LEADING THE ENERGY TRANSITION

HYDROGEN-BASED ENERGY STORAGE SOLUTIONS

Electrolysis & Flexibility

SBC Energy Institute

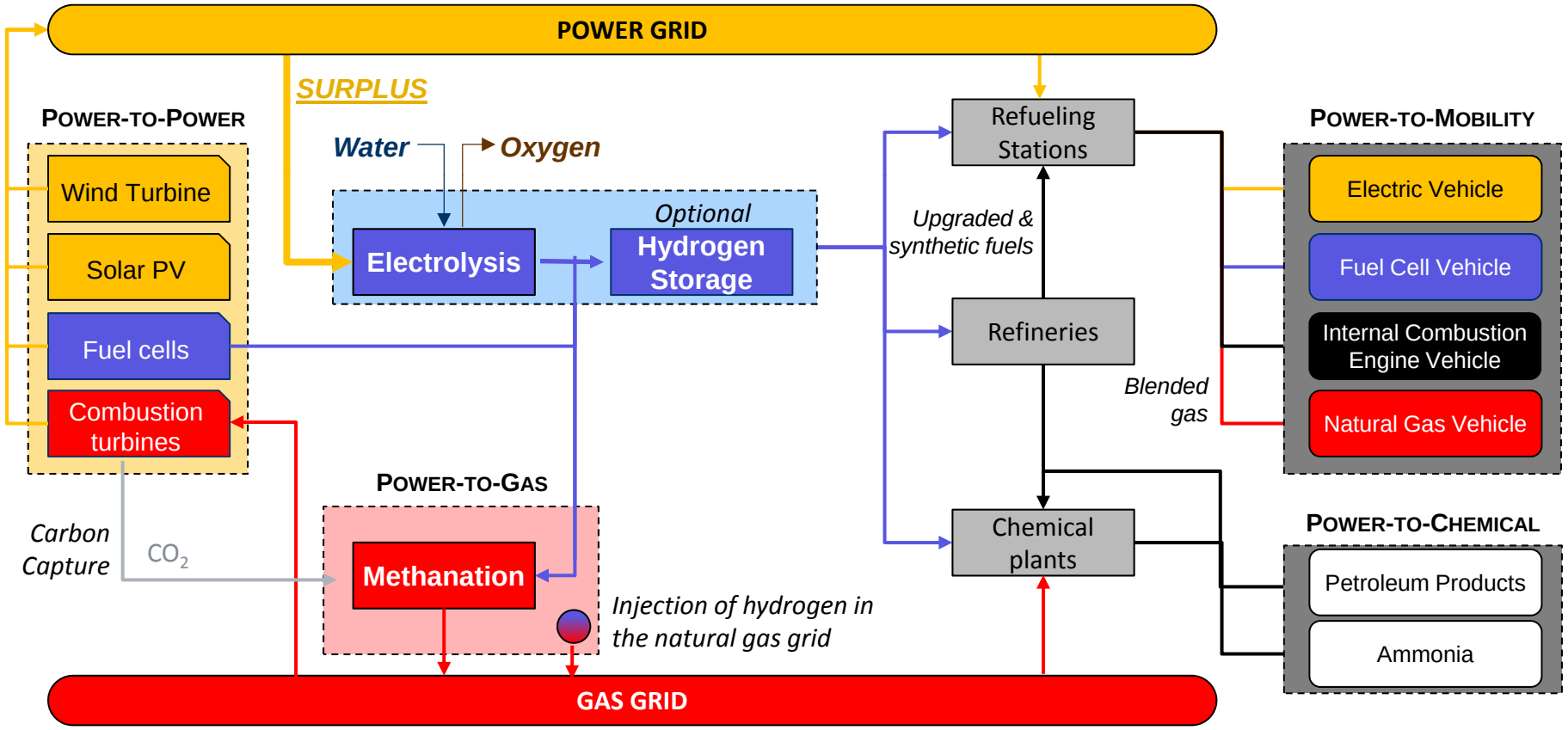
IEA Workshop on Hydrogen Technology Roll-Out in Europe

10th July, 2013

Schlumberger | SBC Energy Institute

More than a storage carrier, hydrogen is a bridge between energy systems

SIMPLIFIED VALUE CHAIN OF HYDROGEN-BASED ENERGY CONVERSION



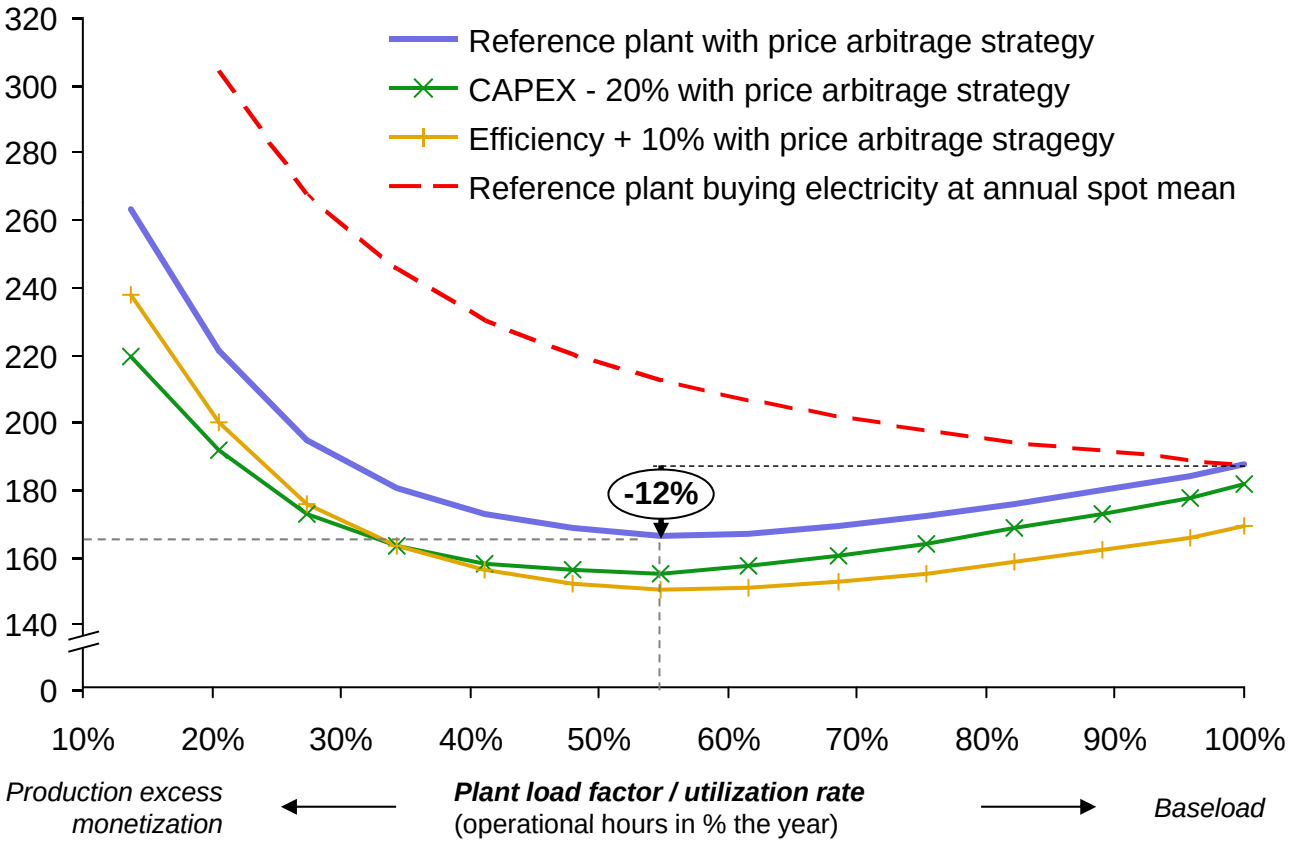
Note: Simplified value chain. End uses are non-exhaustive. Note that the power and gas grids are the main supplier to the residential and commercial end-uses (lighting, heating and cooling, cooking…)

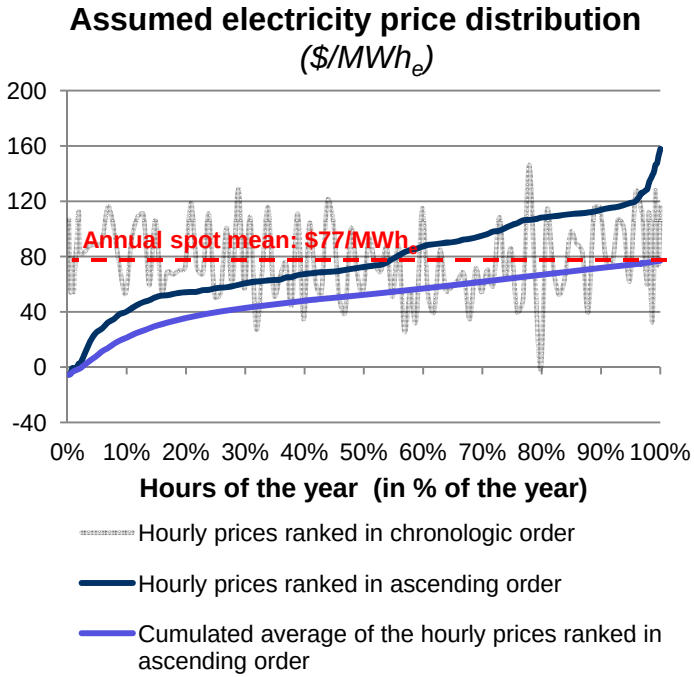
Source: SBC Energy Institute analysis

Electricity price spreads are too small to enable significant hydrogen production cost reductions through price arbitrage

LEVELIZED COSTS OF HYDROGEN FOR A GRID-CONNECTED ELECTROLYSIS PLANT

$/MWh_{ch,}$



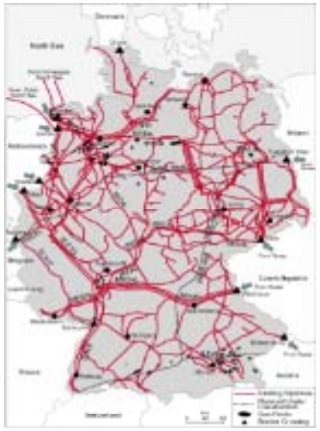


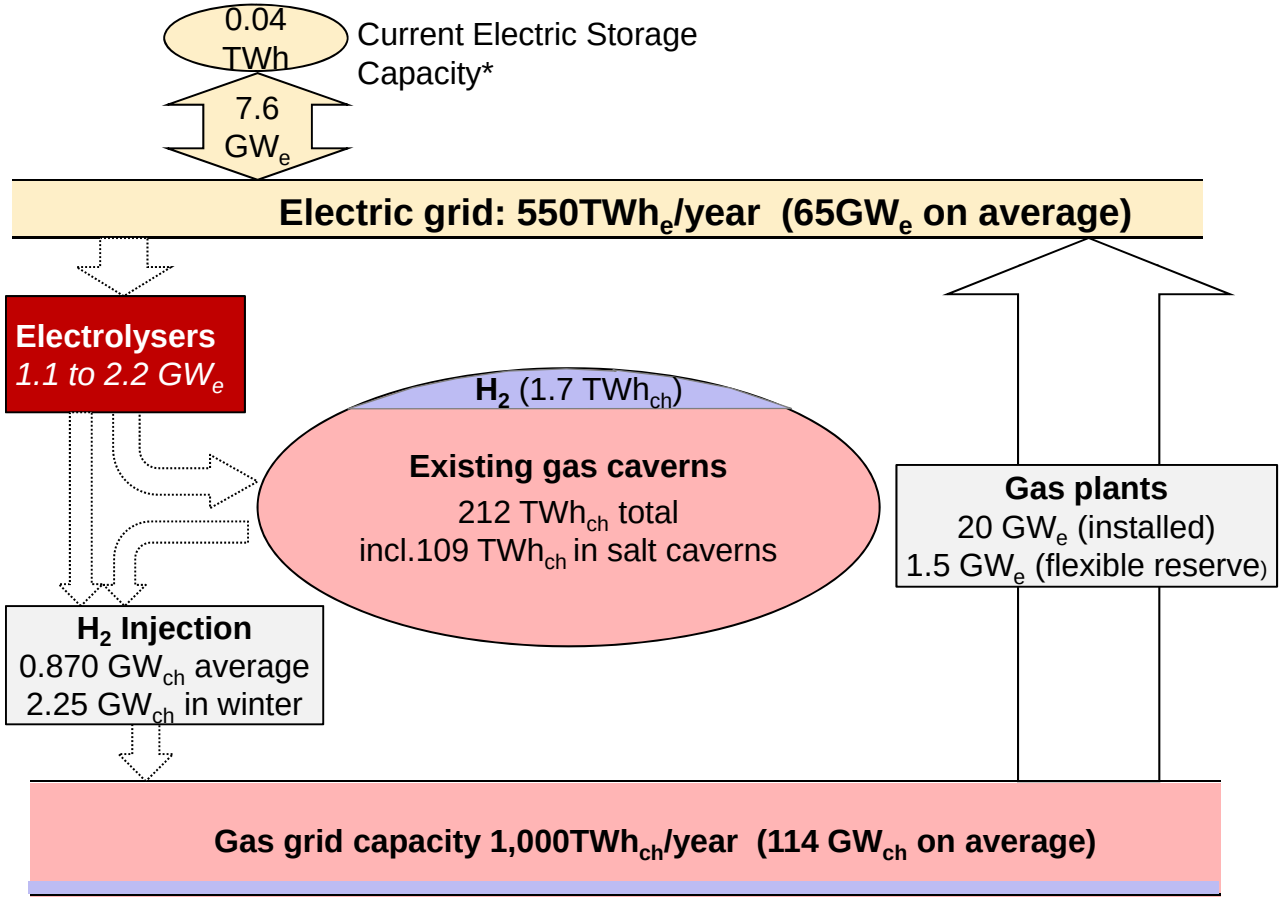
Note: Illustrative example based on 8.5MW_{ch} electrolysis (5 alkaline stacks of 1.7MW_{ch} each), with total installed system CAPEX: \$765/MWh_{ch}, Efficiency: 79%$_{HHV}$, Project lifetime: 30 years and real discount rate after tax:10%.

Source: SBC Simulation based on US DoE H2A Model

Injection of hydrogen into gas networks provides a large end-market in the short to mid term for electrolytic hydrogen

HYDROGEN INJECTION INTO THE GAS NETWORK: GERMAN POTENTIAL AT 5VOL.% BLENDING





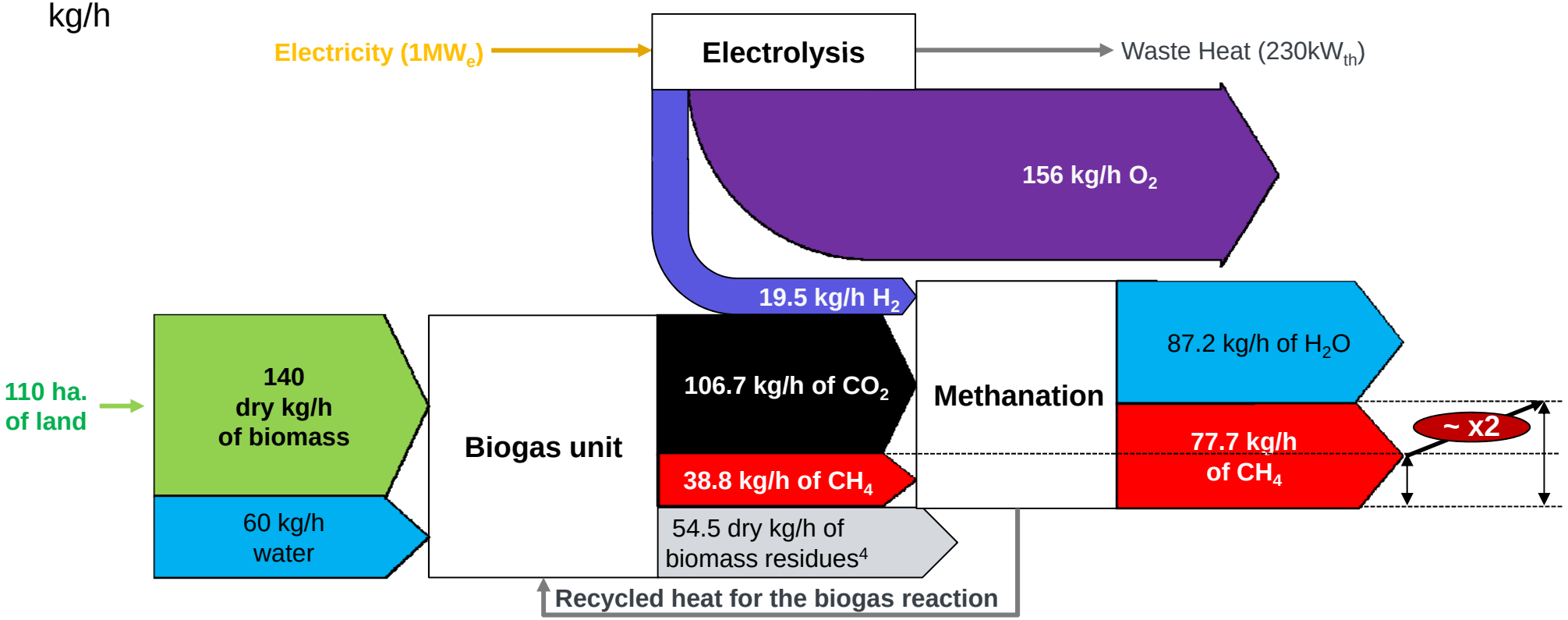
Note: Order of magnitude for 5% blending in volume (*i.e.* ~1.5% in energy) where it does not affect the grid nor the end-use applications. It takes into account the dynamic of the seasonality of the grid (lowest demand in summer of 58 GW_{ch}) for the injection rate (58 GW * 1.5% = 0.870 GW). Electrolyzer could act as negative control reserve (9GW in Germany currently, including 7.6 GW of Pumped Hydro)
Current Electric Storage capacity corresponds mainly to Pumped Hydro Storage capacity, on top of the Hunthorf Compressed Air Energy Storage Facility.

Source: SBC Energy Institute analysis

Synthesis of methane is promising but constrained by affordable CO_2 sources

SIMPLIFIED MASS FLOW CHART OF HYROGEN-ENRICHED BIOMETHANE PLANT

kg/h



Biogas generates an excess of CO_2 mixed with methane…

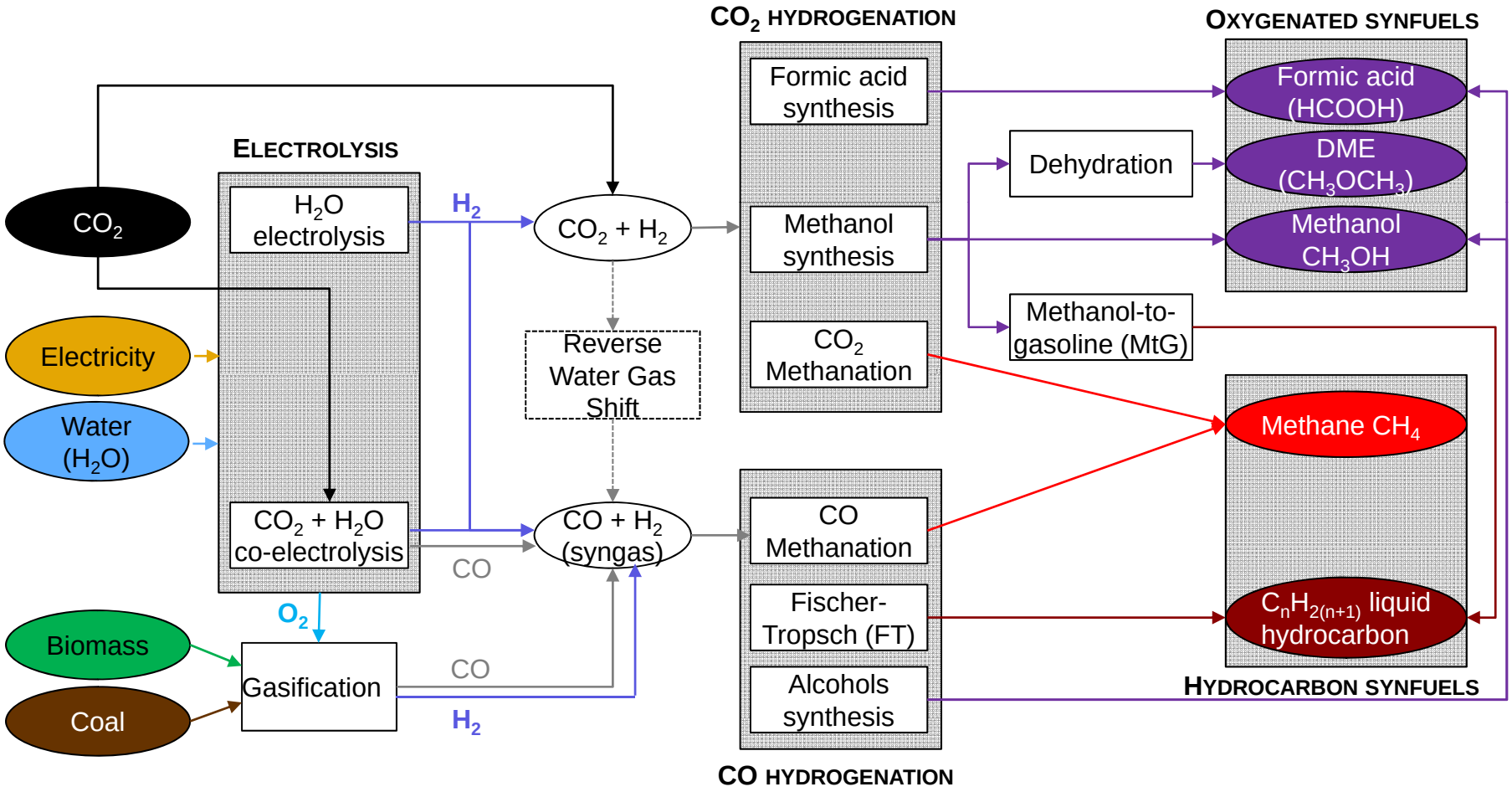
…Enriching biogas with methane doubles the output while increasing the efficiency and mutualizing the injection costs

Notes: 1: Biomass feedstock is a maize silage of 5kWhch/kg of dry matter, cultivated with a land yield of 0.63MWch per km². 2: The anaerobic digestion of maize silage requires heat and has an total efficiency of 68.7%; 3: Thermochemical methanation at 300°C and 77.7% hydrogen-to-methane efficiency

Source: SBC Energy Institute Analysis

Fuel synthesis from water, electricity and carbon, extends the market potential for electrolysis

POWER-TO-SYNFUELS[1] PATHWAYS FOR H-C-O SYNFUELS PRODUCTION



Source: SBC Energy Institute Analysis

Hydrogen is an essential energy carrier to facilitate the energy transition

- **Hydrogen is an enabler for high intermittent renewable penetration:**
  - Balance deficit (directly or coupled with gas)
  - Ensure security of supply with massive storage
  - Monetize intermittent surplus
- **Hydrogen facilitates the decreased carbon intensity of fossil-fuel based energy systems:**
  - Hydrogenate fossil fuels and maximize land use for biofuel / biogas production
  - Recycle carbon captured from CCS
  - Leverage current infrastructure
- **Hydrogen business cases are not yet profitable in the absence of green supports except for a few early markets:**
  - A few early markets can provide short-term business cases (*e.g.* back-up for telcom towers)
  - Costs reduction on electrolysis side are a pre-requisite (learning curve, manufacturing…)

Source: SBC Energy Institute analysis

SBC Energy Institute is a non-profit organisation that promotes understanding of key global energy issues

INSTITUTE IDENTITY

- **Focused on crossover technologies related to the energy space**
- **Registered as a non-profit organization: all studies publicly available**
- **Governed by its own Board Members, including external people:**
  - Claude Mandil, Former Executive Director of the International Energy Agency
  - Dr. Adnan Shihab-Eldin, Former OPEC Acting Secretary General.
- **SBC Energy Institute website & reports**: www.sbc.slb.com/SBCInstitute.aspx

HYDROGEN STUDY

- **One year effort on electrolytic hydrogen**
- **Release expected Q4 2013**
- **For more information:**

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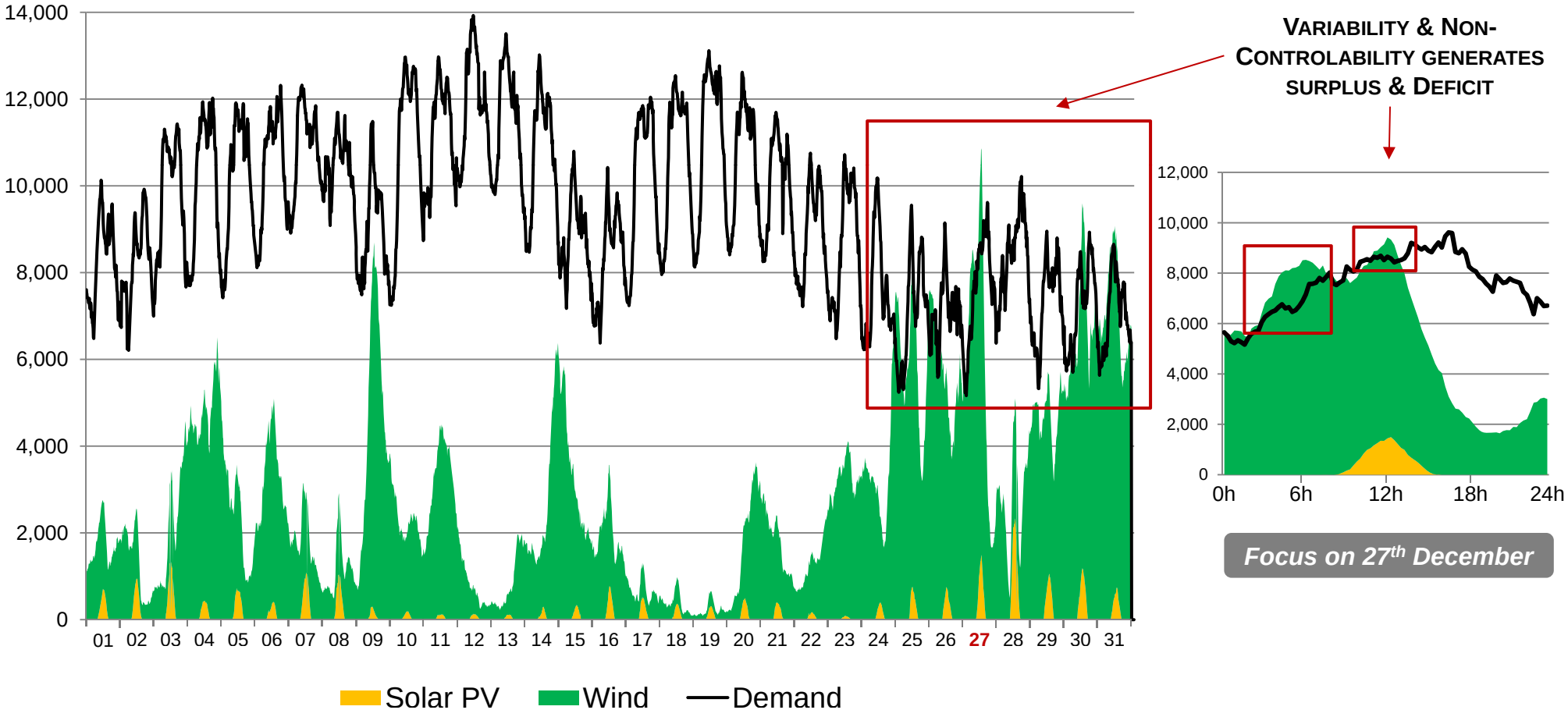
- **Appendix**

Wind and Solar PV are challenging to integrate on the power grid

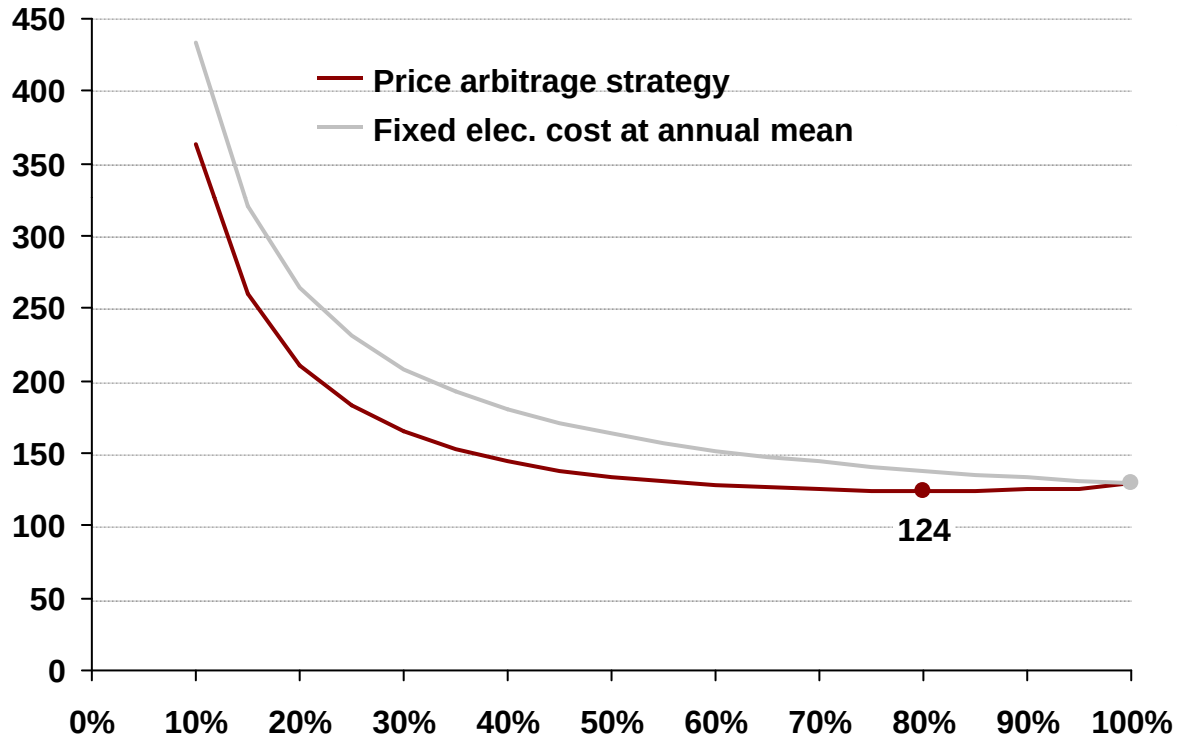
WIND & SOLAR GENERATION VS. DEMAND IN NORTHERN GERMANY
MW, December 2012 on the 50Hertz Operated Grid

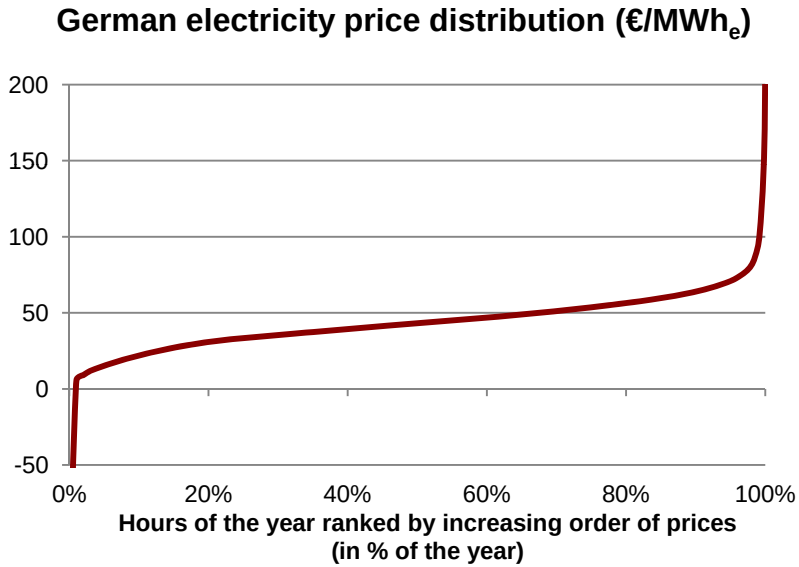


Source: SBC Energy Institute Analysis based on 50Hertz data archive (Wind and Solar Actual In Feed 2012, Control Load 2012)

Electricity price spreads are too small and not frequent enough to enable significant hydrogen production cost reductions through price arbitrage

LEVELIZED COSTS OF HYDROGEN FOR A GRID-CONNECTED ELECTROLYSIS PLANT
€/MWh$_{ch,}$ based on EPEX Spot price 2012 for Germany





utilization rate
(in % of the year)

→ Spot price arbitrage leads to an optimal plant utilization rate of 80% and LCOH only reduced by 4% compared with baseload.

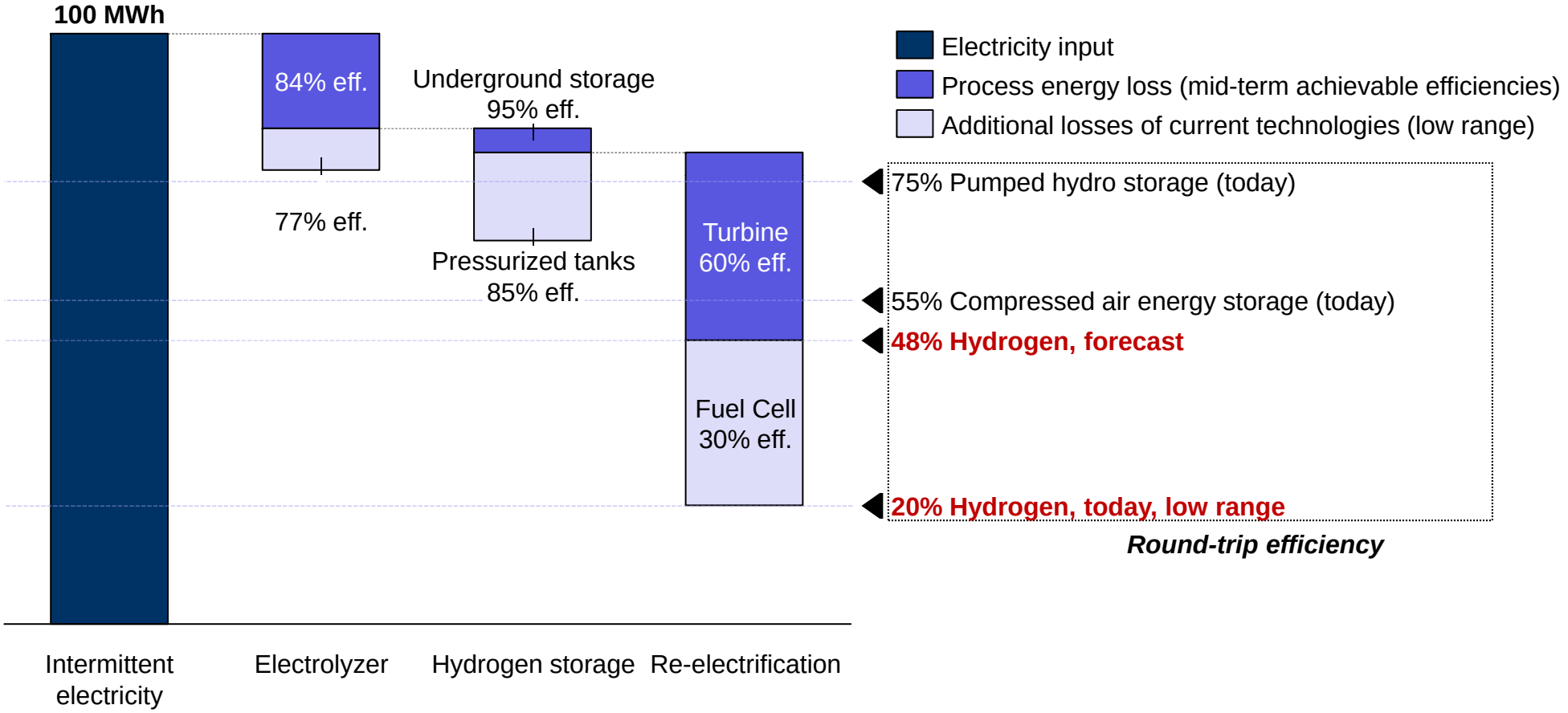
Note: EPEX SPOT intraday trading "index price for each hour of 2012. Intraday SPOT and day-ahead SPOT auctions have been found to give very similar price duration curves. Electrolysis assumptions is based on the US for a 10MW alkaline plant with total installed system CAPEX: $848/MWh$_{ch.}$ Efficiency: 78%. Project lifetime: 30 years. Real discount rate after tax:10%.

Source: SBC Simulation based on EPEX Market Data, US DoE H2A Model

Due to a poor round-trip efficiency, power-to-power is likely to be limited to niche applications

LOSSES ALONG THE RE-ELECTRIFICATION VALUE CHAIN OF A H_2-BASED STORAGE

In MWh, based on a 100MWh storage system, with no hydrogen transport



Notes: Mid-term (<10 years) realistic target for efficiencies.
Source: SBC Energy Institute Analysis; NREL (2009), "Lifecycle cost analysis of hydrogen versus other storage options"