RISK ANALYSIS OF COMPLEX HYDROGEN INFRASTRUCTURES

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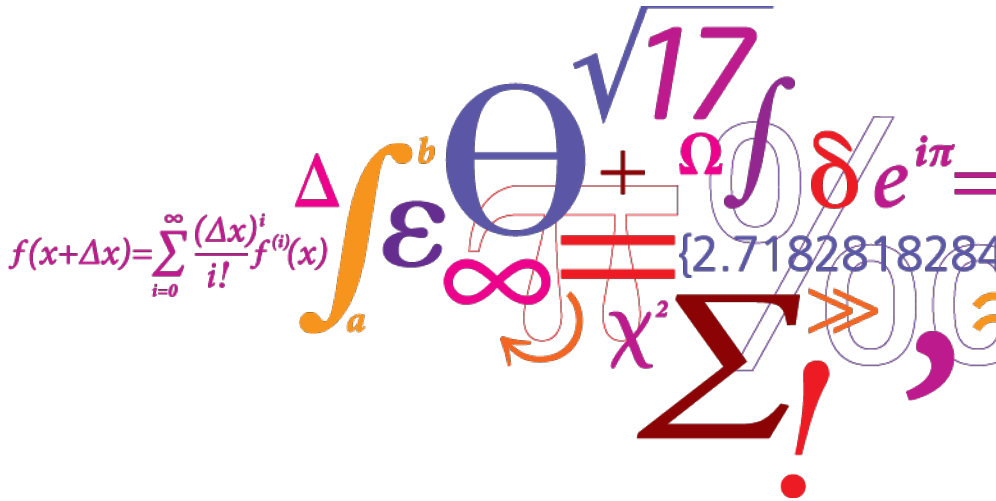

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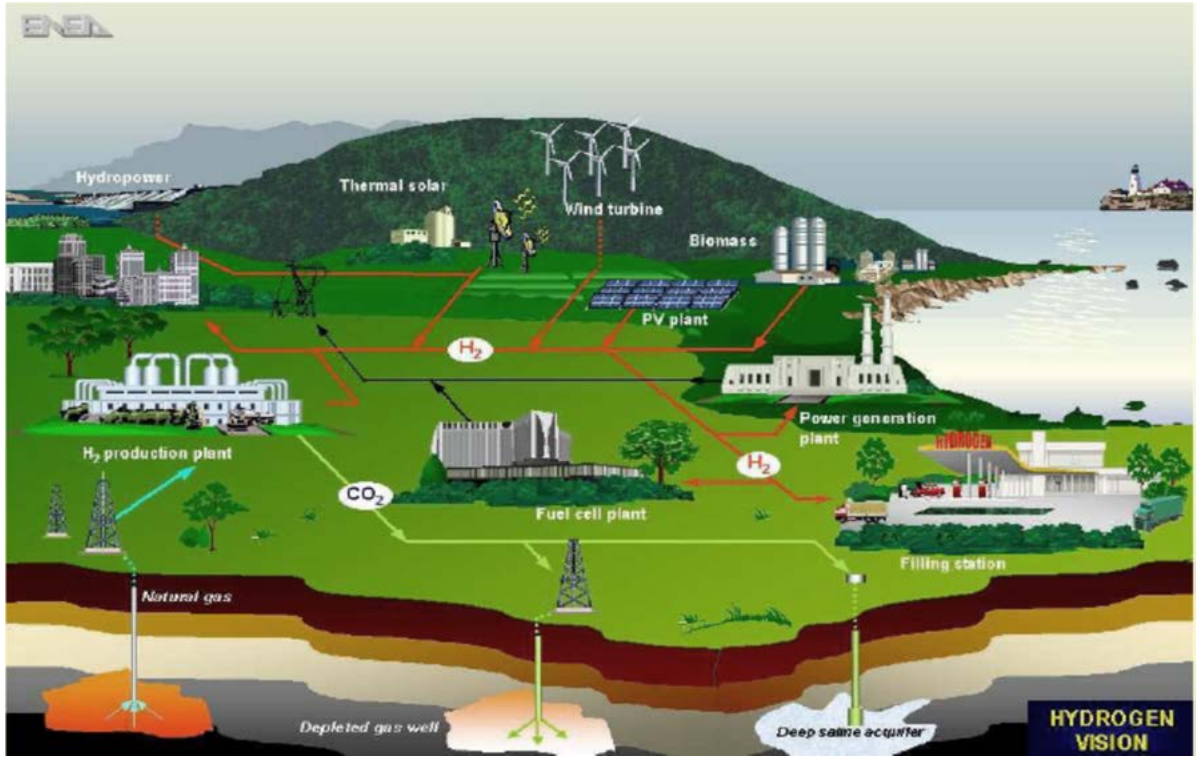
Developing a sustainable H2 refueling station network

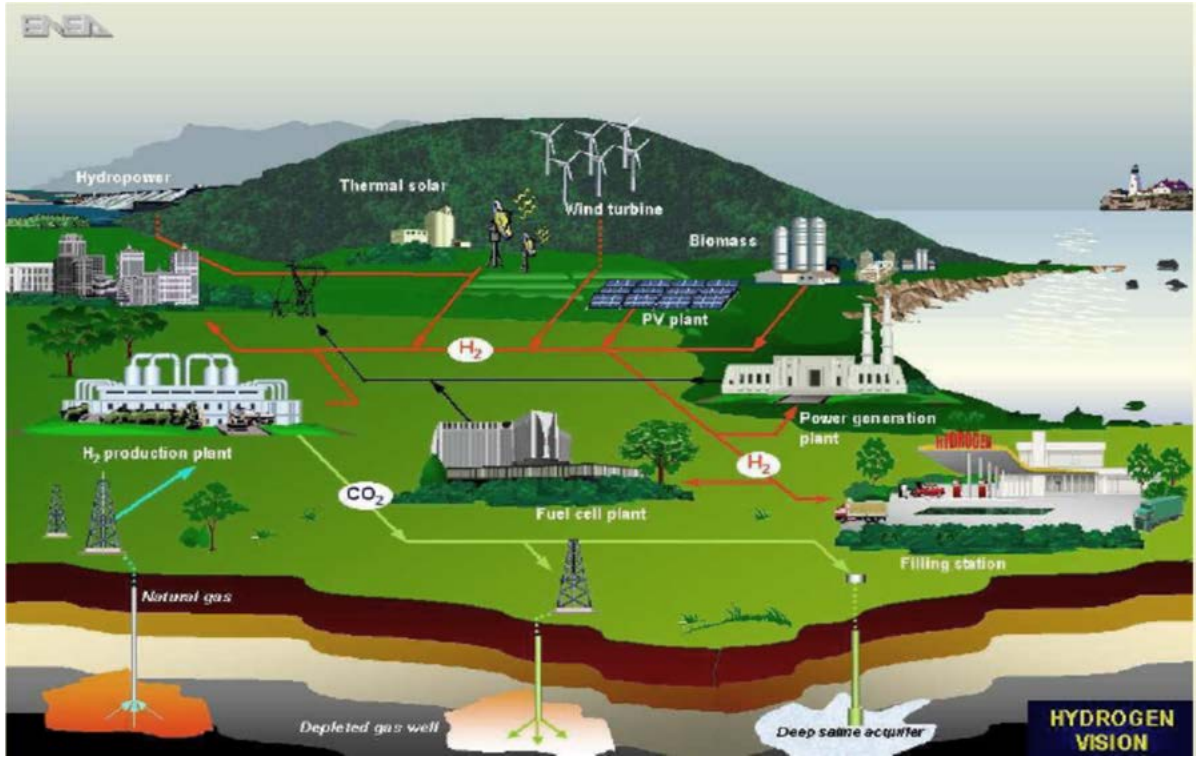
- Hydrogen driven vehicles need a developed hydrogen refueling station (HRS) network
- Presently, first stations and starting networks are being established
  - E.g. Nordic hydrogen highway connecting Norway, Sweden, Denmark and Northern Germany



Decision support is needed

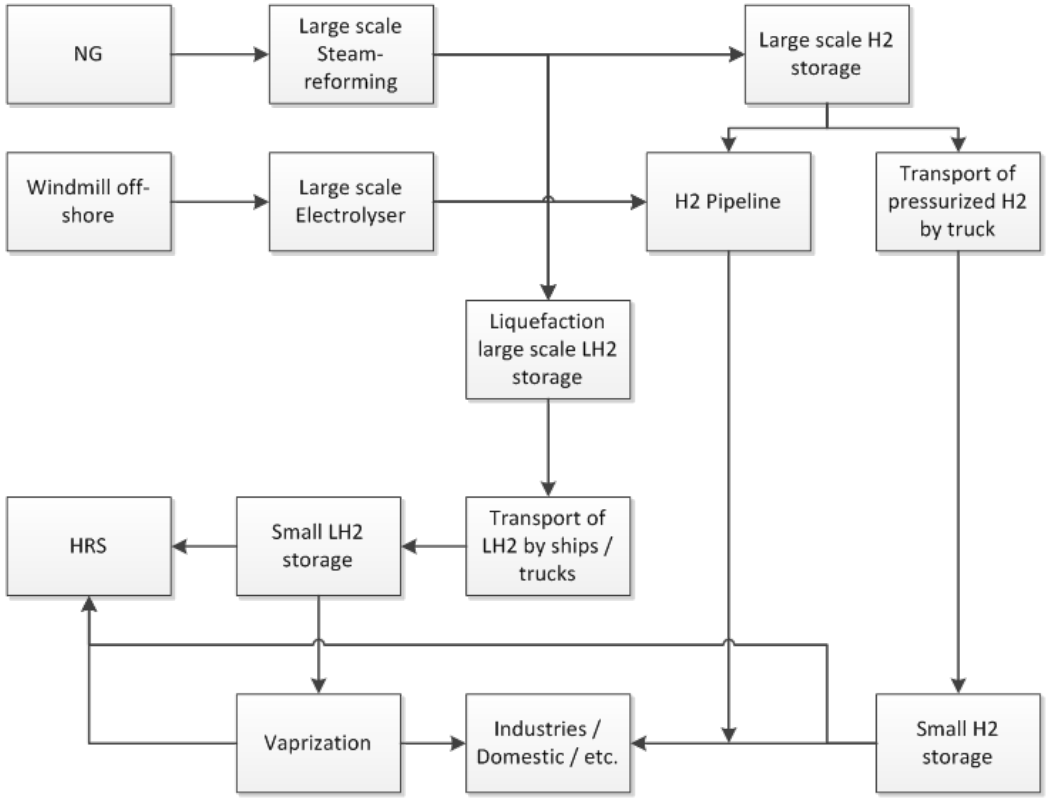
- How to integrate new HRS with existing refueling stations?

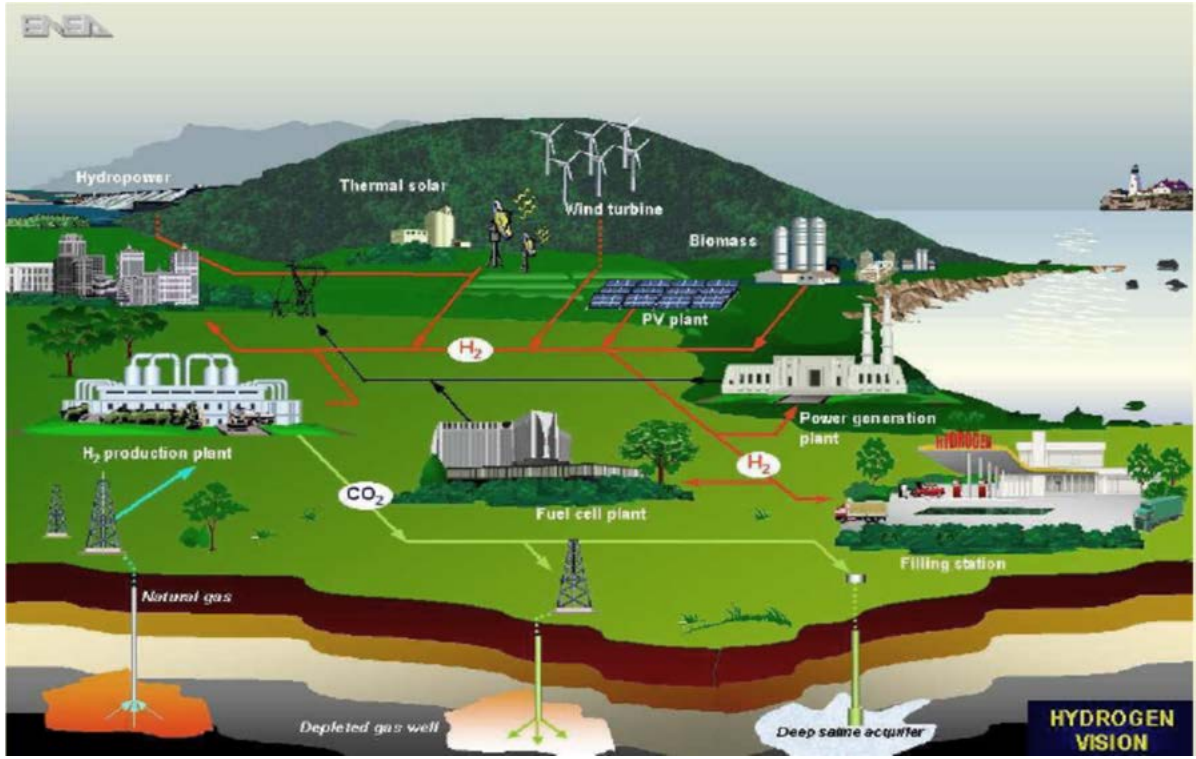
- What is the best strategy to place the HRS in network of refueling stations?
  - Considering for HRS & supply chains:
    - Risk minimization
    - Sustainability
    - Cost benefit aspects and Life Cycle costing
    - …



➢ **How to secure a coherent decision support for all requirement?**

Development of a model





Lit.: "Fuel Cells and Hydrogen Research in the European Union" 2004 DOE Hydrogen and Fuel Cell Program Review Philadelphia, 24 May 2004
Mr. Joaquín MARTIN BERMEJO Unit "Energy production and distribution systems" DG Research – RTD/J-2

A generic problem

Is it possible to assess a system consistently?

e.g. to allow for consistent comparision between different design?

The problem decision support is based on different models for e.g.

- Risk Assessment (RA)
- Life Cycle Assessment (LCA)
- Life Cycle Costing (LCC)

- The data requirement of the methods for decision support are different
- Different domain experts do the assessments separately

- The results may not be comparable when different designs of such networks have to be decided on

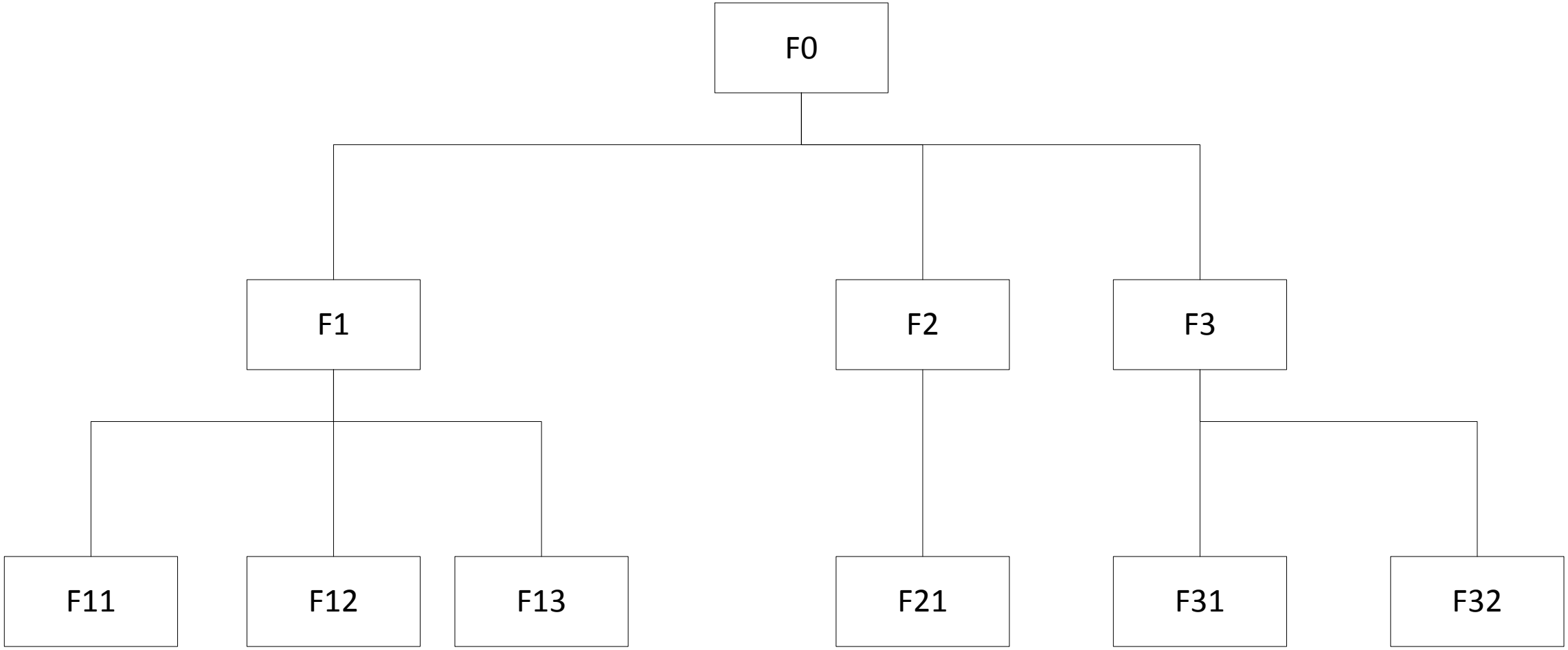
Quality in Decision support: How to reduce the model and data uncertainty ?

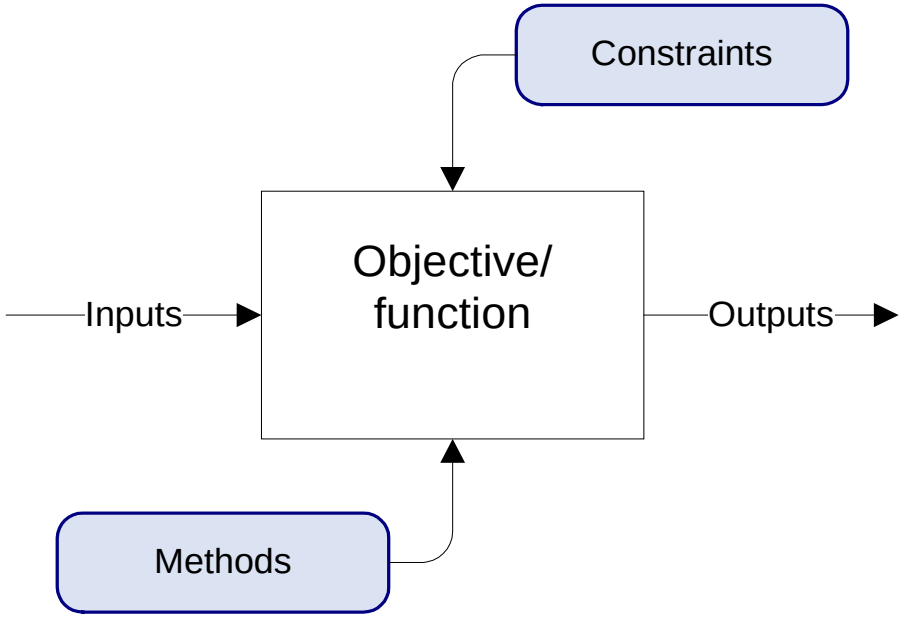
- Ensuring for all kinds of decisions:
  - the same system model applies
  - the same assumptions are used for each of the assessments

A possibility: Development of a “Metamodel”

- A Meta model of the system is established that includes all the aspects of the methods of decision support (RA, LCA, LCC,…)
- The model shall ensure that the same design is analyzed for each RA, LCA, LCC,..
- The model ensure consistency in the assumption to be made
- The model supports data quality
  - being a reference database for all the data
    - E.g. a central server solution

Theory of Functional Model





This function block can be interpreted as:

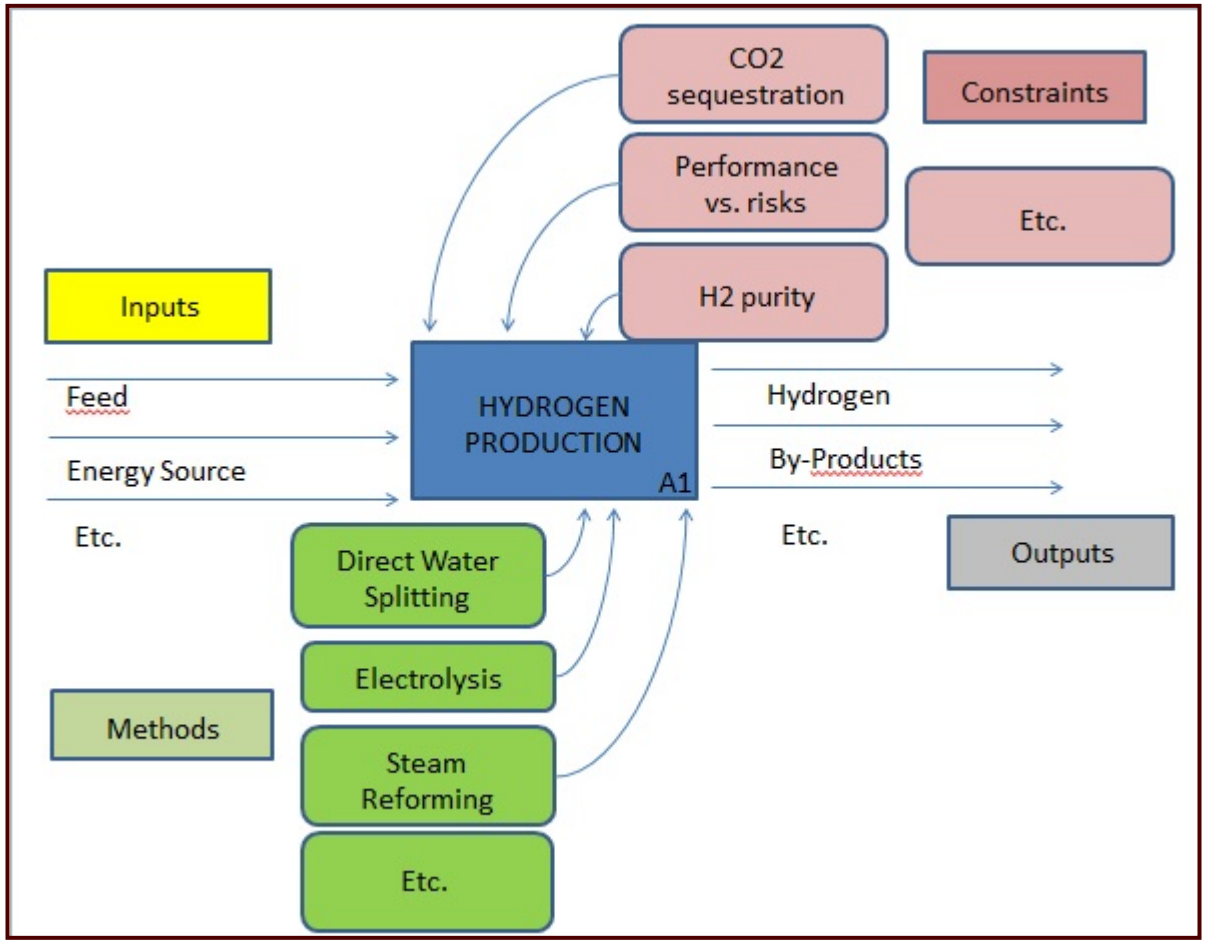
Do <Objective> by <Methods> respecting <Constraints>

Or:

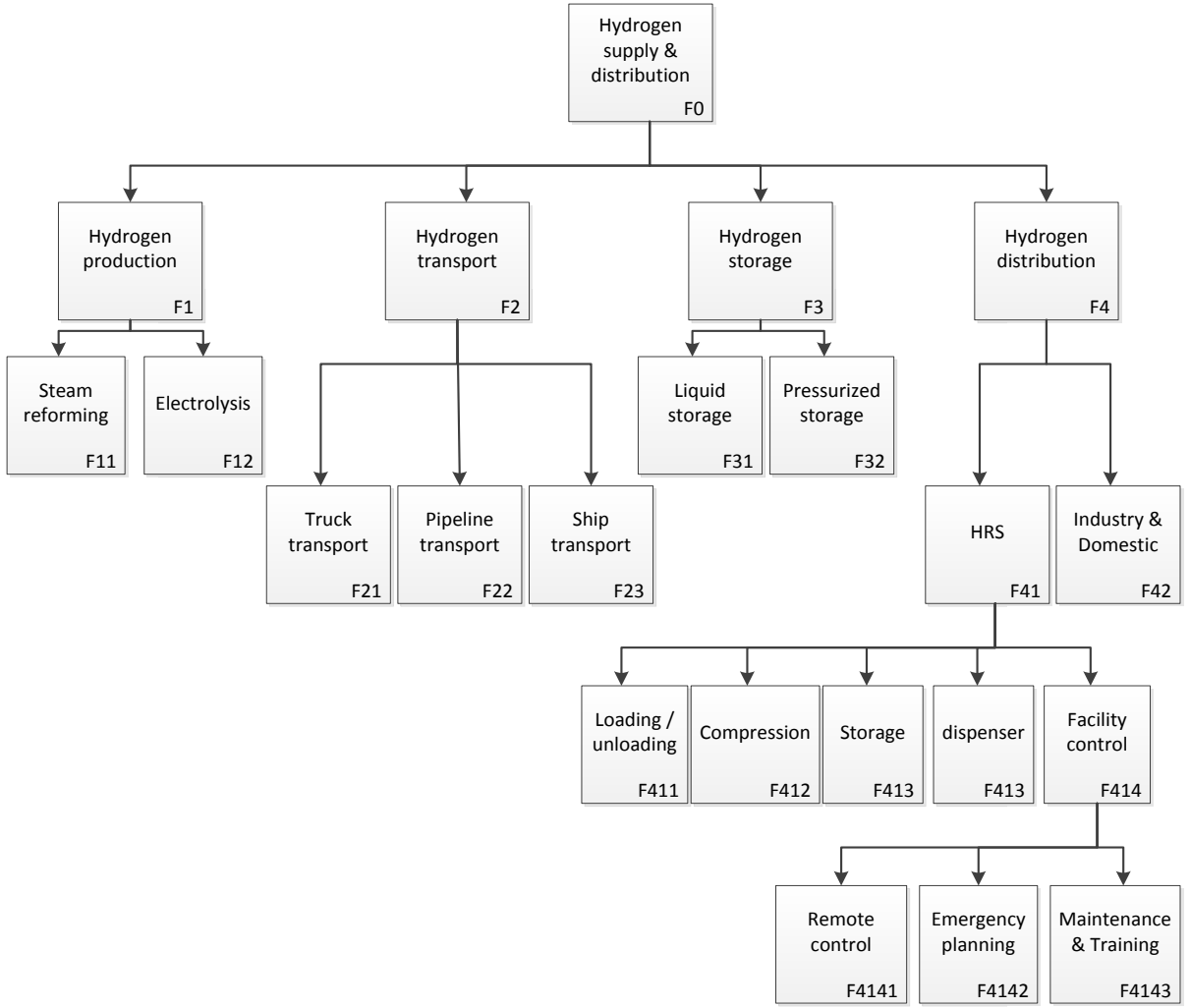
Produce <Outputs> from <Inputs> by <Methods> respecting <Constraints>

Hierarchy is introduced by expanding each Method as a Function (a child function of the function it contributes to).

Specific example for Hydrogen production



Example of hydrogen system



Example of hydrogen system: tabular output

Code	Inputs	Intent	by	Method	with	Constraints	Outputs
F3	Hydrogen gas energy Etc.	Hydrogen storage at large amounts		Cryogenic storage Pressurized storage		Max. pressure Temperature control Evaporation control	Hydrogen gas / liquid Engine pollutants Etc.
F12	Electrical power Water Etc.	Hydrogen production		Electrolyser		Max. pressure Availability of cheap power sources Hydrogen purity Etc.	Hydrogen Oxygen Etc.
F4141	Data Power; Etc.	(HRS) remote control signals		Internet/ software HRS safety functions Surveillance: Detection & Alarm →Decision→Action Communication Training		On-line uninterrupted power supply, intercultural understanding Etc.	Control of HRS

Keywords for Concept Hazard Analysis

Flammables	Ignition Fire Explosion / detonation
Chemicals	Toxicity Corrosion Off-specification
Pollutants	Emissions Effluents Ventilation
Health hazards	Chemical contact Noise Illumination
Electrical / radiation hazards	Electrical Radiation Laser
Thermodynamic hazards	Over- / under pressure over- / under-temperature

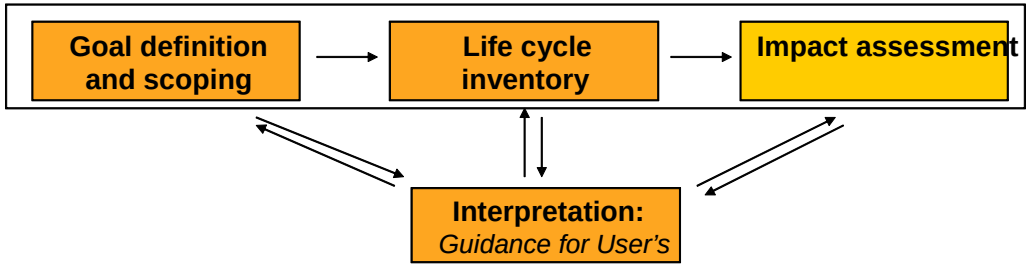
Mechanical hazards	Structural hazards Collapse, drop
Mode of operation	Start-up / Shutdown Maintenance; Abnormal Emergency
Release of material	Release on rupture Release by discharge Fugitive & periodic emissions
Loss of services	Electricity Water Other services
External threats	Accidental impact; Drop/fall Extreme weather External interferences, a.o.

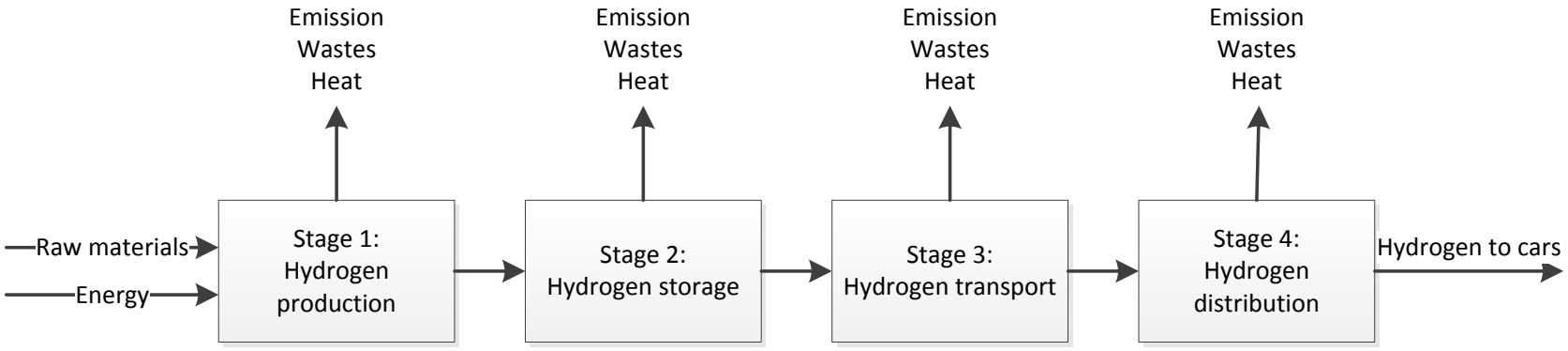
Function		Concept Hazard Analysis				
Ref	Description	Keyword	Main variance	Consequences	Mitigation	Notes
F12	Water electrolysis	Chemicals: Corrosion	Release → Fire	Heat radiation on equipment	ATEX	
F21	Truck transport (pressurized)	Thermodynamic hazards: over temperature	Weakening of truck tank walls under filling	Tank rupture	Slow filling, pre-cooling	Depends on storage type
F3	Hydrogen storage	External: Accidental impact due to obstacle collision	Structural damage: →leakage →insulation	Release of hydrogen / overpressure in cryogenic system	Fences authorization to enter	
F4141	On-line with data connection	Mode of operation: Abnormal	Off-line → Loss of control of HRS	Possible escalation of minor events	High SIL level local operation	HRS shuts automatically down on loss of data connection

GIS – preservation of geographical relations

- An important issue, when analyzing hydrogen supply and distribution networks, is the knowledge about the specific geographical positions of the hazardous areas:
  - to evaluate for social risk criteria.
    - to decisions on additional preventive and mitigating measures to ensure the acceptance criteria of a given installation.
- Along the networks it is important to know about
  - the population density,
  - the environmental vulnerability and
  - the location of hospitals, emergency service etc.
- For this GIS is a very efficient and valuable tool for QRA
  - Information on system state (amounts, pressures, temperature, etc.) could as well be attached to the graphical objects supporting consequence assessments,
  - while necessary weather, population densities and other data could be provided by respective thematic maps. .

Life cycle assessment





Discussion and Conclusion

- **The risk assessment of a complete supply chain is analyzed using**
  - the functional modelling approach
  - the conceptual hazard analysis methodology.

- The functional modelling allows the modelling of new designed technologies
  - may be more and more detailed as new information and alternative technologies are implemented.
  - The high level risk analysis enables the efficient risk assessment
    - help to concentrate the assessment to the hazardous parts of concern.

- At a certain level there is a transition where a low level assessment is appropriate,
    - application of FMEA and HazOp

Discussion and Conclusion

- the functional model database may be used as the comprehensive database to :
  - collect relevant input, output, methods, constraints, graphical data and inventory data to ensure a single place storage and maintenance of the needed data and assumptions.
  - The latter may be also implemented as a GIS database – preservation of geographical data
  - The basic model used for the functional breakdown can be similar to the stages of the LCA/LCC

- Support for a holistic decision support
  - other sustainability aspects may be integrated and assessed
  - Environmental aspects
  - Economical aspects
  - Social aspects

THANK YOU FOR YOUR ATTENTION