-in replacement for present-day *conventional* fuels**
  - **Medium for storage of energy**
    - ***i.e.* for electricity generation**

- **Environmental effects**
  - **Some residual effects in most applications**
  - **Not fully evaluated, needs further study**

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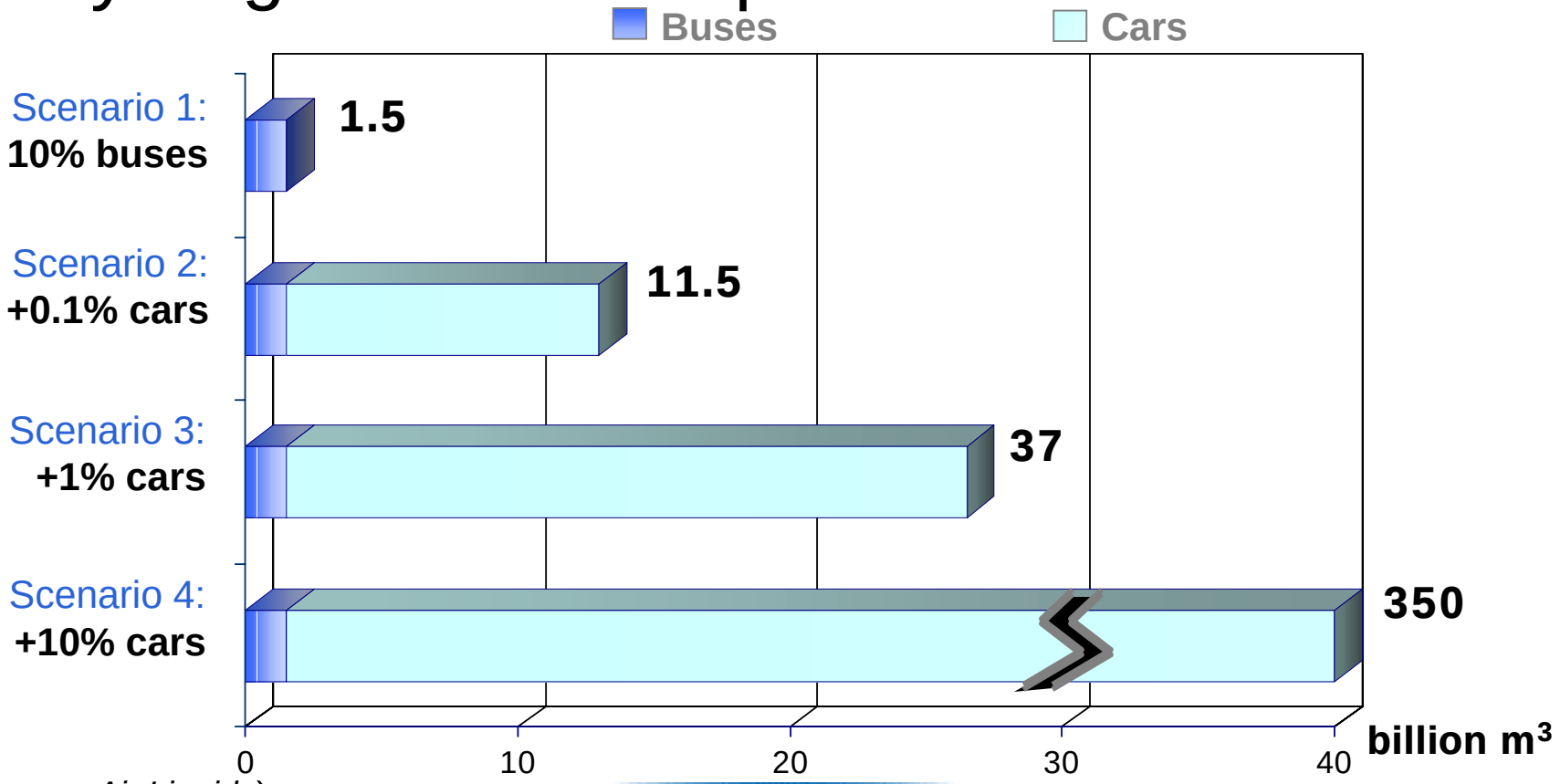
The Future of Hydrogen

- ***How much will we need?***
- Hydrogen as a transportation fuel



(*source: Air Liquide*)

The Future of Hydrogen

- ***How much will we need?***

- **As a transportation fuel**
  - **Will require about 10x current production**
  - **Assumes certain increases in vehicle efficiency**
- **Total Energy Market**
  - **Will require about 18 – 20 x current production**

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Summary

- Hydrogen is plentiful
  - Easy to find, produce and store
- Safety concerns
  - We know how to address these
- Environmentally issues
  - Not fully defined, but looks promising
- The Future of Hydrogen
  - Details uncertain
  - Very much a reality