HYGEAR

Sustainable Hydrogen Production - Discussion

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Definitions

- What does Green mean?
  - Green is a color
- CO_2-Neutral
  During H_2-production, no net CO_2 is emitted to environment
  - CO_2 capture & segregation
  - Nuclear
- Sustainable/Renewable
  H_2 production is based on renewable sources and thus CO_2-neutral

Why Hydrogen?

- Hydrogen is energy-carrier not a source

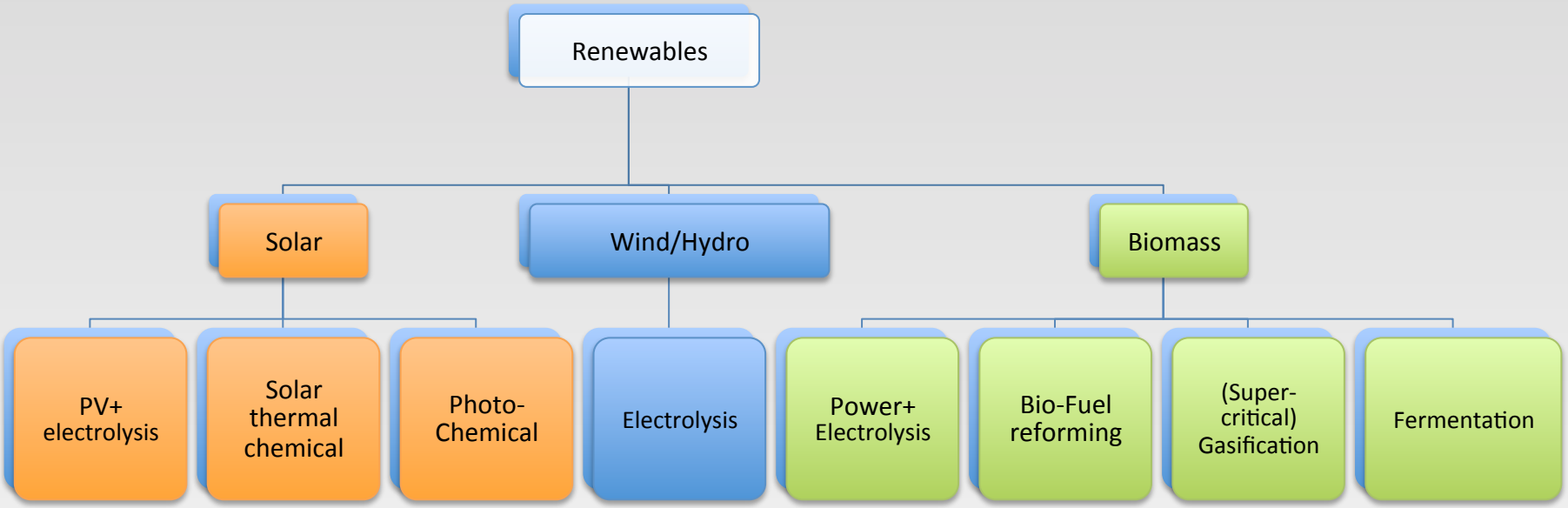
- Using H_2 decouples energy-sources and usage
  - Allows multiple sources for production
  - Creates security of supply
  - Reduces foreign interdependency
  - Allows CO_2-neutral production
  - Allows gradual shift from fossil power to renewable power

- H_2 and electricity are a good match

H_2-sources

- H_2
  - Fossil
    - Reforming
      - CCS
      - Conventional
      - Localized
    - Power+Electrolysis
  - sustainable

H_2-sources


Renewables
Solar
Wind/Hydro
Biomass
PV+ electrolysis
Solar thermal chemical
Photo-Chemical
Electrolysis
Power+ Electrolysis
Bio-Fuel reforming
(Super-critical) Gasification
Fermentation

H_2 sources by Electricity

- Renewable electricity is valuable…
- Renewable electricity is subsidized

- USE renewable electricity wisely!

- Electrolysis → H_2-storage → Fuel Cell
  η=85% η=95% η=50%
  – Total efficiency <40%

- Best to use electricity direct!

- Use H_2-storage for peak-shaving and match intermittent power (De Bruijn, June 2010. Brey Dec. 2010)

Solar Sources

- Thermo-Chemical water splitting
  - Thermally reduce metal oxides, oxidize with H_2O to produce H_2
  - Suitable for centralized Production
  - Cost reduction needed for production and upgrading
  - SOLASYS, HYTHEC and HYDROSOL EU projects

- Photo-Chemistry
  - Catalytic water splitting by UV
  - Decentralized production
  - Photon yields low, low efficiency.
  - Fundamental breakthroughs needed

Bio-sources

- Thermo-Chemical routes
  - Bio-fuel reforming
    - Ethanol, bio-diesel, Bio-gas
  - Gasification
    - Classical: dry feeds
      Semi-Centralized production. Gas-cleaning cost prohibitive
    - Super-critical: wet feeds
      In pilot/demonstration development phase

- Biological processes
  - Information by Pieternel Claassen

Allowable Costs

- Cost targets derived from comparison to gasoline costs
- Assumptions:
  - Cost per driven km equal for economic adoption
  - Fuel cell cars will be twice as efficient as gasoline vehicles

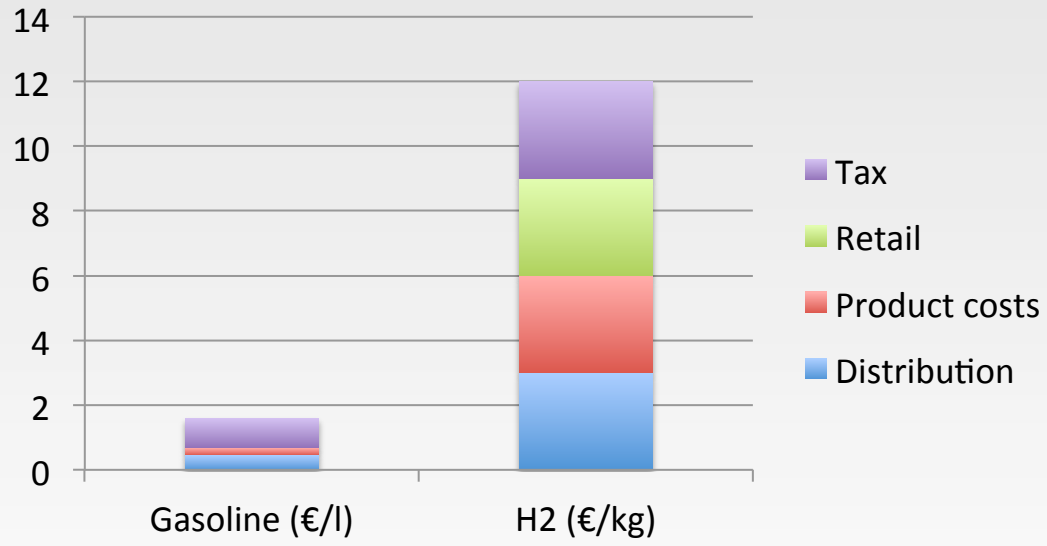
- 1kg of H_2 can then be 7.5 times price of 1l of gasoline*
  - Max Cost of 1kg H_2 will be around €6 at the pump
    - Based on current price of gasoline
    - Expected increased gasoline prices can change cost targets

- Price of gasoline is mainly tax driven
  - Assumption is that cost of green fuel can be higher if lower taxation
  - How to include CO_2 credits?

* Based on caloric value and efficiency of fuel cell vehicle

Retail price and costs of H_2 – Dutch example

- Retail price of gasoline in Netherlands is €1.60
- Max. price of 1kg H_2 = €12
- Cost come from production, distribution, retail and taxes
- Cost split for H_2 is arbitrary as unknown. If the split is equally, cost target at retail site is €6.0



Future

- The future will bring a mix of energy-technologies
  - Hydrogen
  - Biomass
  - Electricity

- Estimation for transport: mix of battery-vehicles, plug-in hybrids and fuel cell cars (McKinsey, Nov2010)

- There is a positive business case for hydrogen powered vehicles

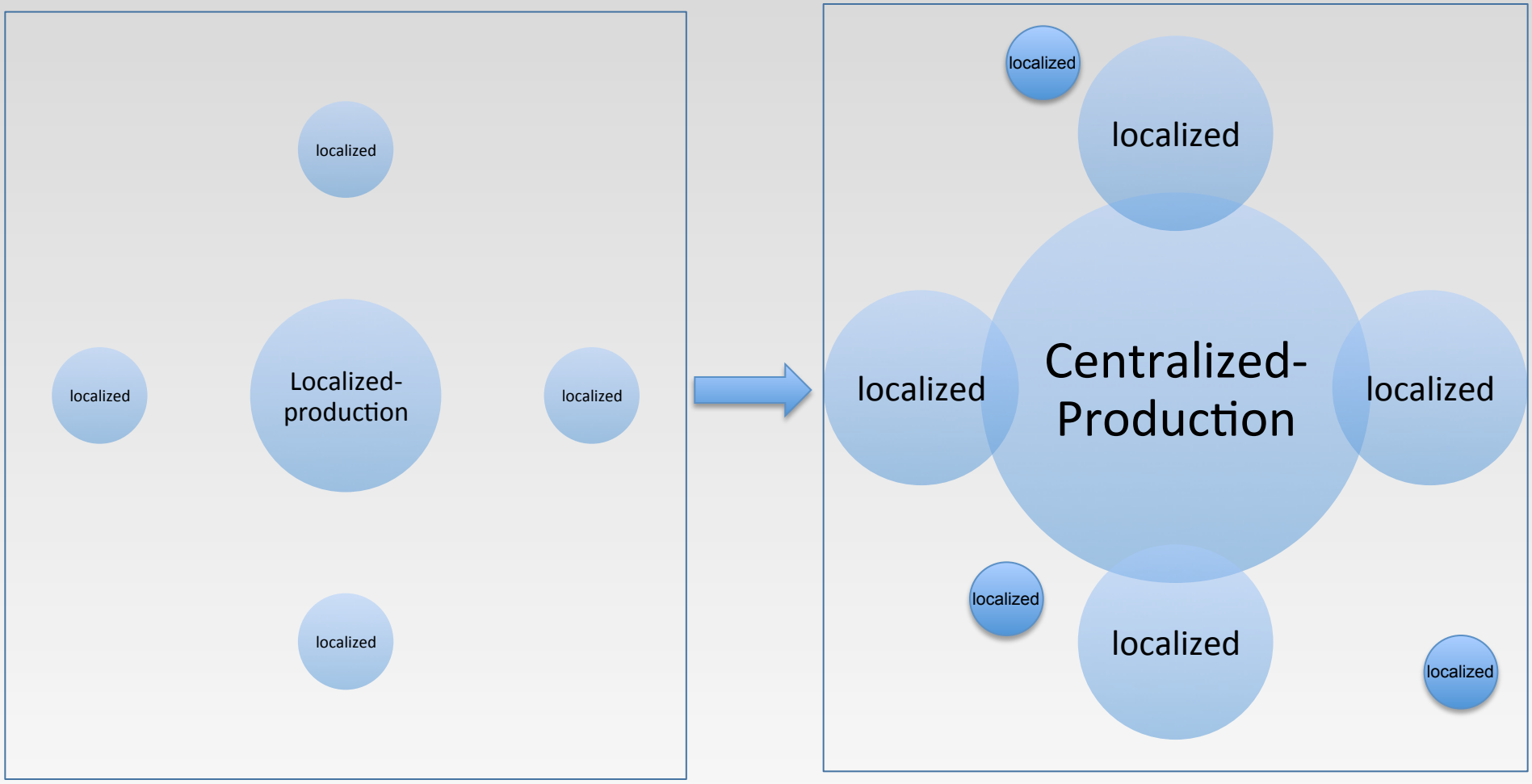
- Most difficult hurdle:
  - Transition

Roll-out infra-structure

- Most cost-effective solution today = Natural gas reforming (with CCS)
- Need for H_2 transport
  - H_2-pipelines
    - Very capital intensive
    - Have a minimal and maximum flow-rate!
  - Only build pipeline at end-game of transition
    - Needs to make local sense
    - Not cost-effective in most remote locations (non-EU)

- Need of intermediate & remote solutions

Growing & Connecting H_2-grids



Driver of change is cost per kg H_2

Renewable sources utilization

- Some production centralized (solar)
  - Use H_2 transport
- Biomass is best used locally
  - Low energy content → convert to H_2 and use locally
  - Upgrade energy content and refine centralized
- H_2 road-transport is energy intensive
  - Use localized production from easily transportable fuels
    - Natural Gas
    - Bio-Ethanol
    - Bio-Diesel

Transition with localized production

- Fuel companies want to minimize transport
  - Use as much same fuel as possible

- Produce H_2 from currently available fuels
- Produce renewable H_2 if possible

- On-site H_2 generation from locally stored:
  - Bio-diesel
  - Bio-ethanol
  - (DME)