



Hydrogen

“Paving the way to a brighter new future in fuel”

33rd Symposium on “Green Hydrogen in Pakistan”

Organized by the Pakistan Academy of Engineering (PAE).

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Hydrogen..

A Plentiful Element

- Hydrogen is the most abundant substance within the universe, making up 3/4 of all matter.
- The sun still being in the early stages of it's life is made up of 75% hydrogen.
- Millions of years ago Hydrogen reacted to produce Helium and all the energy was emitted to space, but a small amount was captured on Earth by plants that had died and have now become the fossil fuels that are now the basis of today's leading world industry.
- Exists in nature, an invisible gas which is extremely flammable.

Sources of Hydrogen

Sources that Hydrogen can be extracted from:

- Natural Gas, Water, Coal, Gasoline, Methanol, Biomass
- Other sources being researched include the uses of solar energy, photosynthesis, decomposition, and fuel cells themselves can tri-generate electricity, heat, and hydrogen.

Hydrogen Production

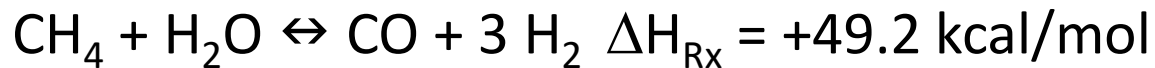
- H is difficult and costly to compress, store, and transport; it has one of the lowest energy densities of any fuel, $1/3^{\text{rd}}$ of any natural gas. Hydrogen has major safety issues; it's flammable over a wide range of concentrations and is very easily ignited.
- Hydrogen is one of the most leak prone gases, set to a strict set of regulations and standards.
- There is no natural source of hydrogen
- To supply the hydrogen for energy needs, economical processes are needed to produce hydrogen from abundant energy sources

Hydrogen Production – Fossil Fuels

- In the short-term, hydrogen may produced from fossil fuels
 - Natural gas
 - Coal
 - Gasoline
- Advantages:
 - Established distribution networks
 - Economical conversion processes
- Disadvantages:
 - Finite resources
 - Shift pollution problem, but don't eliminate it!

Hydrogen Production – Natural Gas

- Well-established technology exists to convert natural gas to hydrogen. Typically done using **steam reforming**:



High temperatures (700-1000°C) are needed for high conversion.



Hydrogen plant in Tosco Corp's Avon refinery¹

¹ <http://www.airproducts.com/PhotoLibrary/restricted/photo-cpi.asp>

Hydrogen Production – Natural Gas

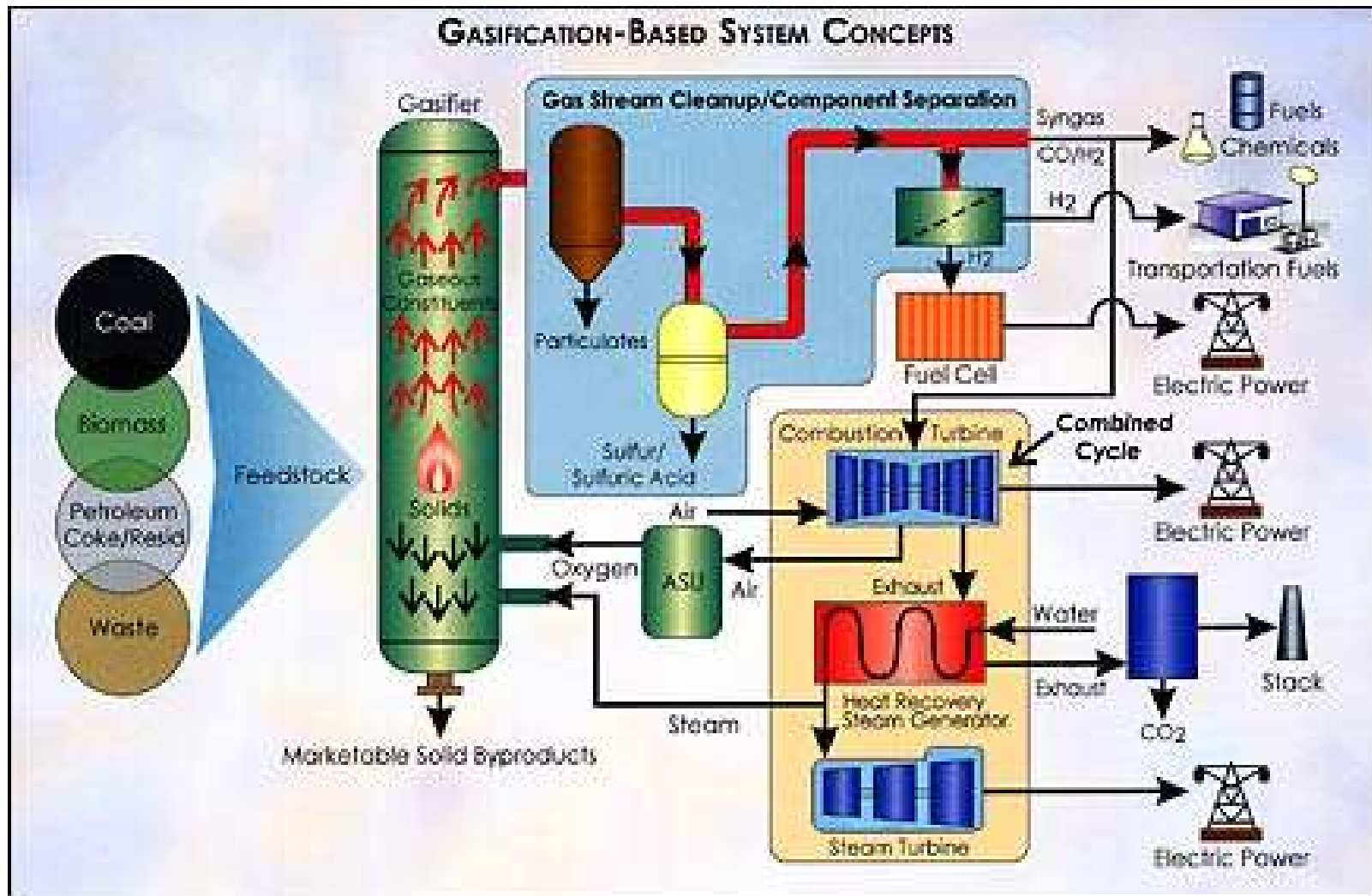
- Advantages

- Pipeline system (on-site production of hydrogen?)
- Most cost-efficient of current hydrogen-generation processes

- Disadvantages

- Finite resource
- Rising natural gas prices
- Not CO₂ neutral

Hydrogen Production - Coal



Hydrogen Production - Coal

- Advantages

- Can be implemented using current technology
- Pakistan has enough coal to make all of the hydrogen the economy needs for a long future
- Lowest cost for hydrogen

- Disadvantages

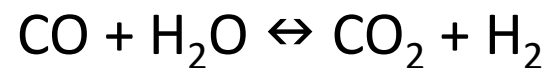
- Produces more CO₂ than other technologies
- Same environmental concerns as electricity generation from coal
- Centralized production
- Purification and separation of hydrogen at high temperatures is challenging

Hydrogen Production - Gasoline

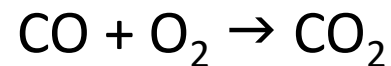
- For transportation needs, a short-term solution could be to convert gasoline, logistic or diesel fuel to hydrogen onboard
- Multiple steps are needed:

Conversion of gasoline to synthesis gas: $C_xH_y + H_2O + O_2 \rightarrow CO + H_2$
(steam or autothermal reforming, partial oxidation)

Water-gas shift



Selective oxidation



(or membrane separation)

Hydrogen Production - Nuclear

- Advantages
 - Long-term energy resource
 - Reduced dependence on foreign energy supplies
 - No CO₂ or air pollutant emissions
- Disadvantages
 - Nuclear waste
 - Public acceptance
 - Material issues at high temperatures

Hydrogen Production – Renewable Resources

- For a true hydrogen economy (no net carbon emissions), renewable resources must be used.
- Possible renewable resources include:
 - Water electrolysis
 - **Biomass conversion**
 - Biogeneration
 - Solar Energy
 - Wind Energy

Scenario for Pakistan For Green Hydrogen

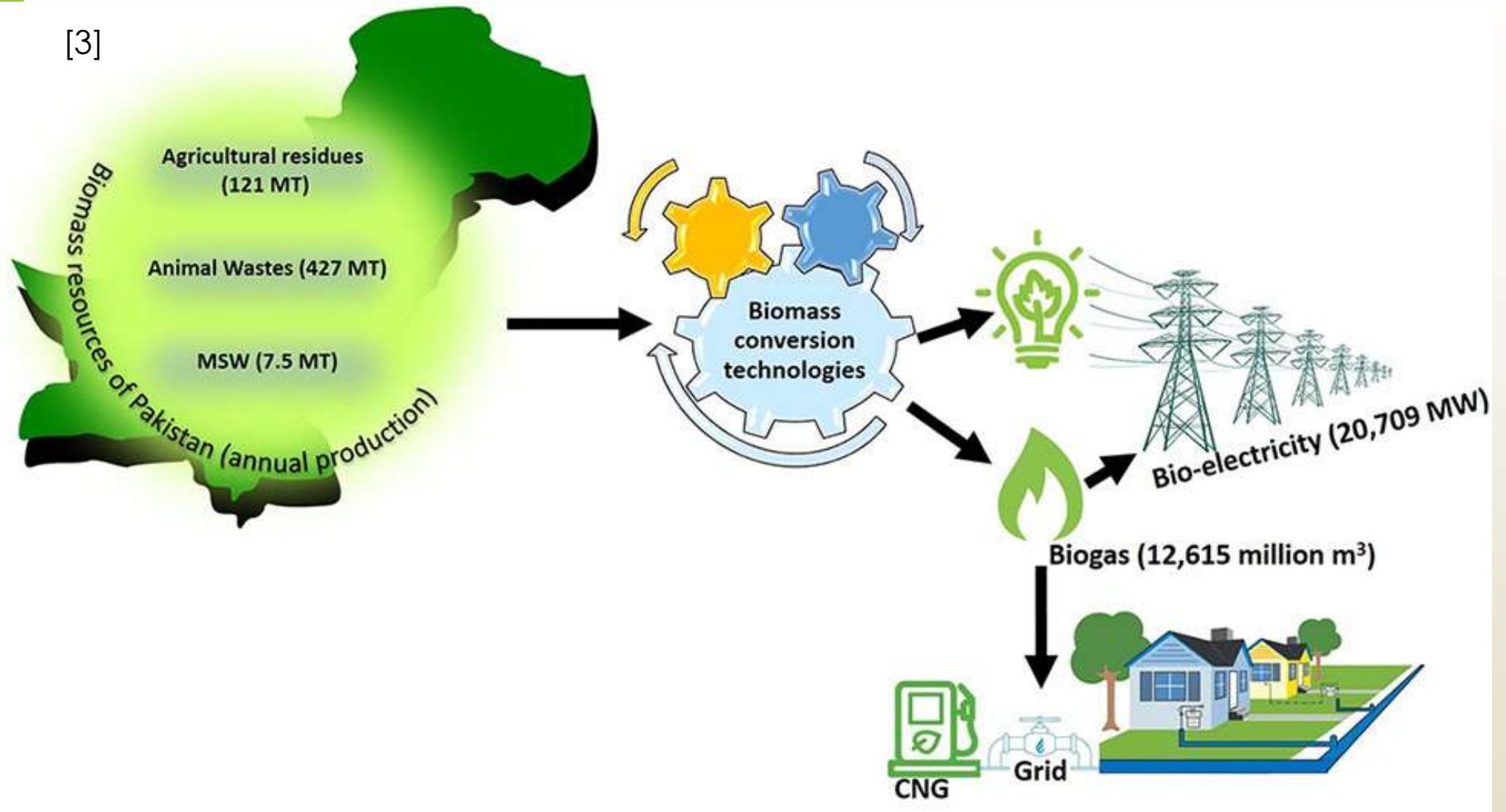
We present an overview of bioenergy in Pakistan in this study. Pakistan is a developing country that is currently suffering from severe energy and economic crises.

The country has an annual primary energy demand of 84 MTOE. Every year, Pakistan imports approximately 60 million barrels of crude oil. In addition, to meet its energy demands, the country imports approximately 248,550 million cubic feet of natural gas, 6.6 million tonnes of coal, and 12 million tonnes of other petroleum products from other countries [1].

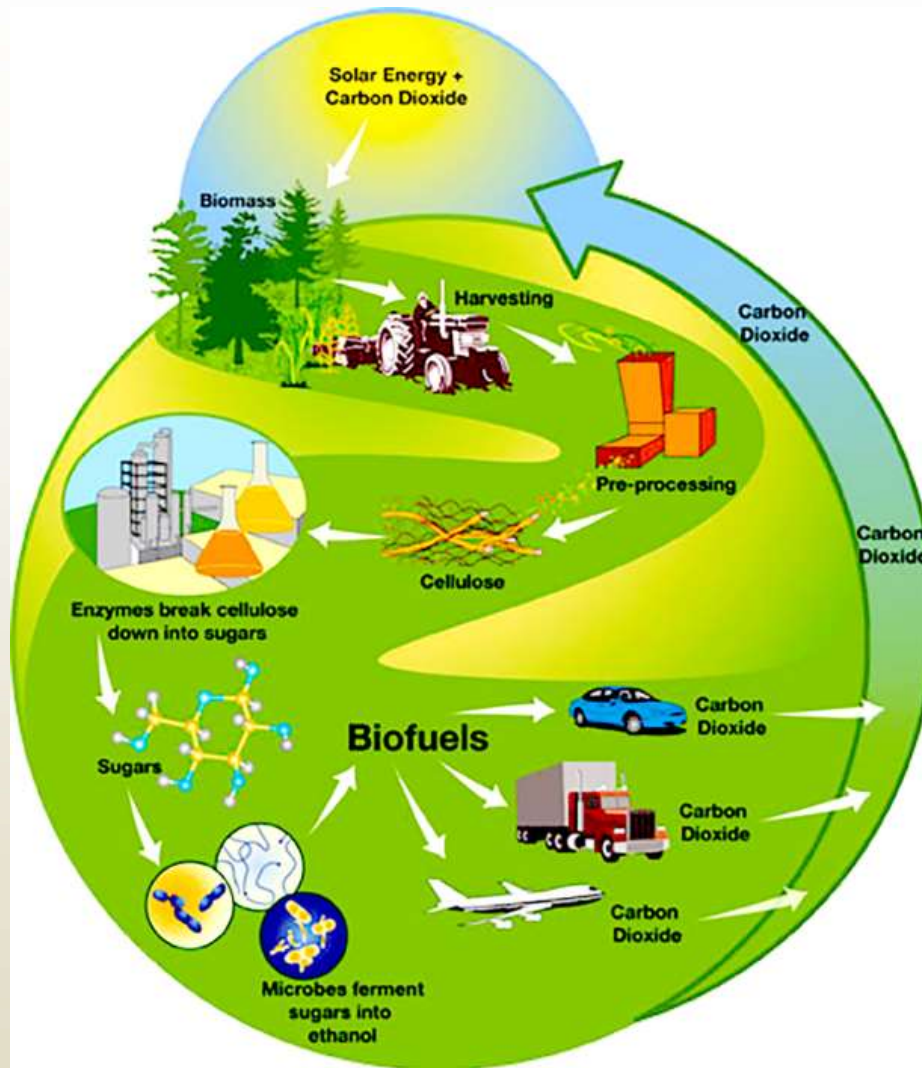
Pakistan is an agricultural country that generates a large amount of biomass each year, which will be available as a valuable raw material for renewable green energy in the future.

With the production of about 121 million tonnes/year agricultural biomass, dung from 200 million animals (buffalos, cows, sheep and, goats), and droppings from 1210 million birds of the poultry sector, Pakistan has a huge potential to produce a significant amount of bioenergy locally [1].

[3]



[2]



- Pakistan is a biomass waste rich country, and there are vast resources of waste generated after every harvesting of wheat and rice. One of the interest could be to reveal new thermo-chemical characteristics data of biomass waste.
- Power producing plants are the major emitters of greenhouse gases that lead to global warming and climate changes. In the past two to three decades, attention has been drawn to reduce their dependence on coal and focus on producing clean energy.
- Pelleting, briquetting, or extrusion processing are methods commonly used to achieve densification. To reduce the amount of hazardous gases, blends, that has undergone torrefaction, can be used to replace a small amount of coal. The gases emitted from torrefied blends combustion are part of the carbon cycle as biomass is produced from CO_2 absorbed from the atmosphere during photosynthesis.

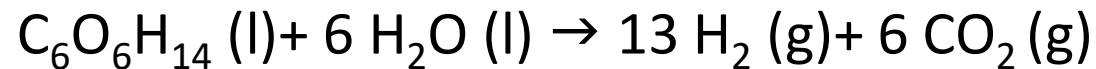


Hydrogen Production - Biomass

- Gasification, analogous to coal gasification, can turn crops or crop residues to hydrogen
- Advantages:
 - CO₂-neutral
 - Decreased dependence on foreign energy sources
- Disadvantages
 - Very inefficient
 - Large amounts of land required

Hydrogen Production - Biomass

- Catalysts can also be used to converted bio-derived molecules to hydrogen¹



Platinum and nickel-based catalysts have been found to catalyze this reaction at 500 K in aqueous solution

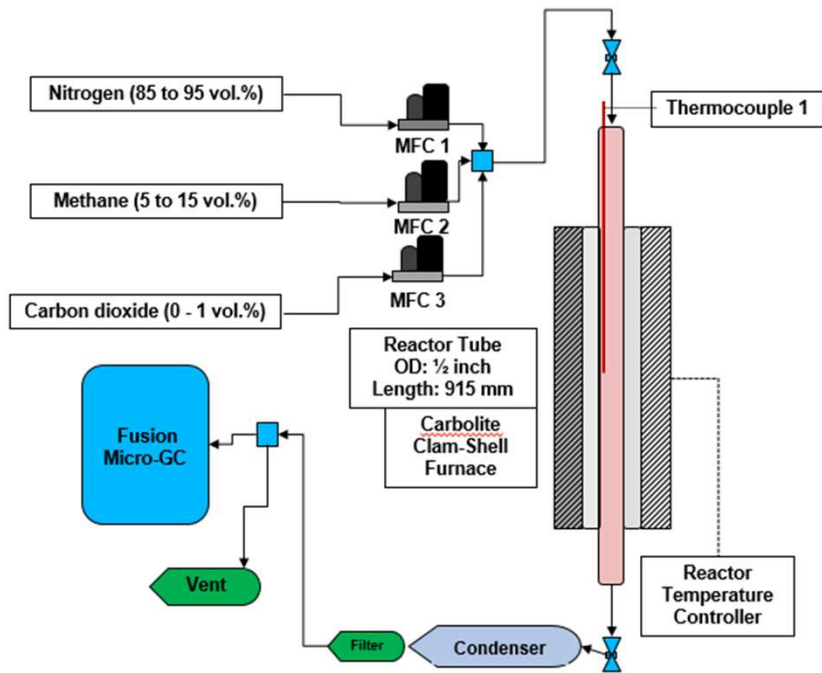
This could be a route to convert carbohydrates, which are extracted from renewable biomass and biomass waste streams, to hydrogen

¹Cortwright, R.D., Davda, R.R, and Dumesic, J. A., *Nature* **418** (2002), 964-967.

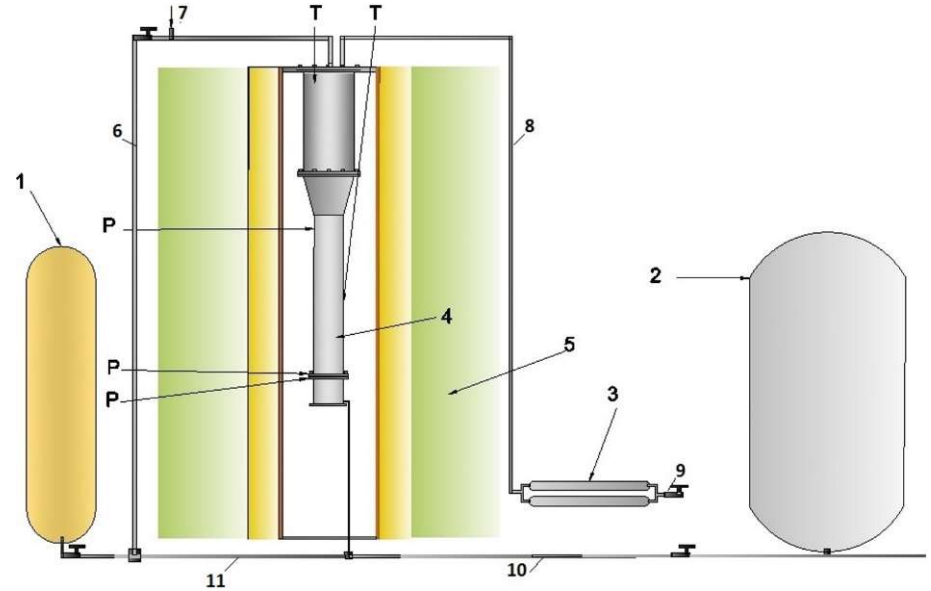
Gasification Reactors

- **Lab scale scale-up of gasification reactor to bench scale fluidized bed reactor**
- **Complexity of fluidization hydrodynamics**
- **Complex reaction engineering of biomass / coal gasification**
- **Gasification process development to improve efficiency**
- **Process intensification**

Gasifier Reactor Configuration



Fixed Bed Reactor Setup



Bubbling Fluidized Bed Reactor Setup

Natural gas – Biomass Co-processing

Biomass Utilization Challenges

- Highly variable composition of feedstock²
- Complexity of solid biomass handling³
- Low energy density and high oxygen content^{1,2}
- HDO of phenolic (C–OH), carbonyl (C=O) functional groups

Advantages of Shale gas / Natural gas

- Abundant availability, low prices
- High energy density⁴
- High H / C_{eff} ratio of methane (4) as compared to biomass (0.3)⁵

<https://www.eia.gov/outlooks/aeo/>

Hydrogen Production - Biogenesis

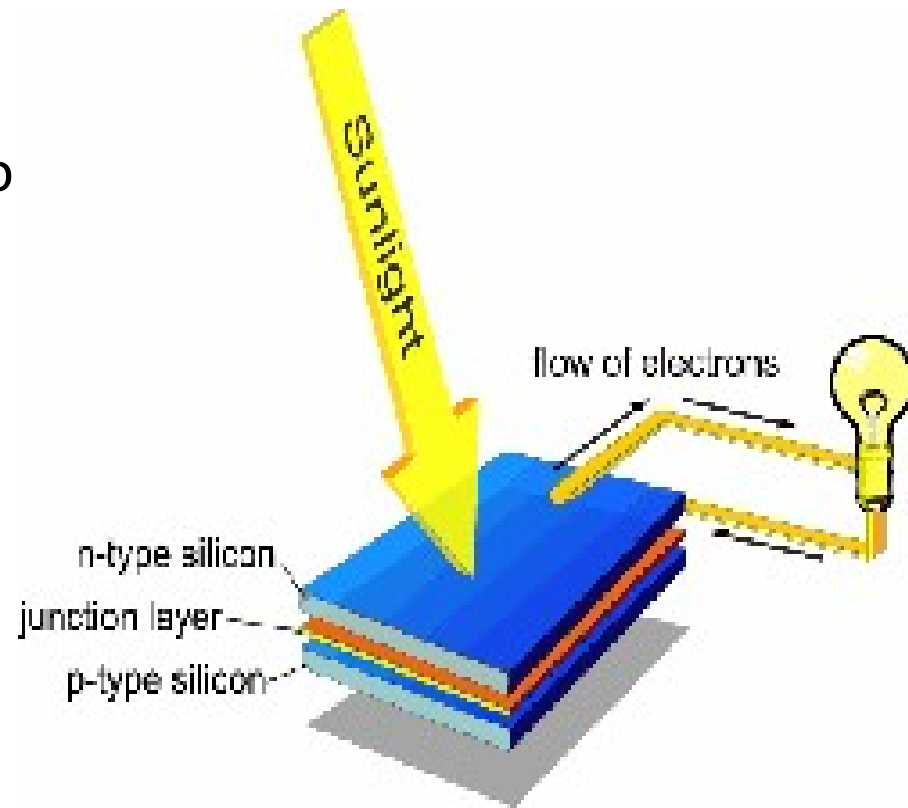
- Biogenesis uses microorganisms to generate hydrogen. Bacteria can take organic wastes (proteins and carbohydrates) and generate hydrogen. For example, members of the *Thermotogales* family produce hydrogen¹.
- Advantages:
 - Environmentally benign
 - Moderate processing conditions
- Disadvantages
 - Large-scale production has not been proven

Hydrogen Production – Solar Energy

Photovoltaic cell

Solar energy creates electron hole pairs, which create electricity

Electricity then drives electrolysis



Hydrogen Production – Solar Energy

- Recent work has studied the combination of these two processes in a single nanoscale process. Photon absorption creates a local electron-hole pair that electrochemically splits a neighboring water molecule
- This requires a material that is both stable in aqueous environments and has a small bandgap so that solar energy can be absorbed.
- Possible solutions:
 - Dye-sensitized photocells that accumulate energy from multiple low-energy photons to inject higher-energy photons into semiconductor
 - Doped oxide semiconductors with reduced bandgaps

Hydrogen Production – Solar Energy

- Advantages:
 - Distribute hydrogen generation
 - No pollution
- Disadvantages:
 - Expensive

Hydrogen Production – Wind Energy

- Wind-turbine electricity can electrolyze water to produce hydrogen
- Advantages:
 - No emissions
 - Cost-competitive
 - Domestic source of energy
- Disadvantages
 - Environmental and siting issues
 - Hydrogen only produced intermittently

The Future of Hydrogen?

- Hydrogen could resolve the fluctuating seasonal and day lighting issues behind storing solar energy.
- Geopolitically the use of the fuel cell would create freedom from foreign oil.
- Hydrogen-producing units can be stored virtually anywhere. BP and Shell have committed millions of dollars to hydrogen production and storage, while other oil companies are extracting hydrogen from gasoline around the nation.

Hydrogen Vehicles



- Stores energy more efficiently than batteries
- Burns twice as efficiently in a fuel cell as gasoline does in an engine
- Doesn't rely on any fossil fuel
- It's only waste product is water

Other Modes of Hydrogen Transport



Summary and Conclusions

- Hydrogen is extremely attractive because of its environmental implications, and because use of hydrogen in fuel cells is efficient
- Many options are being considered for hydrogen production. Production from renewable sources is the most attractive long-term, but has the most technical barriers at the current time
- Hydrogen storage is a critical issue that needs to be overcome for implementation of hydrogen in transportation applications

References

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