FROM HYDROPOWER TO HYDROGEN

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Who Are We?

- **IHA**
  - **founded in 1995 under the auspices of UNESCO’s International Hydrological Program**
  - **formed to advance sustainable hydropower globally**
  - **having more than 1000 corporate and individual members, spanning more than 80 countries**
- **HEA**
  - **founded in 2001 by Alstom Power, VATech Hydro and Voith Siemens Hydro**
  - **formed to promote sustainable development and public acceptance of hydropower**
  - **being affiliated member of IHA**

“Mobile” Hydrogen: The Most Viable Application

- **The Dream:**

  Renewable hydrogen for vehicles
  - **no petrol consumption**
  - **no air pollution**

- **The Problem:**

  electricity -> *electrolysis* -> hydrogen -> *fuel cell* -> electricity
  - **energy losses of two conversions**
  - **high equipment costs**
  - **high transport/storage volume and energy demand**

From Hydropower to Hydrogen (H to H): The Focus and the Challenge

- **The Focus:**

  production of hydrogen by hydropower + electrolysis

- **The Challenge:**

  Optimize efficiency vs. equipment cost
  - **for different scenarios**
    - **A: Small, decentralized hydrogen production facilities**
    - **B: Large, centralized hydrogen production facilities**
  - **with cost comparisons to**
    - **DOE-goal (Washington, 2004)**
    - **NG-reforming + sequestration**
    - **gasoline prices**

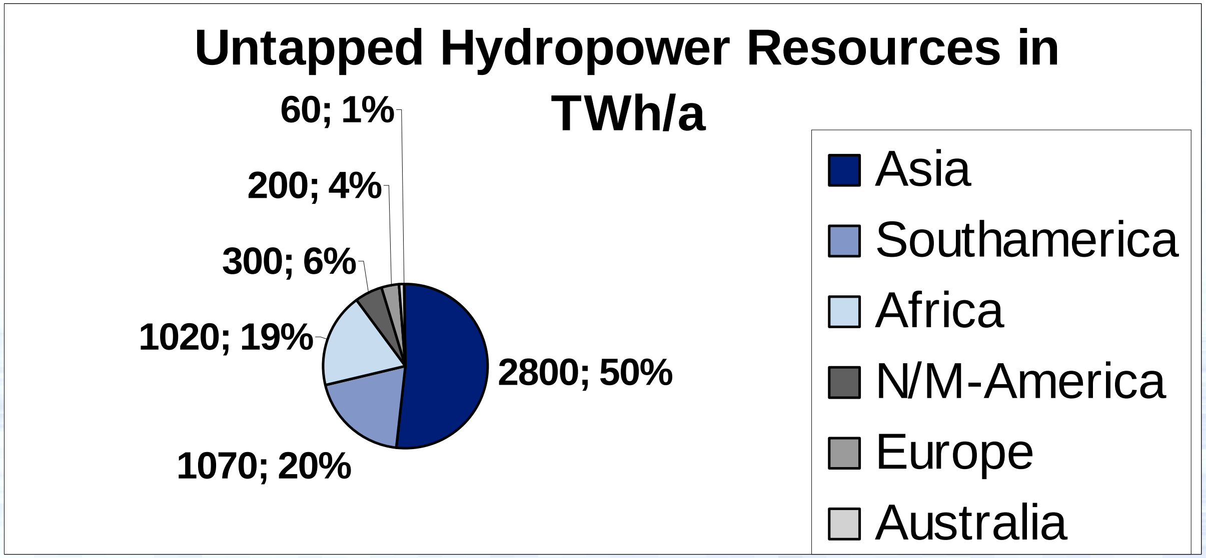
Hydropower

Chamuera, Switzerland

Macagua, Venezuela

SWOT-Analysis of H to H

- **Strength**
  - **plant sizes from a few kW to some GW (->economies of scale, for ex. Itaipu/Brazil generates with 14000 MW on avg. 90 TWh/a) due to the energy density of water**
  - **proven and reliable technology (720 GW installed – 19% of total, 377 GW under construction or planned)***
  - **vast untapped resources (economical: 5450 TWh/a)***



  - **non-intermittent power output (capacity factors > 0,6)**

*Horlacher, 2002, WBGU

SWOT-Analysis of H to H

- **Weakness**
  - power potential in developed countries exploited for electricity
  - higher conversion cost (compared to NG reforming, NOT to wind)
  - potential sites not close to hydrogen consumption centres

- **Opportunities**
  - reduction of plant costs through functional simplification of components and economies of scale
  - power potential in developing countries offers new revenue source for them

- **Threads**
  - scope of renewable hydrogen economy unclear
  - timing depending on oil price policy
  - energy policies with taxes and subsidies unpredictable

H to H: Requirements in Light of the Conversion Losses

- **Hydrogen must be competitive in the long run (all external cost internalized or compensated by differentiated taxes)**
- **The physics of two energy conversions require their “energy price” and additional equipment costs**
- **Therefore, the renewable electrical energy must be the cheapest possible**
- **This requirement is considered for two scenarios:**

H to H: Considerations to Scenario A

Hydrogen production decentralized and close to the hydrogen consumers -> Where does the electrical power come from?

A I)

- **Stand-alone electrolysers will get power from the grid**
  - **directly at the consumer site for saving CGH2 transport cost (i.e. energy transport through electrons).**
- **Grid-connected power plants will sell their power to the grid**
  - **because the electricity market can pay higher prices than the hydrogen market**

=> Optimization only on the electrolyser side

A II)

- **Only small hydro a/o wind energy plants <u>not</u> connected to the grid, but combined with the electrolysis plant, have the opportunity of the lowest overall equipment cost for a truly renewable hydrogen production**

H to H: Considerations to Scenario B

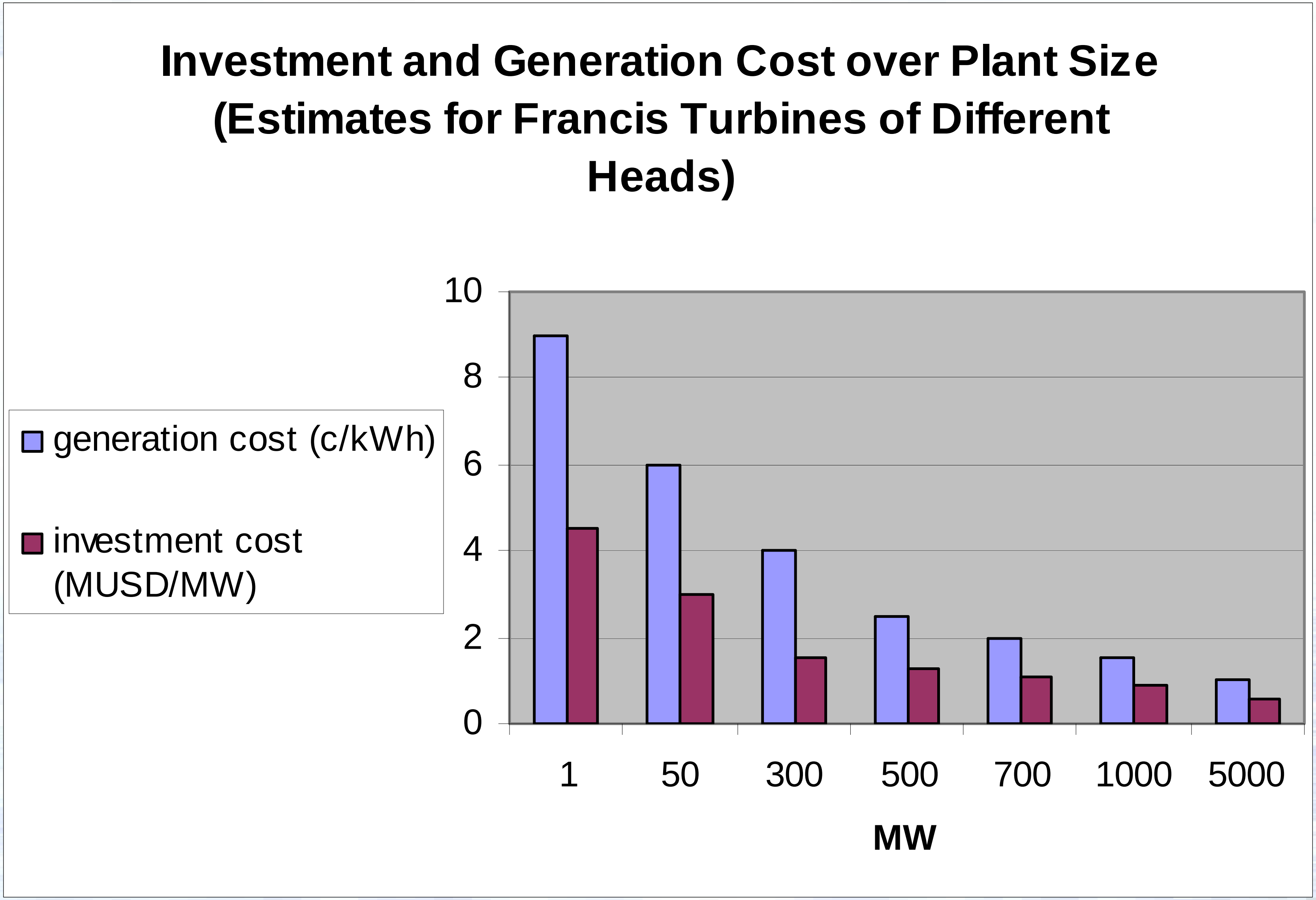
Hydrogen production centralized and far from hydrogen consumer centres

- **Large scale transport**
  - **increase in energy losses by about 20%-points**
  - **additional infrastructure cost**
- **Offset by economies of scale**

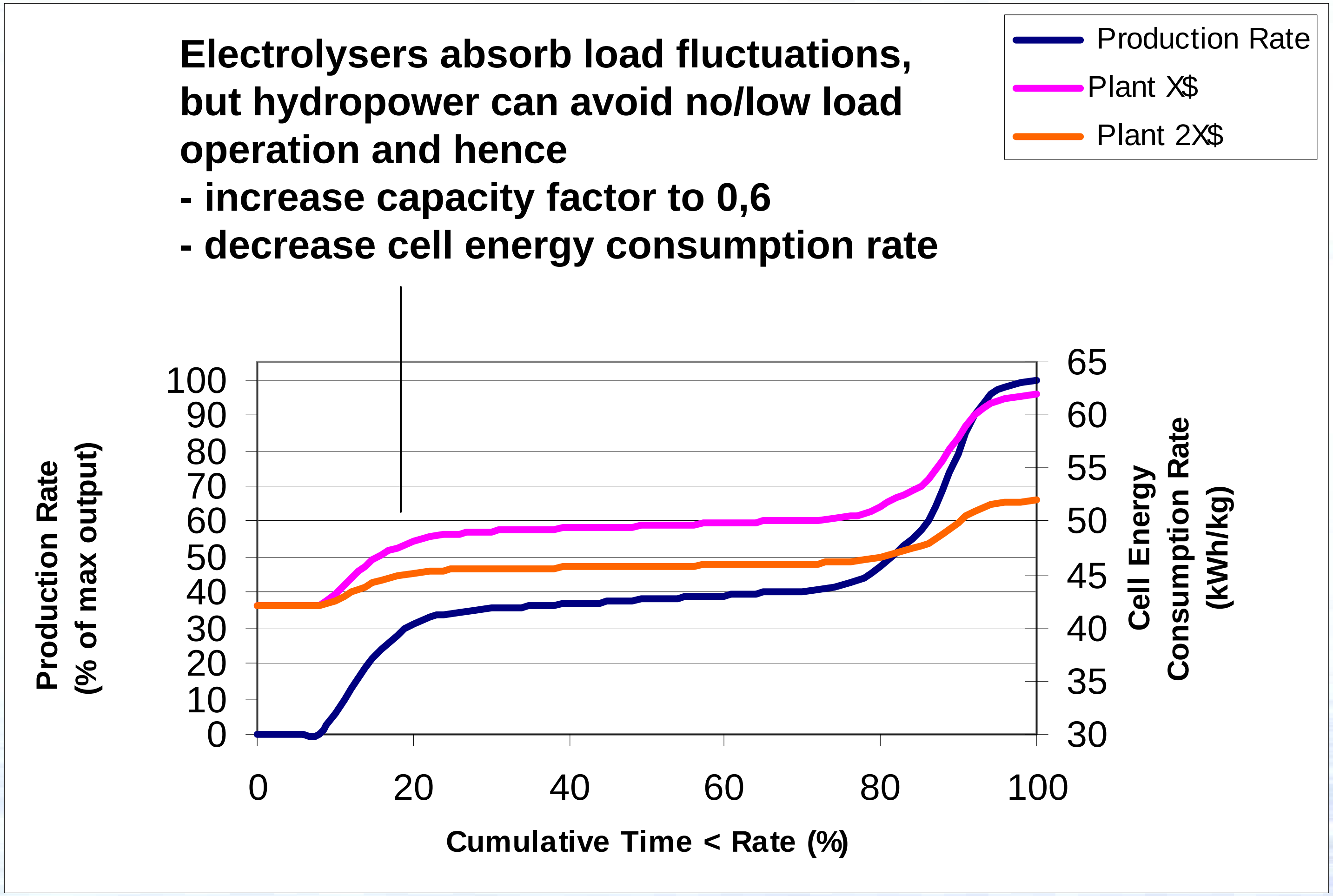
  (only available with hydropower, see next slide)
- **Sites should be in countries**
  - **not needing power for the grid**
  - **able to export hydrogen (-> royalties for its hydro resources)***
- **Further production cost reductions**
  - **look for high capacity factors (see slide after next)**
  - **investigate savings potential of single-purpose combined hydropower-electrolysis plants**

* see JOHN GUMMER and CHRIS HEAD:
HYDROGEN, HYDROPOWER AND WORLD POVERTY
THE INTERNATIONAL JOURNAL OF HYDROPOWER & DAMS (VOL10, ISSUE 5, 2003)

H to H: Economies of Scale



H to H: The Effect of Non-intermittent Power Supply



Source: **stuart**energy

Wind Power to Hydrogen: Cost Target Estimate, Scenario A

The DOE has set a target cost for hydrogen at production site of 2 $/kg

- **Simple Cost Model (source: stuart**energy**):**

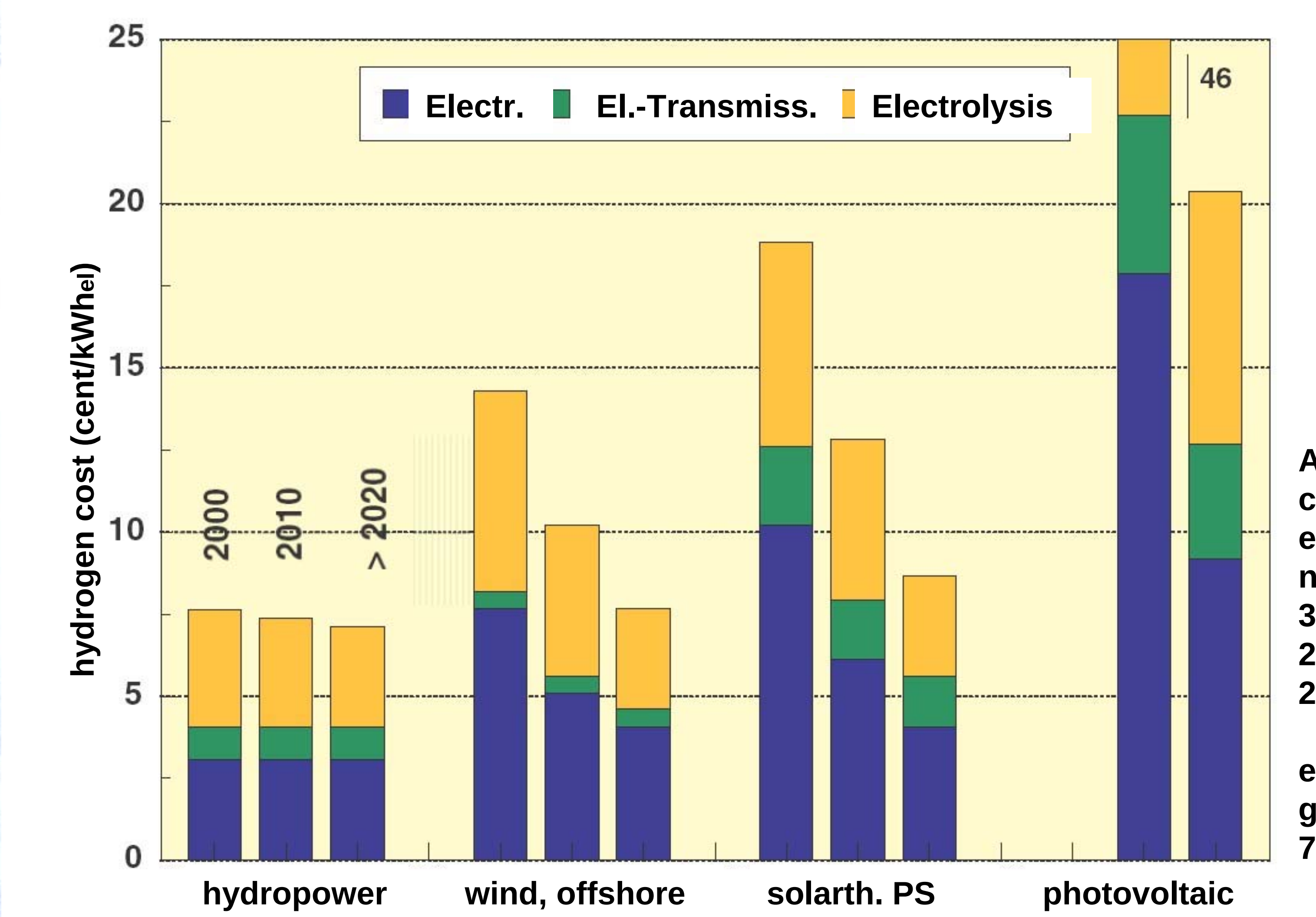
  $/kg = electrolyser efficiency x price of electricity +

  $$\frac{\text{annual (CRF+O/M) x capital cost per kg/h}}{\text{capacity factor x 8760 h/y}}$$

- **Assumptions:**
  - **Avg. electrolyser efficiency = 50 kWh/kg (=approx 80% wrt HHV)**
  - **Price of electricity (wind) = 2,5-3,0 c/kWh**
  - **(CRF +O/M) = 20% p.a. of capital cost**
  - **Capacity Factor (wind) = 0.35**

=> For 3,0 c/kWh the max. electolyser capital cost is 8000 $ p.kg/h, i.e. acc. to stuartenergy, **the DOE goal "is difficult to reach"**

H to H: Cost Comparison of Various Renewable Resources



source: Nitsch, 2002, WGBU

Assumptions:
cost of alkaline electrolyser:
now:
33000 € per kg/h
2020:
22000 € per kg/h

efficiencies going up from 73% to 77%.

Hydropower to Hydrogen: Compare Hydro/Wind with DOE-Goal

Apply Nitsch-assumptions (€=$) and cost targets for scenario A:

Hydro

- **Small hydro electricity cost target** — **4 c/kWh**
  (red. by 30% from 6,0 c/kWh due to reduced equipment cost vs. stand-alone operation)
- **Electrolyser capacity factor** — **0,6**
  (due to non-intermittent power)
- **Electrolyser capital cost** — **28.000 $ per kg/h**
  (red. by 15% vs.stand-alone)

=> hydrogen production cost — **3,0 $/kg**

Wind

- **Wind electricity cost target** (from 8 c/kWh reduced by 30%) — **5,5 c/kWh**
- **Electrolyser capacity factor** — **0,35**
- **Electrolyser capital cost** — **28.000 $ per kg/h**

=> hydrogen production cost — **4,6 $/kg**

H to H, Scenario A: Cost Estimate Conclusions

- The DOE goal seems not to be within reach

- For European vehicle application a less stretched goal seems to be sufficient (due to the high gasoline taxation):

  3 $/kg = 9 c/kWh_{H2} at site => 11 c/kWh_{CGH2} at station
  - equal to the gasoline price in Europe
  - about the double of the non-renewable NG-based hydrogen
  - hydrogen taxation possible due to the better efficiency of fuel cells in comparison to ICE's ($\geq$ factor 2)

- US scenario:
  - good site with stand-alone 3,5 c/kWh could reach with 30% cost reductions 2,5 c/kWh
  - => 2,3 $/kg => 7+1 = 8 c/kWh_{CGH2} at station
  - => 3,6 c/kWh effectively (incl. fuel cell efficiency) = 1,5 $/gal
  - without any tax

H to H: Basic Ideas for Functional Simplifications in Combined Plants

Scenario A, small plants

- **DC-generator instead of AC-Generator with power converter**
- **Asynchronous generator with power converter**
- **Common controls of hydro and electrolysis plant**
- **Saving potential of ommitting or simplifying other components**

H to H, Scenario B: Future Options

- Fundamental advantages of large hydro plants:
  - economies of scale
  - high cpacity factors
  - new revenue source for developing countries

- Further cost reductions by applying the lessons learned from small combined plants, e.g.
  - AC-generator simplification for feeding a power converter without grid requirements
  - Common controls of hydro and electrolysis plant
  - Saving potential of ommitting or simplifying other components

H to H: How to progress?

- Hydro equipment suppliers need to cooperate with electrolysis plant suppliers to

  - verify ideas for functional simplification of components
  - estimate economies of scale
  - agree on development steps for pilot plant designs

  in order to reach the assumed cost reductions of 30/15%

- Governmental support is needed to overcome the barriers of a new technological structure with uncertain perspectives

- The hydro industry is willing to support the necessary clarifications