THE HYDROGEN ECONOMY

(Harnessing wind energy)

Ifejesu Eni-olorunda
Department of Chemical Engineering
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

<table>
<thead>
<tr>
<th>Public Policy Framework</th>
<th>Outreach and acceptance</th>
<th>Public confidence in hydrogen as an energy source</th>
</tr>
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<tbody>
<tr>
<td>Production</td>
<td>Reforming of natural gas</td>
<td>Gasification of coal/biomass</td>
</tr>
<tr>
<td></td>
<td>Electrolysis using renewable and nuclear</td>
<td>Photolytics to split water</td>
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<tr>
<td>Delivery</td>
<td>Pipelines, Trucks, rail, barges</td>
<td>Limited onsite “distributed” facilities</td>
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<td></td>
<td>Integrated central-distributed networks</td>
<td>Regional/national networks</td>
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<tr>
<td>Storage</td>
<td>Tanks (gases and liquids)</td>
<td>Solid state (hydrides)</td>
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<td></td>
<td>Solid state (carbon, glass structures)</td>
<td>Mature technologies for mass production</td>
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<tr>
<td>Conversion</td>
<td>Combustion</td>
<td>Fuel cells Advanced combustion</td>
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<td></td>
<td>Mature technologies for mass production</td>
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<tr>
<td>Applications</td>
<td>Fuel refining Space shuttle</td>
<td>Bus fleets Portable power</td>
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<tr>
<td></td>
<td>Commercial fleets Distributed CHP</td>
<td>Personal vehicles Utility systems</td>
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</tbody>
</table>

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

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

*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

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
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

![Graph showing cost of energy and wind speed](image)

![Graph showing cost of energy for large and small windfarms](image)
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

<table>
<thead>
<tr>
<th></th>
<th>Current Technology</th>
<th>Future Technology</th>
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<tbody>
<tr>
<td></td>
<td>With Grid Backup</td>
<td>No Grid Backup</td>
</tr>
<tr>
<td>Average cost of electricity (cents/kWh)</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Wind turbine capacity factor (%)</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Hydrogen ($/kg)</td>
<td>6.64</td>
<td>10.69</td>
</tr>
<tr>
<td>Carbon emissions (kg C/kg H₂)</td>
<td>3.35</td>
<td>0</td>
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</tbody>
</table>
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

Let's see... our current alternative fuel plan, ethanol, takes as much energy to produce as it yields.

Whereas our new alternative fuel plan, hydrogen, will also take as much energy to produce as it yields.

This plan doesn't make any sense.

Maybe not.

But you don't realize how much energy went into producing it.

I could produce an alternative plan, if you like.
Thanks!!!

Questions?