Systems thinking in a H$_2$ economy

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Some Questions:

• What is driving the dash to a hydrogen economy?
  • Is it logistics?
  • Is it simplicity?
  • Is it environmental efficiency?
  • Is it safety?

• What is the goal?
  • Is this a goal shared by society or is it skewed towards the potential beneficiaries?
  • Are the steps currently being taken good and effective steps toward achieving this goal?
What is the Goal?

• Currently the goal(s) of a „Hydrogen Economy“ is/are not clearly defined, however:
  • Hydrogen production is intended to increase both in the number of units and the capacity of these units.
  • Hydrogen is envisaged as replacing hydrocarbons as a combustible fuel.
  • Hydrogen is envisaged as being a ‚“building block“ to manufacture the chemicals previously obtained through traditional petro-chemical processes from ,for example carbon dioxide.
Current Energy, Fuel, Feedstock Systems

**Electrical Energy**
- Nuclear
- Coal, oil, gas
- Hydroelectric
- Waste
- Wind, solar, tidal
- Wood

**Transportation Fuel**
- Gasoline
- Diesel
- Kerosene (Jet)
- LPG, CNG, LNG
- Electric (battery)
- Hydrogen

**Fuel Storage**
- Natural gas reservoirs, gas network
- LPG, LNG
- Petroleum depots

**Industrial Energy**
- Coal, oil, gas, electric

**Domestic Heating and Cooking**
- Gas, coal, oil, electric (from grid), wood
- Solar, wind, geothermal (self generation)

**Feedstock**
- Petroleum refining products
Energy, Fuel, Feedstock Systems in a Fossil Fuel Free Economy

**Electrical Energy**
- Nuclear
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- Hydrogen?

**Transportation Fuel**
- Gasoline
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- LPG, CNG, LNG
- Electric (battery)
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**Domestic Heating and Cooking**
- Gas, coal, oil, electric (from grid), wood
- Solar, wind, geothermal heat (self generation)
- Hydrogen?

**Fuel Storage**
- Natural gas reservoirs, gas network
- LPG, LNG
- Petroleum depots
- Batteries
- Hydrogen?

**Industrial Energy**
- Coal, oil, gas, electric
- Hydrogen?

**Feedstock**
- Petroleum refining products
- Hydrogen?
Consequences

• **Transportation** would needed to be fuelled by hydrogen or electrical power.
• **Industrial energy** demands will need reviewing
• **Fuel storage** will need to be redesigned
• **Electrical power generation** with non-carbon resources will have to expand.
• **Hydrogen generation** will have to develop enormously.
• **Hydrogen storage** and transport will need to develop
Centralised versus Decentralised Approach?

- Mimic and/or re-purpose existing centralised and clustered generation, storage and transport of energy and fuel for Hydrogen use versus

- Evaluate decentralised approach where Hydrogen (for use as electrical power and fuel) is generated, stored and transported close to point of use so is co-located with community and industrial users
Centralised versus Decentralised Approach? (2)

- Centralised (mimic existing oil & gas):
  - Large scale hydrogen generation
  - Large scale storage
  - Extensive transportation network in pipelines or transport containers

- Decentralised
  - Local electrical power $\rightarrow$ small scale H2-generation
  - Small scale storage
  - Local use in industry, households or transport fuel systems

- Engineering feasibility and safety related risks need to be assessed.
Hydrogen Generation

• Electrolysis of water
• Fresh water in streams, rivers, lakes and underground aquifers is extremely valuable as drinking water and for agriculture.
• Electrolysis of sea-water, requires water purification. Energy is required for the reverse osmosis process.
• Hydrogen must be captured, compressed, stored and transported.
• Hydrogen generation in an economic form is energy intensive
Hydrogen Storage and Transport

• Currently hydrogen is not stored on the same scale as hydrocarbons.

• Unsolved questions:
  • Is a hydrogen pipeline network feasible? High pressures, losses need to be managed, safety of pipelines – new or repurposing?
  • Is hydrogen storage in caverns, rock formations or aquifers possible? – This is the way that natural gas is stored to balance winter demand.
  • If hydrogen is used to power vehicles, what could a large scale distribution network look like?
H₂ Economy without Hydrocarbons

• What happens to the:
  • steel (and other metals) industry;
  • cement industry;
  • polymer industry?

• These industries are required to achieve a H₂-based economy

• If these industries no longer exist in Europe, then they will move to developing economies.
Thoughts on the Decision Making Process (1)

• Just because a technology functions, does not make it:
  • safe;
  • environmentally sound;
  • economically and politically desirable.

• Just because government funding and incentives are provided does not make it:
  • economically and politically desirable;
  • a good long-term decision for the energy future of the country.
Thoughts on the Decision Making Process (2)

- When technology is exported to developing economies will it be:
  - safe;
  - managed in an environmentally responsible manner;
  - beneficial to the economy of the new host country?

- Engineers need to think about inter-connected technologies and the effects on the whole system.

- Complex decision making is not just a science and engineering decision, but also an economical, political, sociological and ethical decision which needs to look at longer term impacts.
Example Influence Diagram for Hydrogen Use Decision Making

- Hydrogen production method
- Scale of demand
- Novelty
- Complexity
- Accessability
- Policy
- Physical properties
- Chemical properties
- Raw materials and energy required
- Risks
- Finance
- Stakeholders
- Balance of centralised/decentralised
- TOR demonstrated
  - Individual
  - Societal
  - Environmental
- Economically feasible
- Sustainability demonstrated
- Technically feasible
- Socially acceptable
- Politically acceptable
- Finance
- Socially acceptable
- Politically acceptable
- Economically feasible

*Objective node which provides the aim for the model*

*Decision node under direct control*
Finally

• Energy supply is highly complex.
• Hydrocarbons are not just fuels, but also feedstocks. Replacing them is a risky decision with many unknowns.
• Decision making in a complex system does not lead to one optimum result.
• Engineers will be confronted with ethical decisions.
• A H₂-Economy is unlikely, however an increase in H₂ in a more diverse energy and material supply system is a realistic outcome.
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Mina-Al-Ahmadi oil refinery night

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