CHAPTER 1

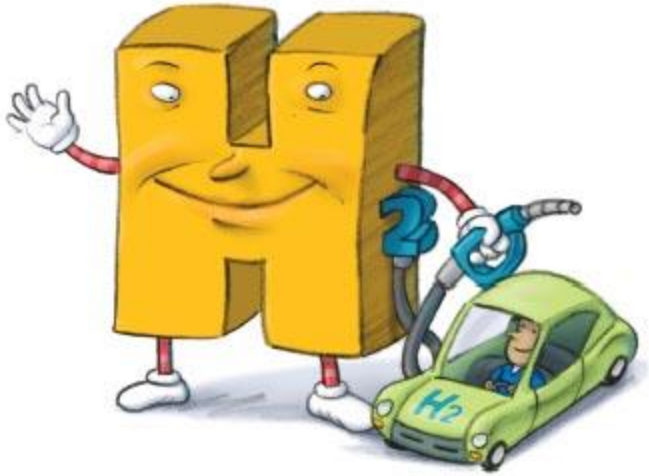
Hydrogen economy

Expected Outcomes

Hydrogen production technique & Role of hydrogen as a future fuels storage issue

Introduction

- Hydrogen Economy is a concept of using hydrogen as the energy transporter rather fossil fuels.
- There are many benefits from converting to a Hydrogen Economy.



Few hydrogen chemistry

- Lightest element electron
- Isotopes contain one or more neutrons
- Most abundant element in universe (75% by mass)
- Component of most stars; as plasma

Hydrogen on earth

- Easily reacts with most other elements, particularly oxygen, carbon, nitrogen, most metals.
- Carbon-hydrogen compounds are basis of organic chemistry.
- Basis of acid-base reactions.
- Occurs in diatomic form in atmosphere

Molecular hydrogen is combustible

- $2\ H_2(g) + O_2\ (g) \rightarrow 2\ H_2O(l)$
  - $\Delta H = -286$ kJ/mol
- Burns at concentrations

  as low as 4%.
- Produces flame visible

  only in UV spectrum

The Properties of Hydrogen

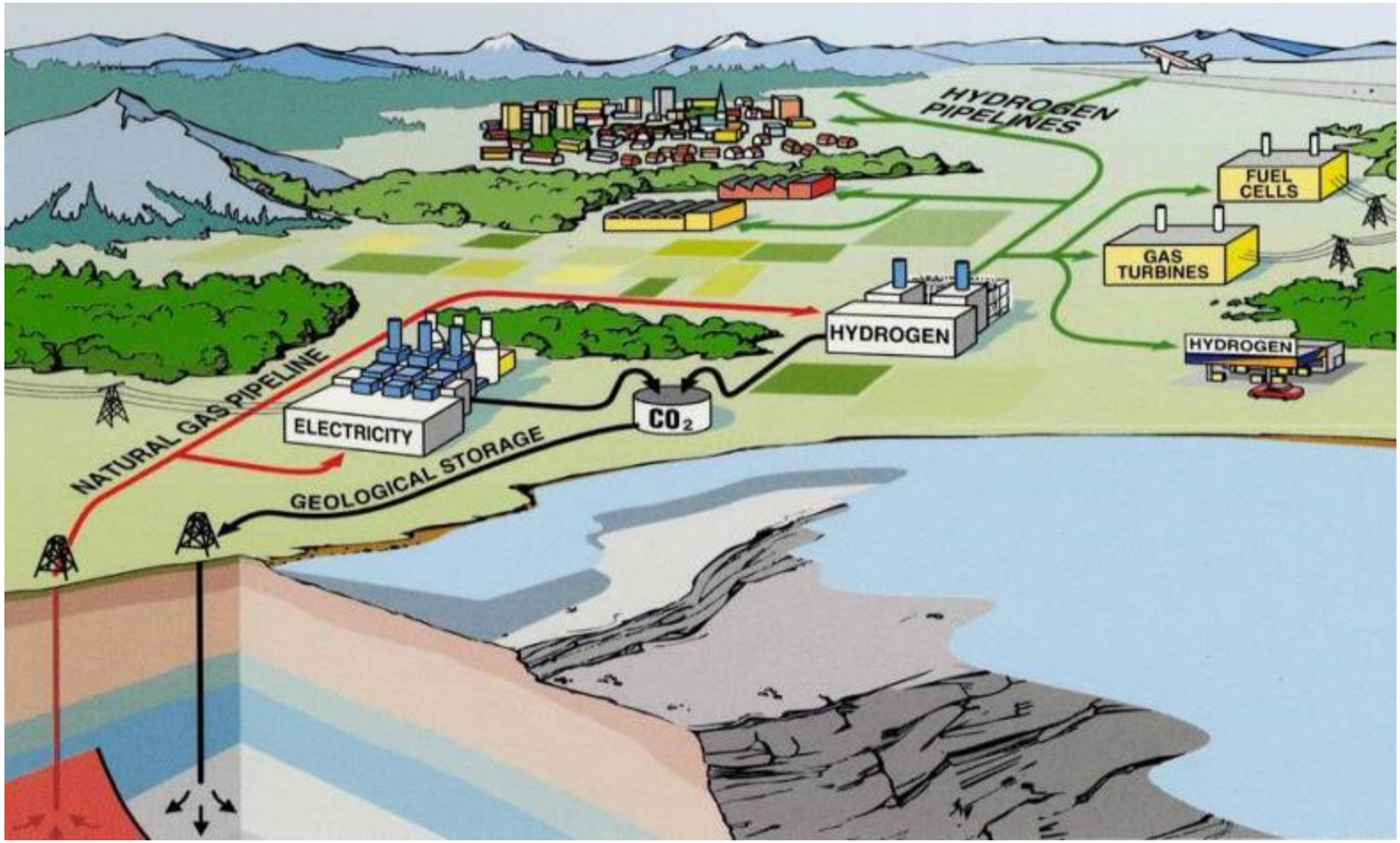
- Hydrogen is the smallest of all atoms
- High energy content per weight
  - 3 times that of gasoline
- Very less energy density per volume
  - Requires large storage tanks

A Vision of a Hydrogen Future

"I believe that water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable. I believe then that when the deposits of coal are exhausted, we shall heat and warm ourselves with water. Water will be the coal of the future."

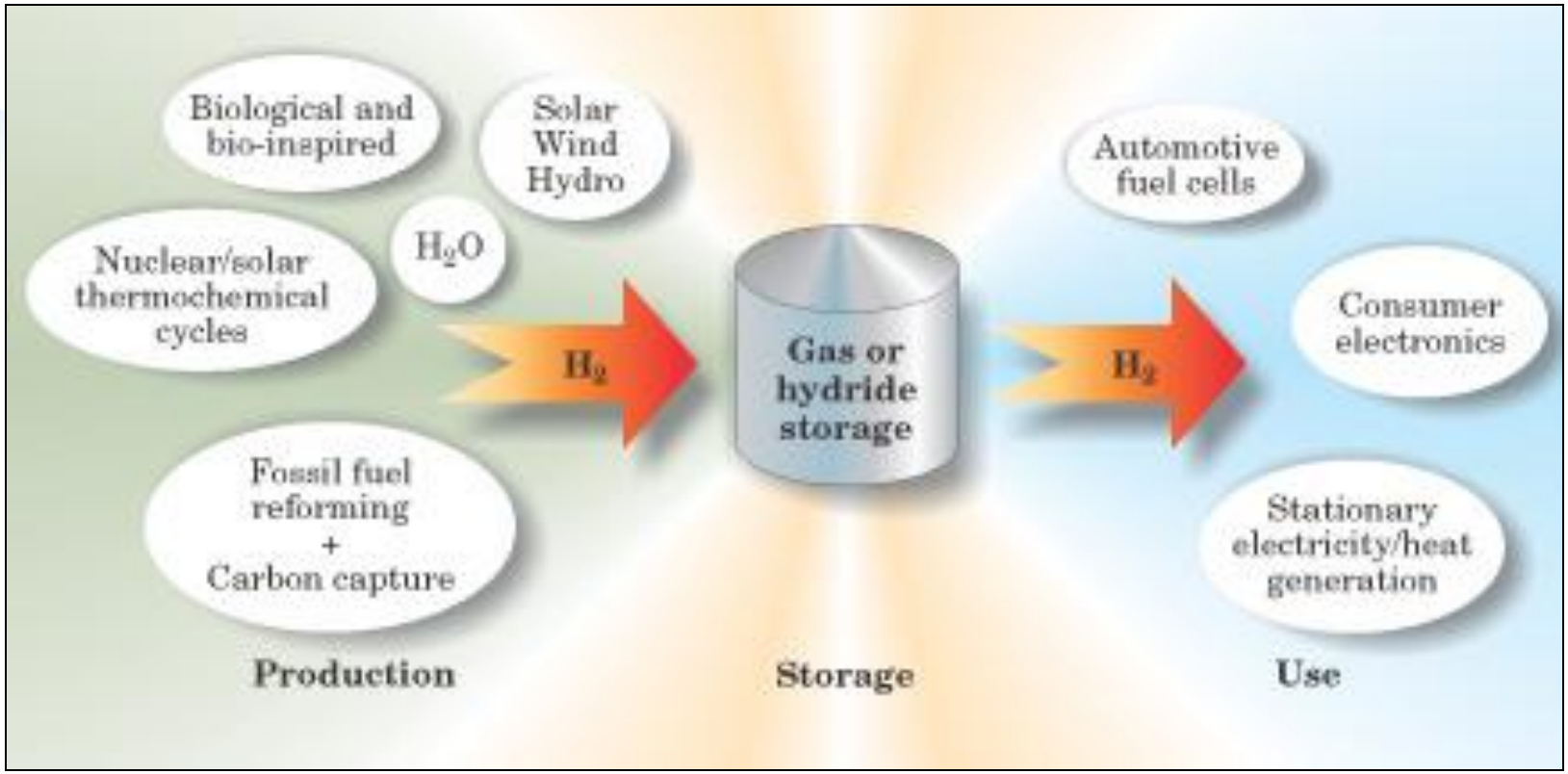
Jules Vernes (1870) *L´île mystérieuse*

Hydrogen Economy Schematic



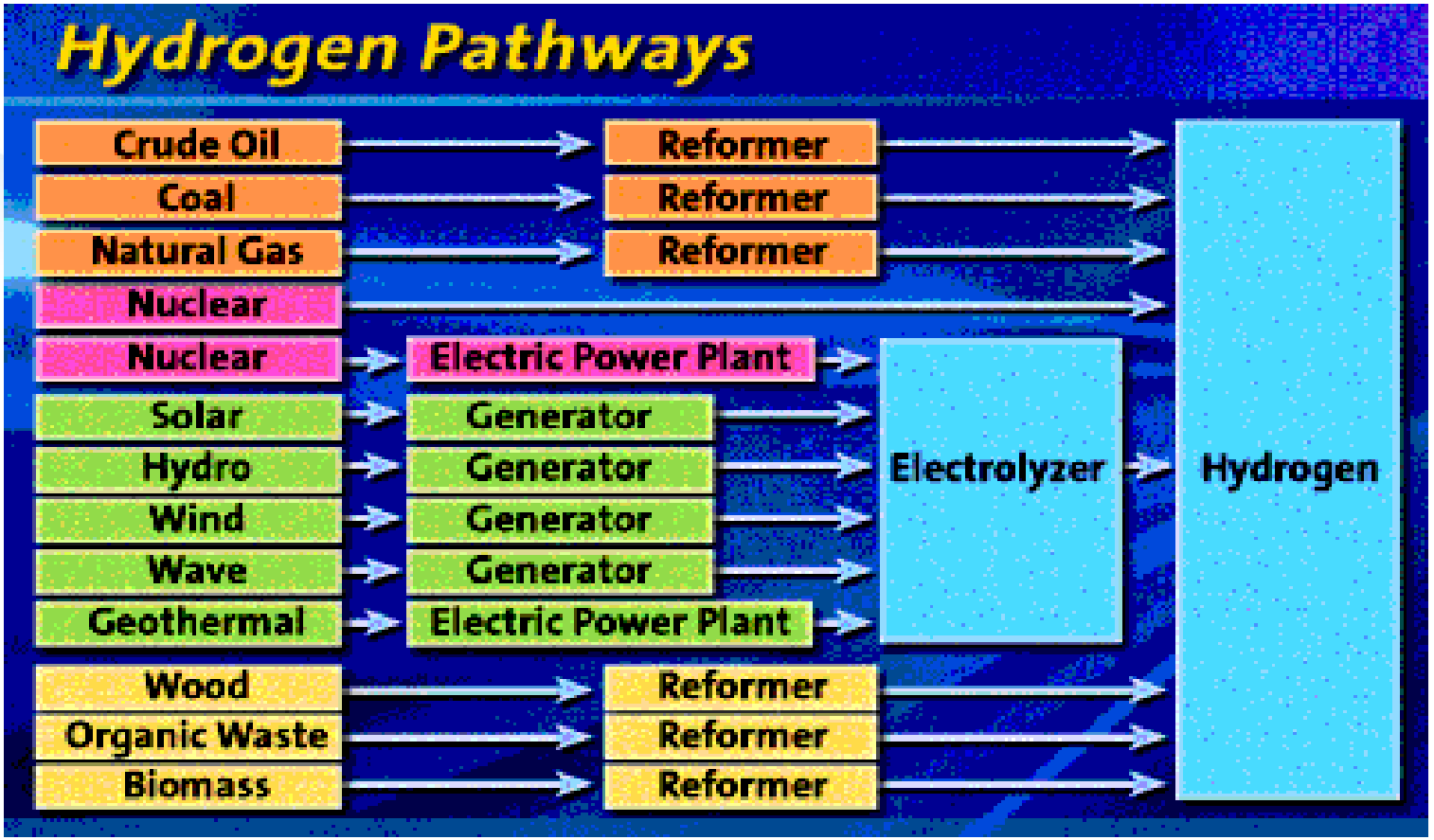
Source: homework.uoregon.edu 12/19/2015

Hydrogen Production Cycle



Crabtree *et al.*, "The Hydrogen Economy," *Physics Today*, Dec 2004

Hydrogen Pathways



Hydrogen Economy Advantages

- Waste product of burning H_2 is water
- Expulsion of fossil fuel pollution
- Expulsion of greenhouse gases
- Expulsion of economic dependence
- Distributed production

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Issues with Hydrogen

- Not widely present on planet earth
- Generally chemically combined in water or fossil fuels (must be separated)
- Fossil fuel sources contribute to pollution and greenhouse gases
- Electrolysis requires prodigious amounts of energy

Technological Questions

- From where does hydrogen come?
- How is it transported?
- How is it distributed?
- How is hydrogen stored?

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How is Hydrogen Produced?

- Reforming fossil fuels
- Electrolysis of water
- High Temperature Electrolysis
- Biological processes

Steam Reforming

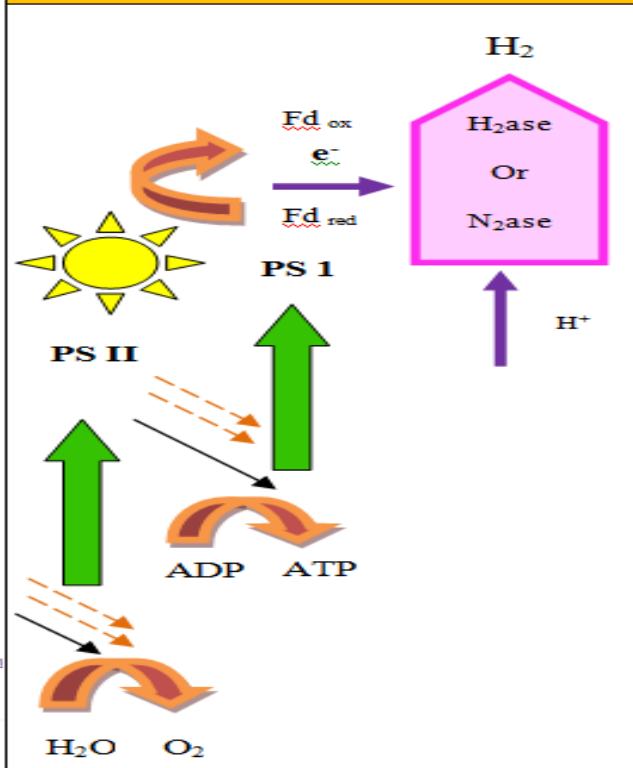
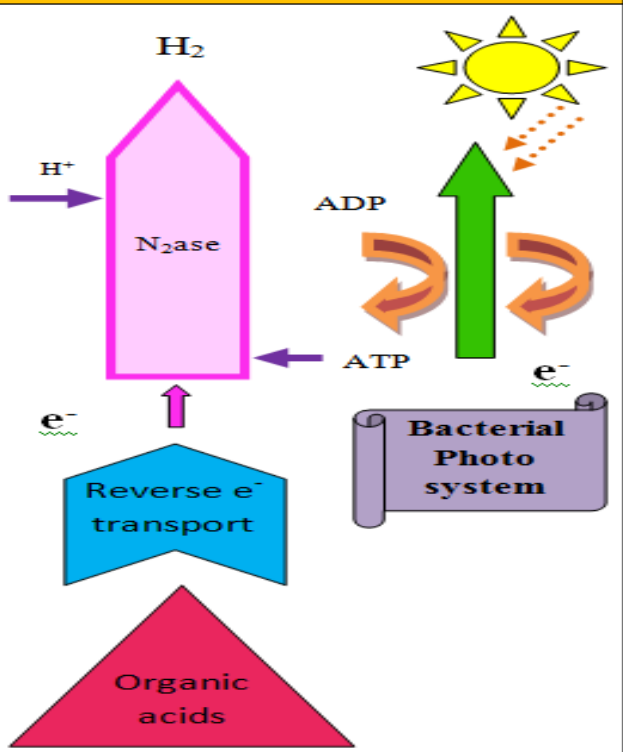
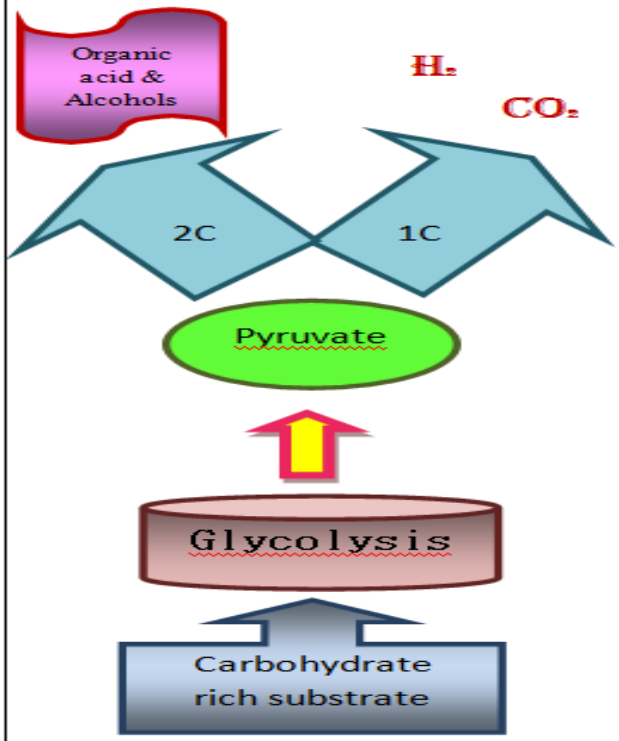
- From any hydrocarbon
- Water (steam) and hydrocarbon mixed at high temperature (700–1100 ° C)
  - Steam (H_2O) reacts with methane (CH_4)
  - $CH_4 + H_2O \rightarrow CO + 3\ H_2$ - 191.7 kJ/mol

Carbon Monoxide Reforming

- Extra hydrogen can be recovered using carbon monoxide (CO)
  - low-temp (130° C) water gas shift reaction
  - $CO + H_2O \rightarrow CO_2 + H_2 + 40.4$ kJ/mol
- Oxygen (O) atom stripped from steam
  - Oxidizes the carbon (C)
  - Liberates hydrogen bound to C and O_2

Biological H2 Creation

Crabtree *et al.,* "The Hydrogen Economy," *Physics Today,* De

Direct biophotolysis	Photo fermentation	Dark fermentation
		
Advantages: 1) Can produce H_2 directly from water and sunlight 2) Solar conversion energy increased by tenfolds as compared to trees, crops	Advantages: 1) A wide spectral light energy can be used by these bacteria 2) Can use different waste materials like distillery effluents, etc. and can produce H_2 all day without light	Advantages: 1) A variety of carbon sources can be used as substrates 2) It can produce H_2 all day without light 3) It produces valuable metabolites like butyric, lactic, propionic, succinic and acetic acids as byproducts
Disadvantages: 1) Requires light 2) O_2 can be dangerous for the system	Disadvantages: 1) Light conversion efficiency is very low – only 1-5% 2) O_2 inhibits some hydrogenases	Disadvantages: 1) Relatively lower achievable yields of H_2 2) As yields increase H_2 fermentation becomes Thermodynamically unfavorable 3) Product gas mixture contains CO_2 4) O_2 is an inhibitor
Example: Green algae	Example: Photosynthetic bacteria	Example: Fermentative bacteria

Storing & Transporting Hydrogen

Hydrogen Storage

- H_2 has low energy density per volume it requires large tanks to store.
- H_2 can be compressed to reduce volume so that why it requires heavy, strong tanks
- H_2 can be liquefied to reduce volume which requires heavily insulated, expensive tanks
- Both compression and liquefaction require a abundant of energy

Ammonia Storage

- H_2 can be collected as ammonia (NH_3)
- Exceptionally high hydrogen densities
- Ammonia very common chemical
  - Huge infrastructure already exists
- Easily reformed to produce hydrogen
  - No harmful waste
- BUT
  - Ammonia production is energy intensive
  - Ammonia is a toxic

Metal Hydride Storage

- Metal hydrides can carry hydrogen
  - Boron, lithium, sodium
  - Good energy density, but worse than gas
- Volumes much larger than gasoline
  - Three times more volume
  - Too(4 times heavy) heavier
- Hydrides can react violently with water
- Leading contenders
  - Sodium Borohydride
  - Lithium Aluminum Hydride

Storing & Transporting Hydrogen

- Store and Transport as a Gas
  - Heavy gas
  - Compressing H_2 requires energy
  - Compressed H_2 has far low energy than the same volume of gasoline
- Store and Transport as a Solid
  - Sodium Borohydride
  - Calcium Hydride
  - Lithium Hydride
  - Sodium Hydride

Transport with Hydrogen Fueled

Hydrogen-Powered Autos

Hydrogen-Powered Trucks

Hydrogen-Powered Aircraft

Hydrogen powered aircraft with cryogenic tanks along spine of fuselage. Hydrogen fuel requires about 4 times the volume of standard jet fuel (kerosene).

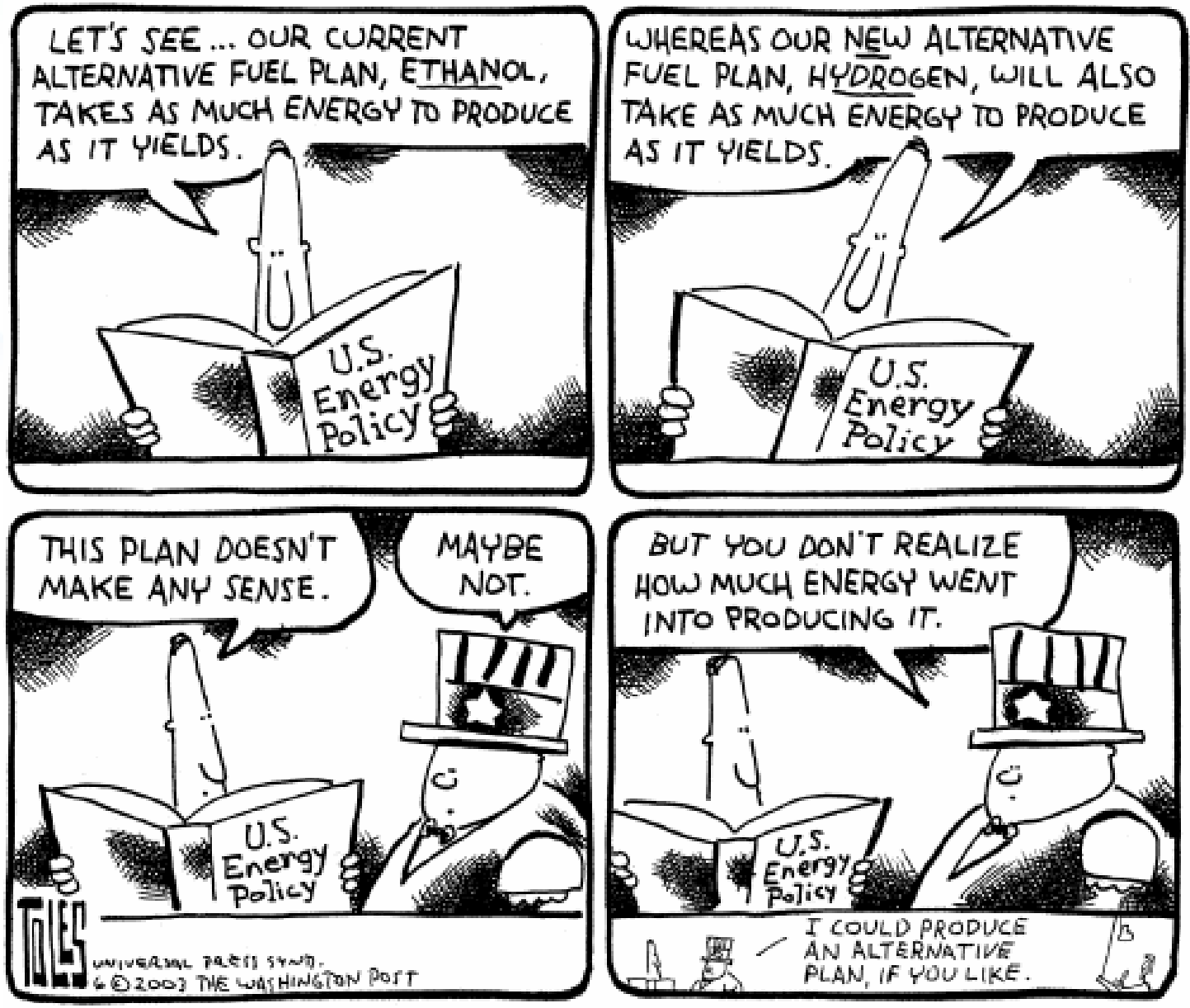
Problems with Hydrogen

Environmental Concerns

- Half of hydrogen made from natural gas
  - Creates CO_2 – a greenhouse gas
- Hydrogen H_2 necessarily leaks from containers
  - Creates free radicals (H) in stratosphere due to UV
  - Could act as catalysts for ozone depletion

Criticism of Hydrogen Economy

- Hydrogen economy idea does not work for multiple reasons.
- Problems with physical & chemical properties of hydrogen
- Compact / convenient future energy carrier needed
- Difficult to understand the enthusiasm for hydrogen


LET'S SEE... OUR CURRENT ALTERNATIVE FUEL PLAN, ETHANOL, TAKES AS MUCH ENERGY TO PRODUCE AS IT YIELDS.
U.S. Energy Policy
WHEREAS OUR NEW ALTERNATIVE FUEL PLAN, HYDROGEN, WILL ALSO TAKE AS MUCH ENERGY TO PRODUCE AS IT YIELDS.
U.S. Energy Policy
THIS PLAN DOESN'T MAKE ANY SENSE.
MAYBE NOT.
U.S. Energy Policy
TOLES
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BUT YOU DON'T REALIZE HOW MUCH ENERGY WENT INTO PRODUCING IT.
U.S. Energy Policy
I COULD PRODUCE AN ALTERNATIVE PLAN, IF YOU LIKE.

6-2-03

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Thank you