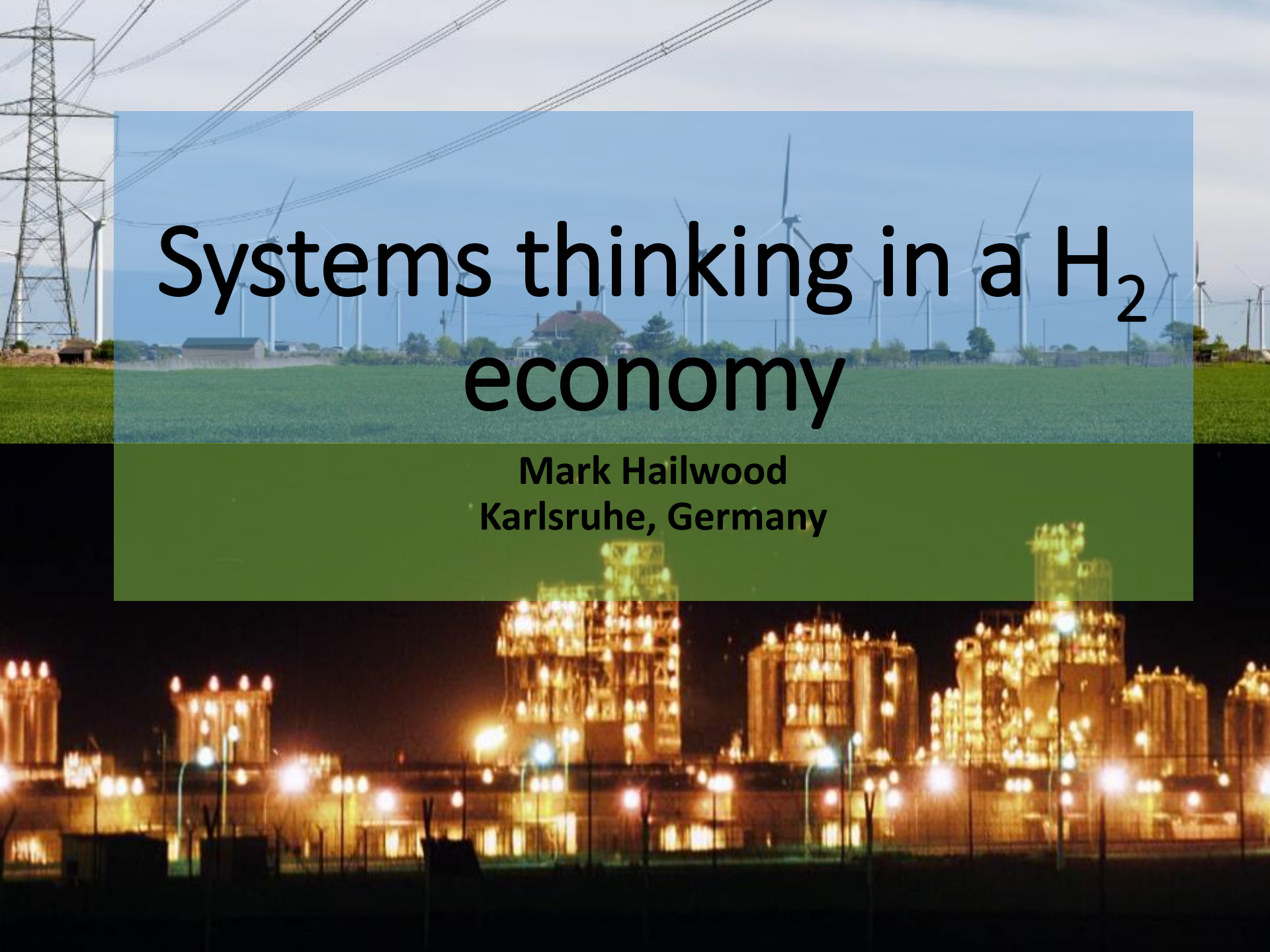

# Systems thinking in a $H_2$ economy

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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
- ~~Coal, oil, gas~~
- Hydroelectric
- Waste
- Wind, solar, tidal
- Wood

- Hydrogen?

**Transportation Fuel**

- ~~Gasoline~~
- ~~Diesel~~
- ~~Kerosene (Jet)~~
- ~~LPG, CNG, LNG~~
- Electric (battery)

- Hydrogen

**Fuel Storage**

- ~~Natural gas reservoirs, gas network~~
- ~~LPG, LNG~~
- ~~Petroleum depots~~
- Batteries

- Hydrogen?

**Industrial Energy**

- ~~Coal, oil, gas,~~ electric

- Hydrogen?

**Domestic Heating and Cooking**

- ~~Gas, coal, oil~~, electric (from grid), wood
- Solar, wind, geothermal heat (self generation)

- 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 → 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?

# $H_2$ Economy without Hydrocarbons

- What happens to the:
  - steel (and other metals) industry;
  - cement industry;
  - polymer industry?
- These industries are required to achieve a $H_2$-based economy
- If these industries no longer exist in Europe, then they will move to developing economies.

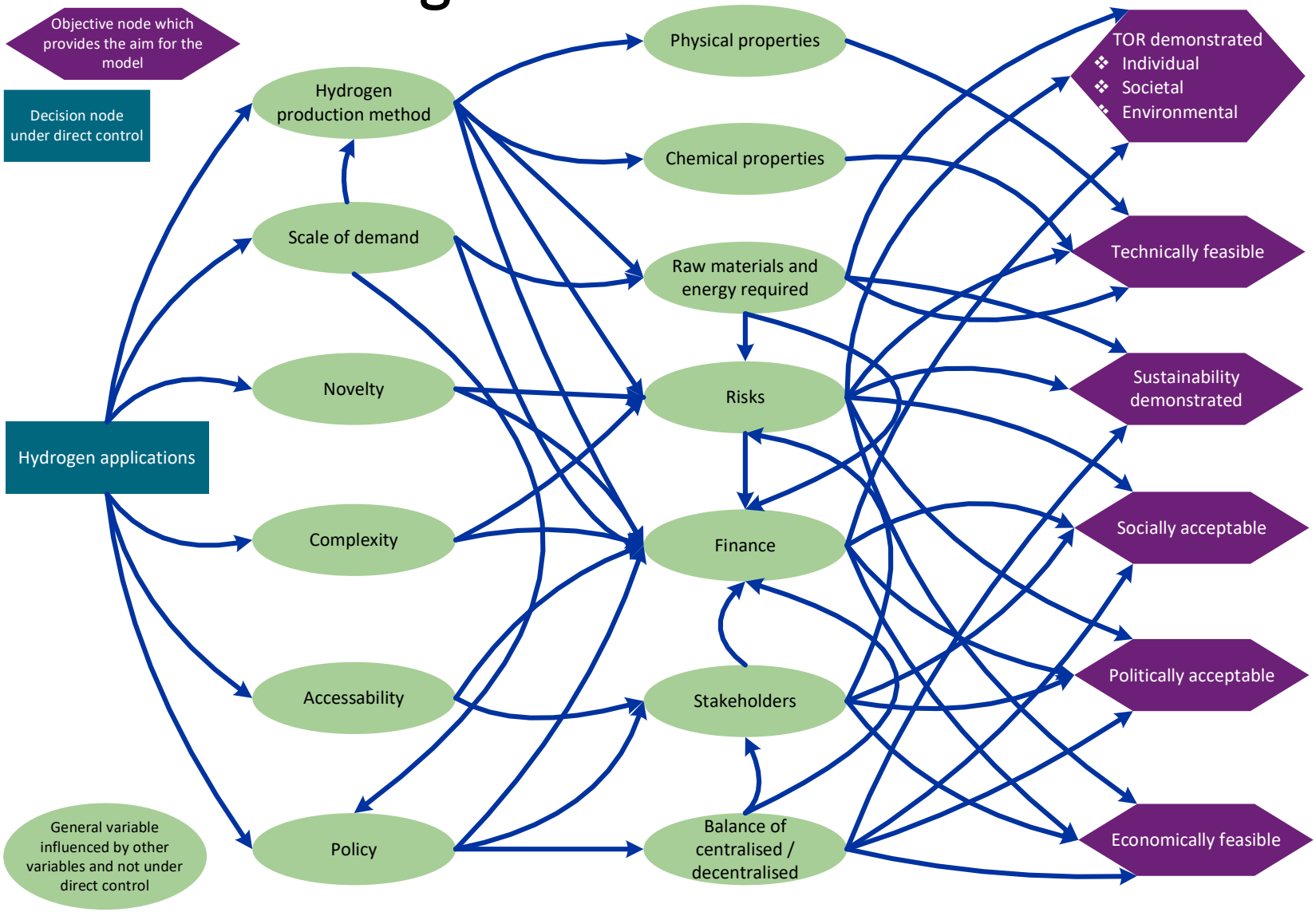
# Thoughts on the Decision Making Process (1)

- 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



# Finally

- Energy supply is highly complex.
- Hydrocarbons are not just fuels, but also feed-stocks. 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 $H_2$-Economy is unlikely, however an increase in $H_2$ in a more diverse energy and material supply system is a realistic outcome.

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Wind Turbines and Power Lines, East Sussex, England - April 2009

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Mina-Al-Ahmadi oil refinery night

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