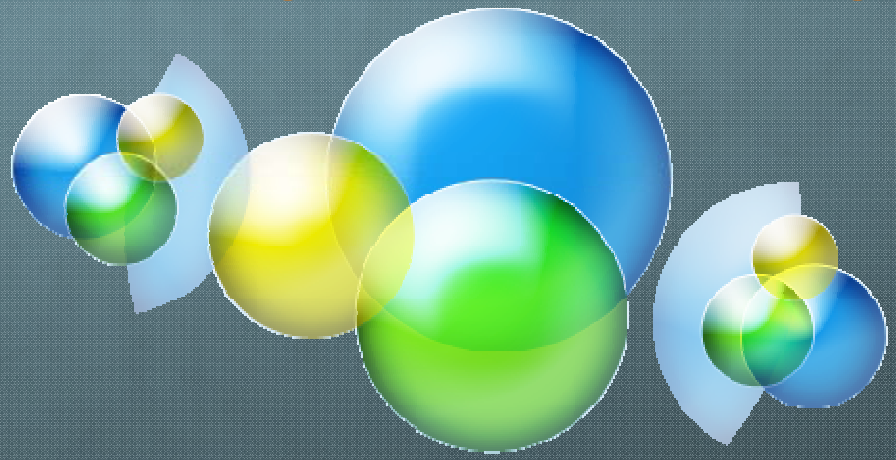
THE HYDROGEN ECONOMY



(Harnessing wind energy)

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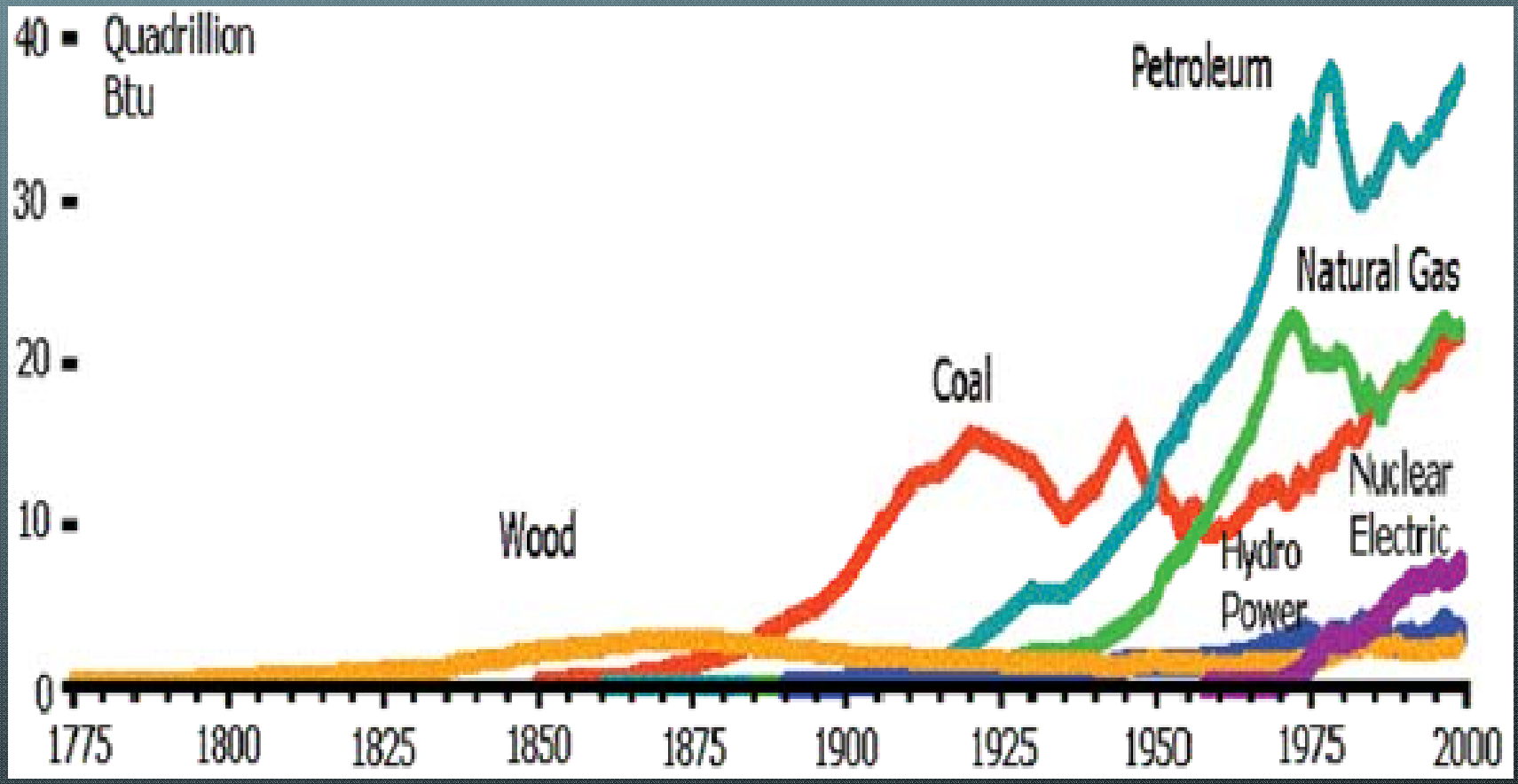
Aim of presentation

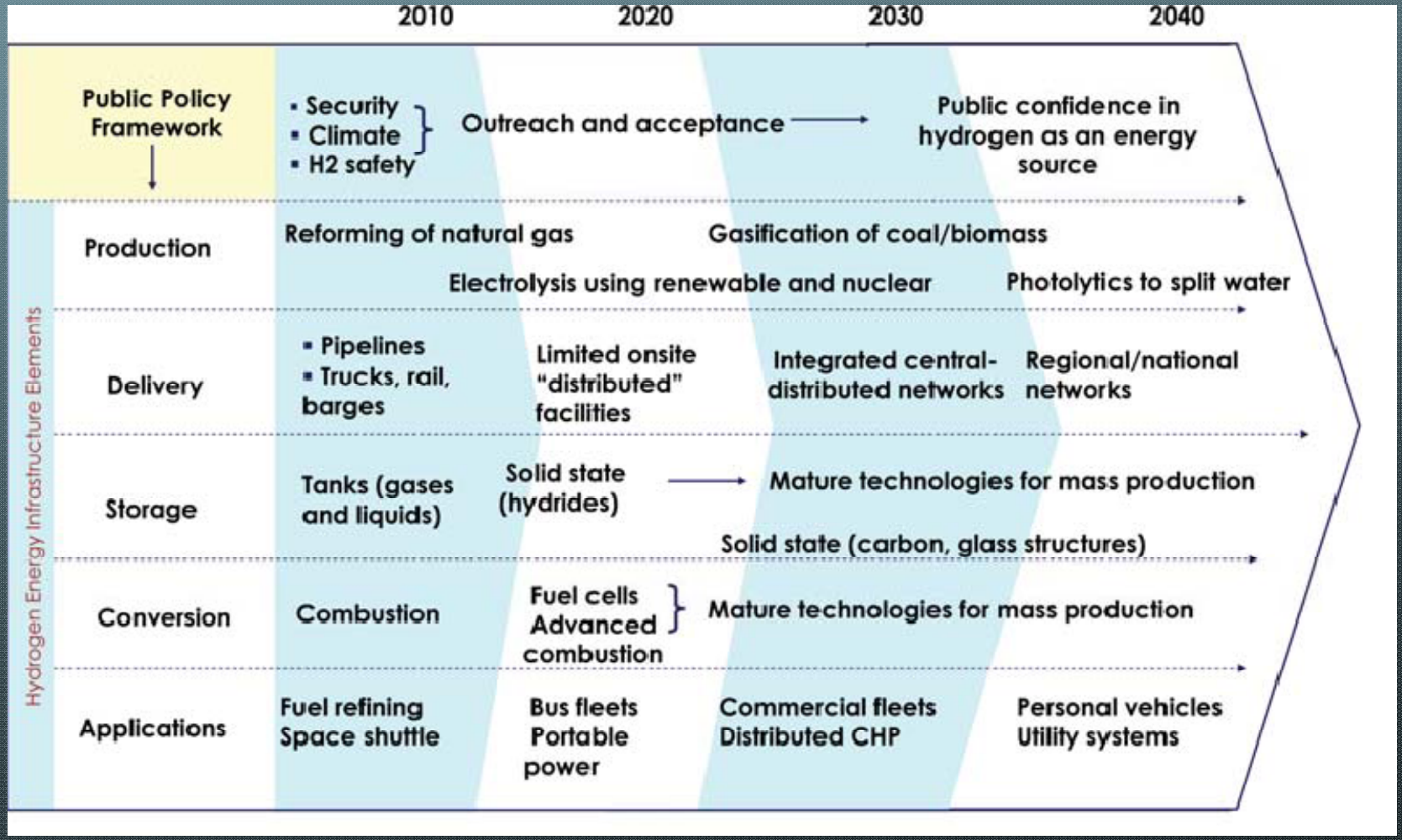
- Overview of current carbon economy
- Link hydrogen production with energy generation
- Introduce wind as a renewable energy source
- Economics of wind energy
- Prospects of the hydrogen economy

Carbon economy: Energy Consumption in the United States, 1775-1999



Source: U.S. DOE

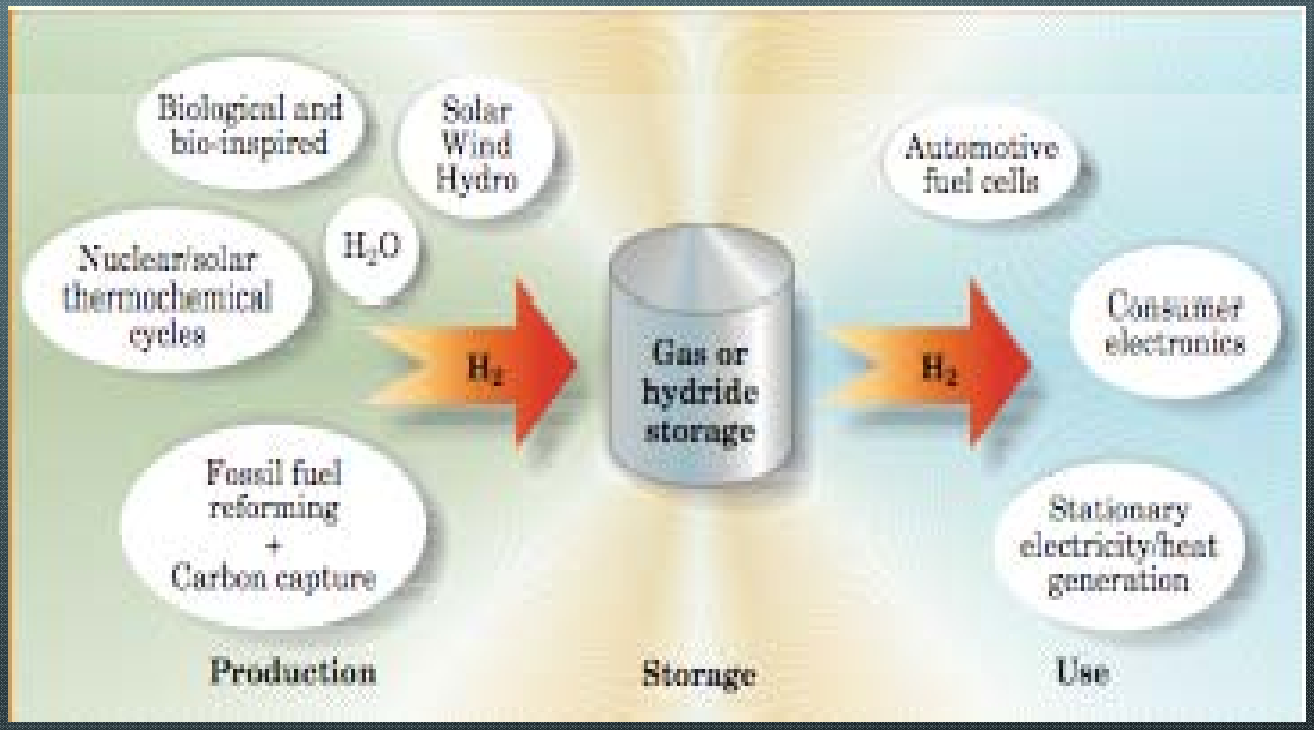
Transition to Hydrogen Economy



Source: U.S. DOE

The hydrogen economy

- A hypothetical economy in which all forms of energy are stored and transported as hydrogen



Source: The Hydrogen economy, USA Today, 2004

Hydrogen production

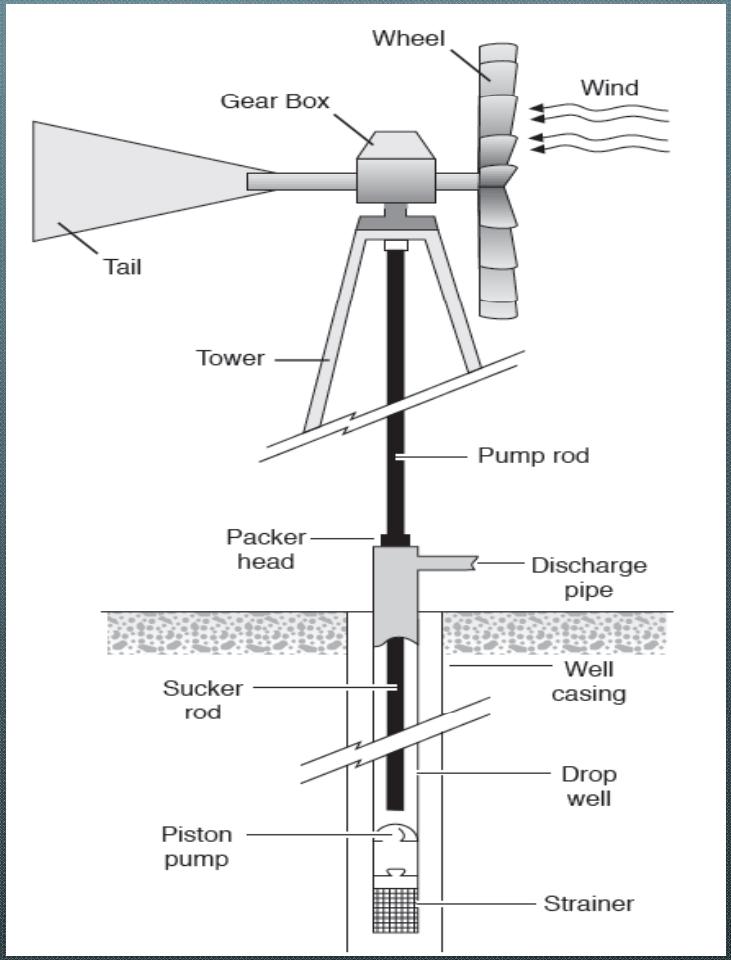
Primary Method	Process	Feedstock	Energy	Emissions
Thermal	Steam Reformation	Natural Gas	High temperature steam	Some emissions. Carbon sequestration can mitigate their effect.
	Thermochemical Water Splitting	Water	High temperature heat from advanced gas-cooled nuclear reactors	No emissions
	Gasification	Coal, Biomass	Steam and oxygen at high temperature and pressure	Some emissions. Carbon sequestration can mitigate their effect.
	Pyrolysis	Biomass	Moderately high temperature steam	Some emissions. Carbon sequestration can mitigate their effect.
Electrochemical	Electrolysis	Water	Electricity from wind, solar , hydro and nuclear	No emissions
	Electrolysis	Water	Electricity from coal or natural gas	Some emissions from electricity production.
	Photoelectrochemical	Water	Direct sunlight	No emissions
Biological	Photobiological	Water and algae strains	Direct sunlight	No emissions
	Anaerobic Digestion	Biomass	High temperature heat	Some emissions
	Fermentative Microorganisms	Biomass	High temperature heat	Some emissions

Source: National Hydrogen Foundation (NHF)

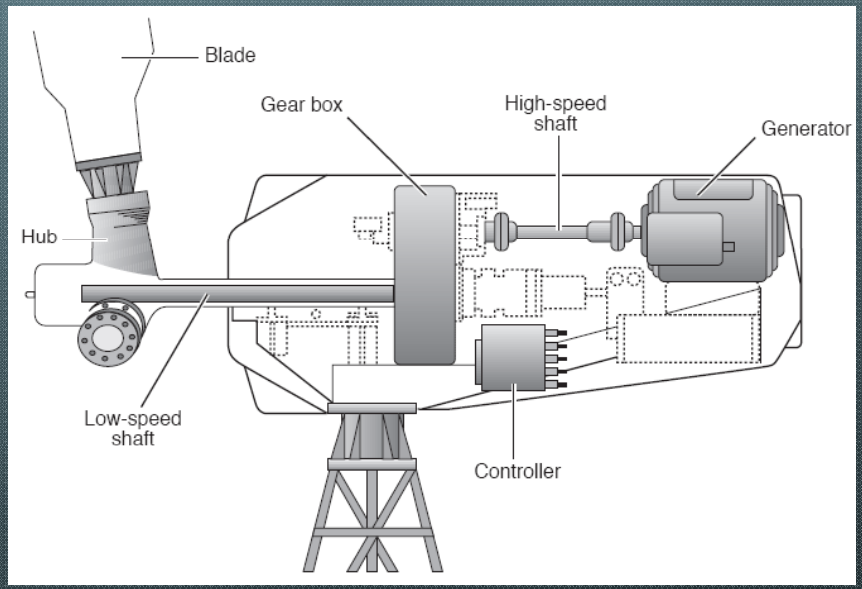
Wind as an alternative energy source

- Wind power is one of the oldest renewable technologies
- Wind is created from differences between higher and lower pressure caused by unequal heating and cooling of the earth and atmosphere
- Offers an inexpensive, clean and reliable form of power
- As wind speed doubles, power generation capability increases eightfold
- The higher the better: On average a five-fold increase in elevation, say raising the height of the wind machine from 10 feet to 50 feet, will result in twice as much available wind power

Mechanism of the windmill



Mechanical pump windmill



Electricity generating wind turbine

Design Components:

- blades
- shaft
- gearbox
- generator

How much energy can one wind turbine generate?

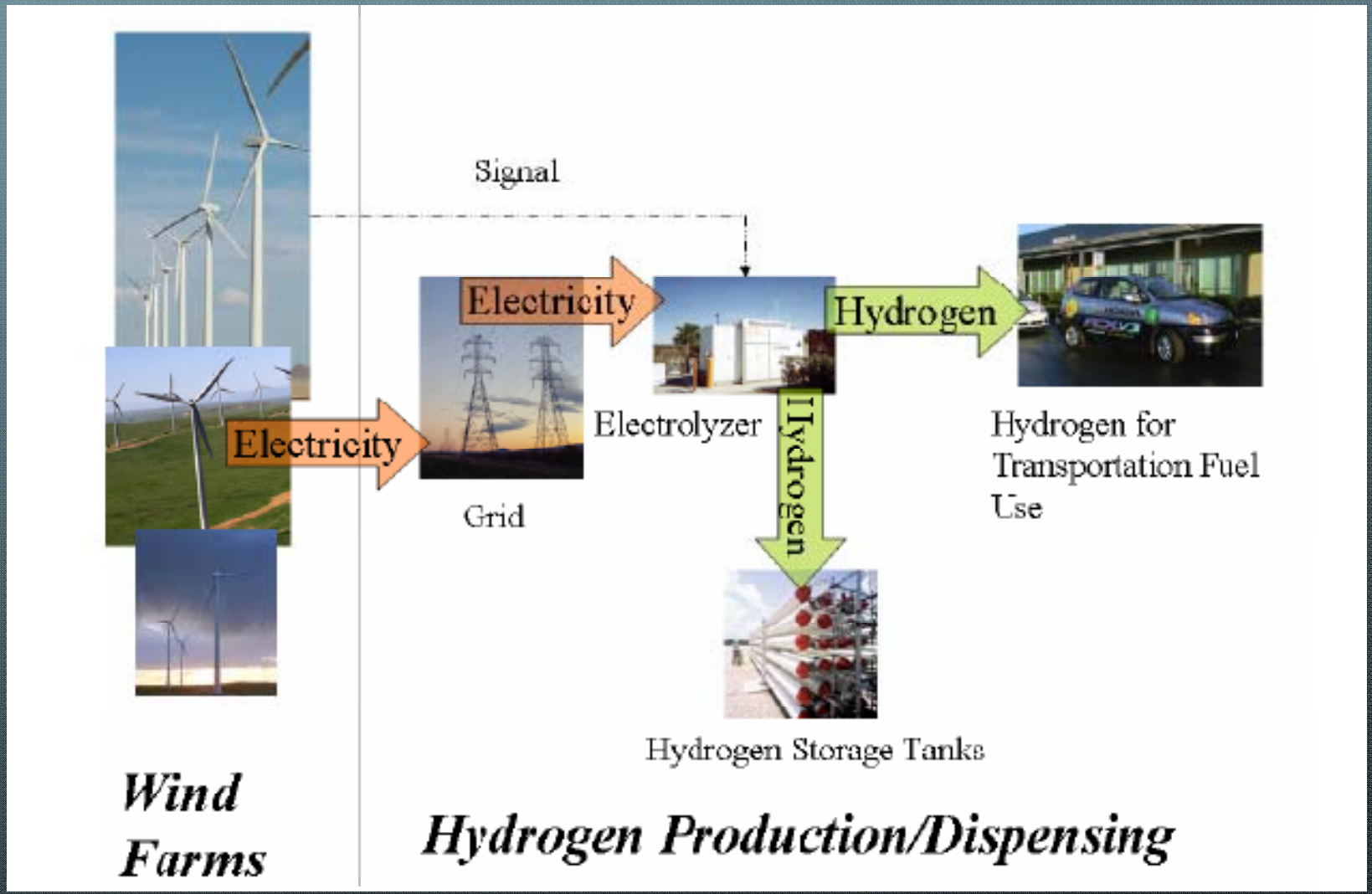
- The output of a wind turbine depends on the turbine's size and the wind's speed through the rotor
- Wind turbines manufactured today have power ratings ranging from 250 watts to 5 megawatts (MW)
- A 5-MW turbine can produce more than 15 million kWh in a year--enough to power more than 1400 households
- The average U.S. household consumes about 10,000 kWh of electricity each year
- 1-MW of wind energy can generate from 2.4 to more than 3 million kWh annually. Therefore, a megawatt of wind generates about as much electricity as 225 to 300 households use

Practical illustration

- A 50-MW wind farm can be completed in 18 months to 2 years. Most of that time is needed for measuring the wind and obtaining construction permits—the wind farm itself can be built in less than 6 months.

- A 250-kW turbine installed at the elementary school in Spirit Lake, Iowa, provides an average of 350,000 kWh of electricity per year, more than is necessary for the 53,000-square-foot school. Excess electricity fed into the local utility system earned the school $25,000 in its first five years of operation.

From wind farms to consumer

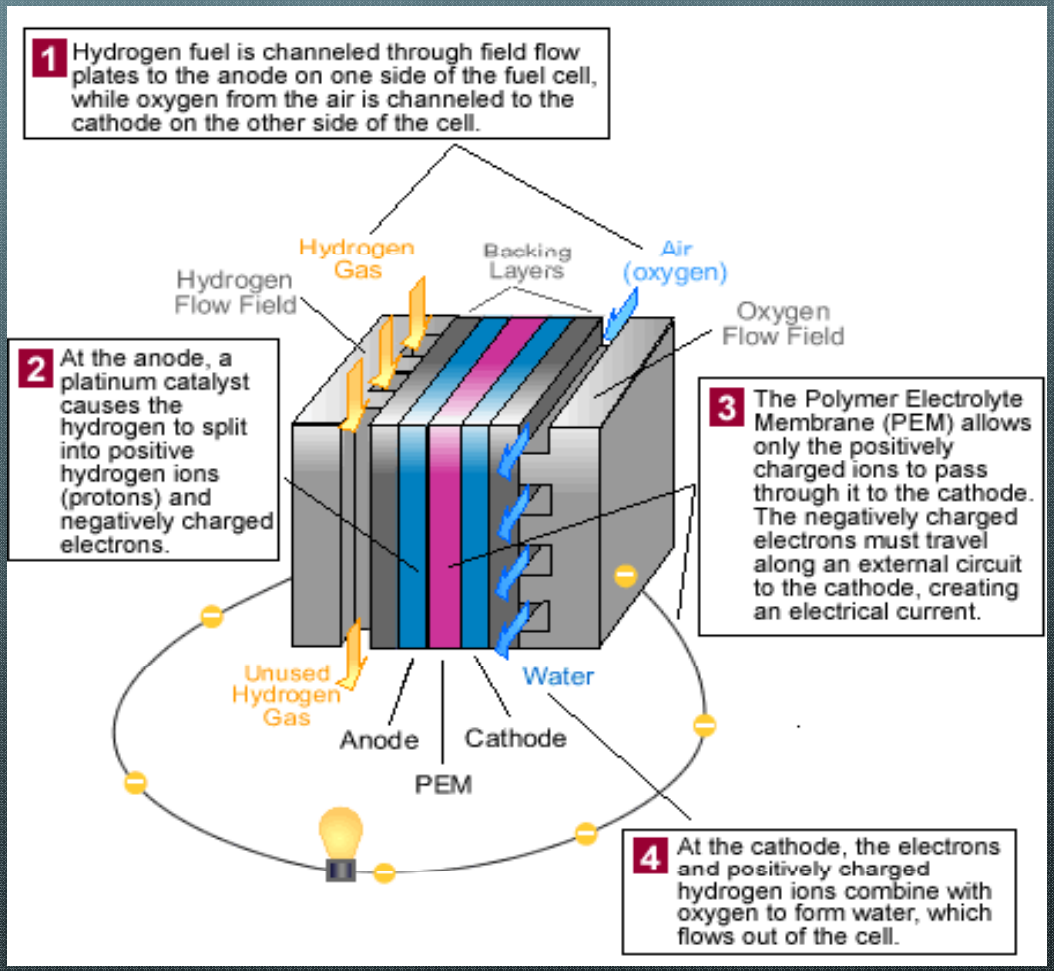


Source: National Hydrogen Foundation

Electrolysis of water (PEM Fuel Cell)

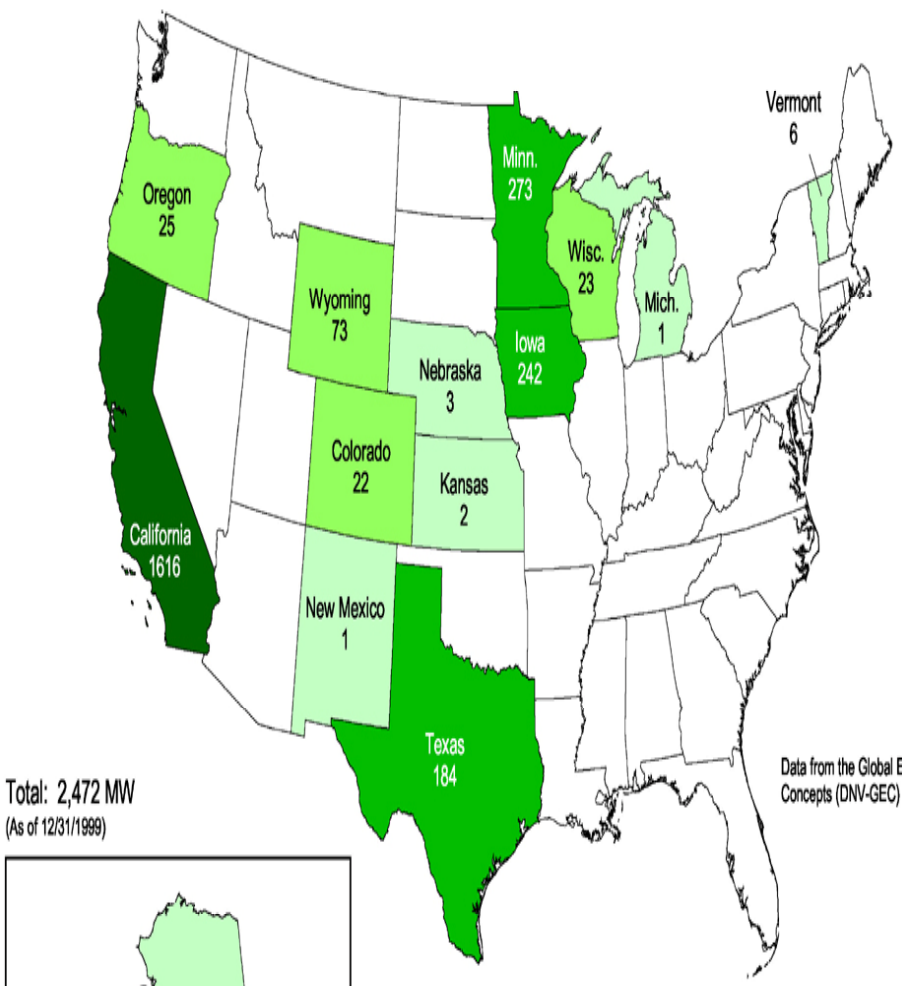
- **Net reaction:**

$$2H_2O \text{ liquid} + \text{electricity} \rightarrow 2H_2 + O_2$$



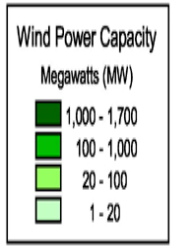
Source: http://www.fueleconomy.gov

1999 Year End Wind Power Capacity (MW)



Total: 2,472 MW
(As of 12/31/1999)

Data from the Global Energy Concepts (DNV-GEC) database.



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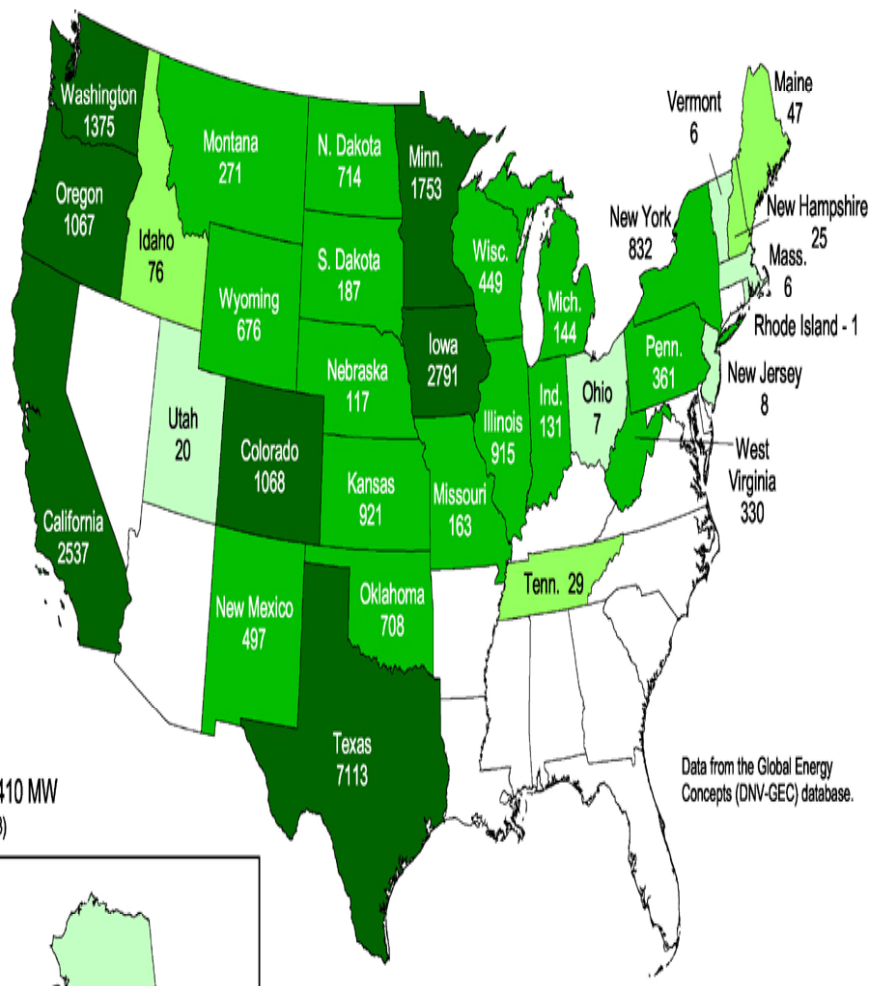
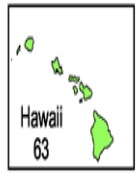
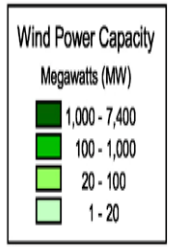
2008 Year End Wind Power Capacity (MW)



Total: 25,410 MW
As of 12/31/08)

Data from the Global Energy Concepts (DNV-GEC) database.





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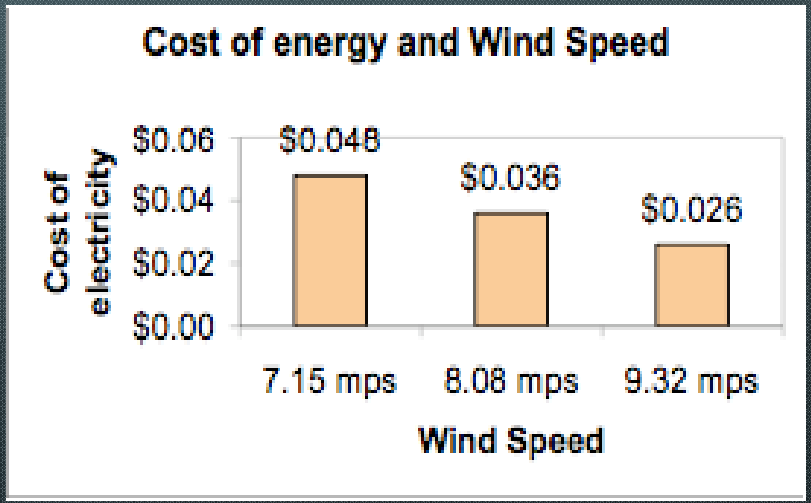
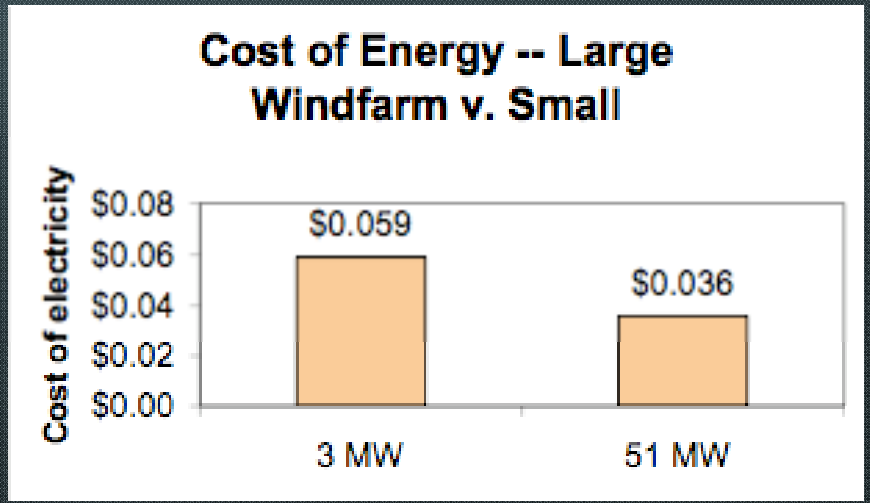
Economics of wind energy

- Wind energy is proportional to the cube of the wind speed
- Larger wind farms are more economical
- Improvements in turbine design bring down costs
  - Increasing the height of the turbine tower
  - Increasing rotor (blade) diameter which increases sweep area
  - Improving electronic monitoring and control





Why we should invest in wind technology

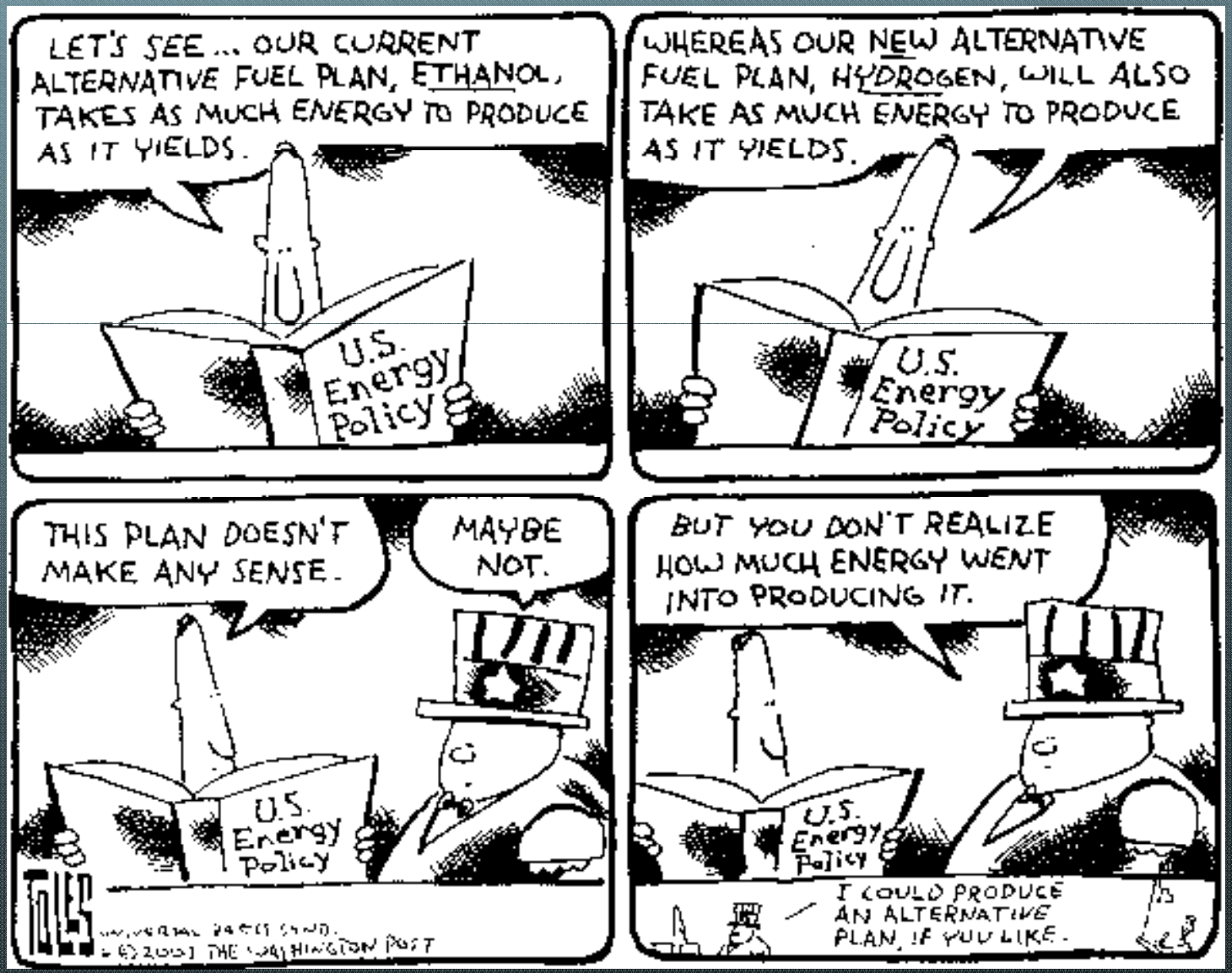
- U.S. wind resources could provide over 10 trillion kWh (Deyette et al) for land areas with wind speeds of about 7 meters per second [m/s] [15.7 mph] at a height of 50m (over 4 times the total electricity currently generated from fossil fuels)
- As much as 20 percent of the U.S. electricity demand by 2030 would be met if wind technology could meet its full potential pursued on land and offshore. It would also create as many as 250,000 jobs in the US (Obama on earth day in Iowa)
- Installation costs of a wind turbine today costs less then $1000/kW using suitable wind sites; compared to over $2500/kW in the early 1980s
- Zero emissions since the 'fuel' does not contain any carbon elements

	Current Technology		Future Technology	
	With Grid Backup	No Grid Backup	With Grid Backup	No Grid Backup
Average cost of electricity (cents/kWh)	6	6	4	4
Wind turbine capacity factor (%)	30	30	40	40
Hydrogen ($/kg)	6.64	10.69	3.38	2.86
Carbon emissions (kg C/kg H_2)	3.35	0	2.48	0

Challenges of the wind economy

- Relatively expensive installation and miscellaneous costs
- NIMBY (Not In My Backyard) phenomenon – interference with human and industrial activity
- Intermittence and mismatch with demand
- Environmental impacts
  - Visual effects (moving shadows and noise)
  - On-shore and off-shore windmills interference with wildlife (migratory birds and bats)

What others are saying about alternative energy



Thanks!!!

Questions?