Technoeconomic analysis of High Temperature Reactors in cogeneration

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Introduction

- Based on GEMINI+ Deliverable 3.12
- Focused on Polish market:
  - Has public and political support
  - Interested in HTGRs as replacement of old fleet of coal boilers, part of GEMINI+
  - Share of hard coal in cogeneration in Poland was 67,5%
  - Largest fleet of <100MWe coal boilers in EU
  - ~1 Mt of hydrogen produced annually
  - Major phosphate and nitrogen fertilizer producer, ~1/5 of EU production
- Analysis considers production of industrial heat, electricity and hydrogen

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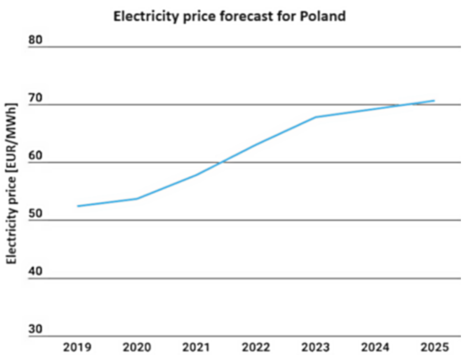
Energy in Poland and EU



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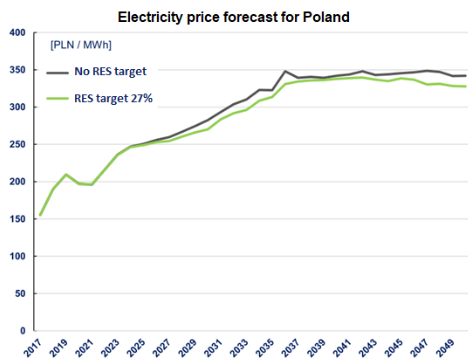

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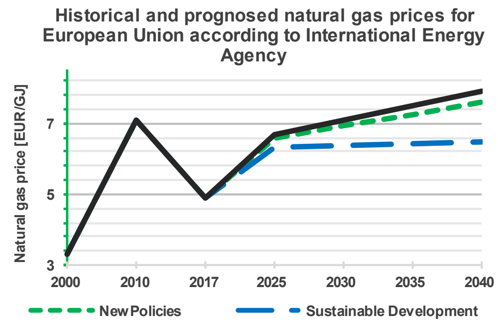
- Gas prices in Poland are typically higher than in the EU
  - High dependence – over 75% imported
  - Difficult to diversify – dependent on Russia
- Coal prices similar to EU – domestic supply
- Gas prices may rise by up to 45%
- Coal by up to 50%
- Assumptions for fuels, excluding taxes and logistics:
  - natural gas - standard 8,67, between 6 and 11,5 EUR/GJ in best- and worst-case scenarios
  - hard coal - standard 2,79, between 2,75 and 4 EUR/GJ in best- and worst-case scenarios
  - HTGR fuel – 1,87 EUR/GJ
- EU has increased its climate ambitions since the report
- Speculations of different sources vary wildly
  - Emission price assumption is 30 as standard, 20 as best- and 60 EUR/tCO2eq as the worst-case scenarios



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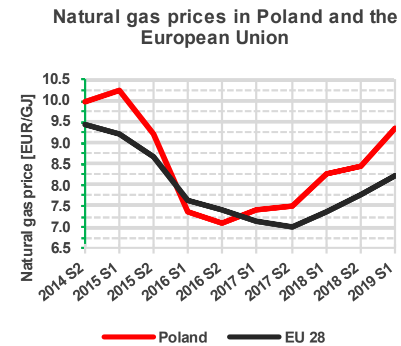

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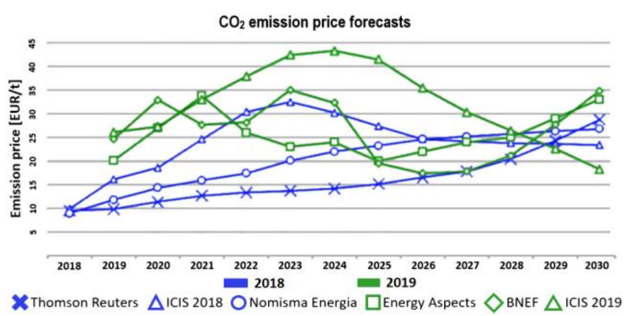

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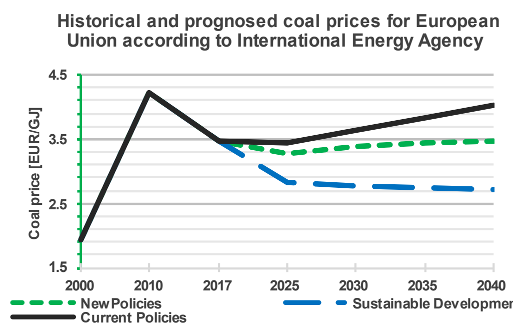

International Energy Agency (IEA). (2018). *World Energy Outlook 2018: The Future is Electrifying*. Oecd/Iea

- Price of electricity in Poland will range between 70 and 90 EUR/MWh in 10 years
  - Increasing CO_2 and fuel prices
  - increasing share of gas and renewables
  - New capacities needed

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Methodology

- Analysis was done through comparison of levelized cost.
- Levelized cost was calculated with:

$$LC = \frac{SOCC \times \sum_{i=1}^{CT} f_i \times (1+r)^{CT-(i-1)} \times CRF}{8760 \times LF} + O\&M + FC$$

- Sensitivity analysis was done through calculation of change to the levelized cost induced by percentage change to a variable, relative to standard assumptions.
- Sensitivity was calculated with $ns = \frac{|LC(v_f)-LC(v_0)|}{\left(\frac{|v_f-v_0|}{v_{ref}}\right)\times 100\%}$
- Some parameters were constant, others were treated as variables.
- Worst- and best- case scenarios were calculated by offsetting two most sensitive parameters by probable values

Acronym	Meaning	Units
SOCC	Specific Overnight Capital Cost	EUR/MW, EUR/(t/h)
CT	Construction time	Years
CRF	Capital Recovery Factor	n/a
f_i	Fraction of investment during construction year *i*	n/a
LF	Effective Load Factor	n/a
O&M	Operations and Maintenance	EUR/MWh, EUR/t
FC	Fuel Costs	EUR/MW, EUR/t
ns	Nominal sensitivity	EUR/(MWh*%), EUR/(t*%)
LC(v)	Levelized cost under standard assumptions	EUR/t
v_0	Lowest value of respective variable	Variable-dependent
v_f	Highest value of the respective variable	Variable-dependent
v_{ref}	Reference value under standard assumptions	Variable-dependent

Variables:		Constants:	
- Overnight cost - Fuel price - CO_2 emission price - Load factor	- Discount rate - Construction time - Operational lifetime	- Boiler efficiency - Electric efficiency - Hydrogen production efficiency - Operations & Maintenance	- Output power - Cost of desalinated water - Grid electricity cost

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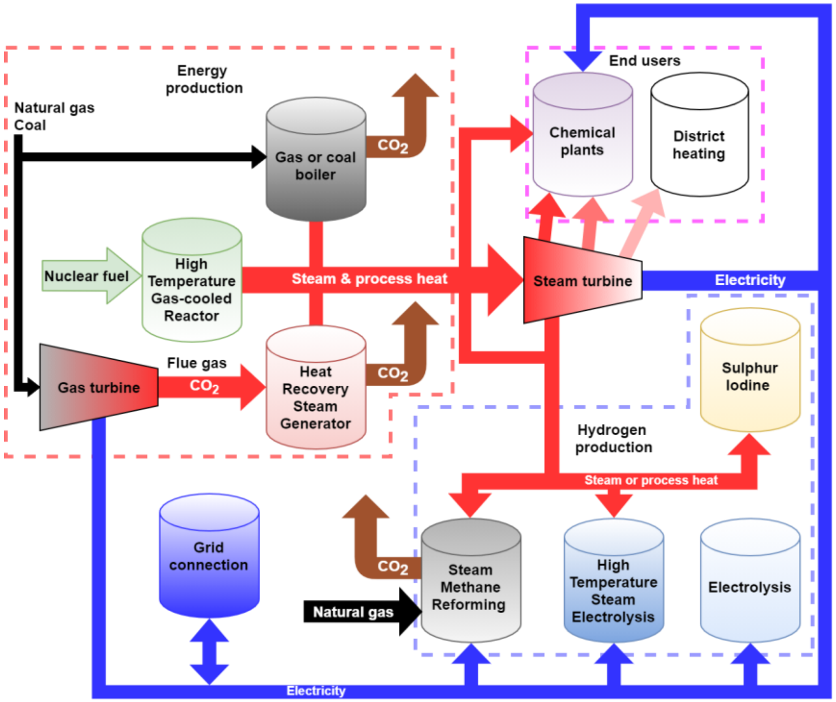
Hybrid Energy Systems considered



- Hybrid Energy System (HES) definition:
more than one energy source and/or more than one product from the sources
- Energy production methods considered:
  - Pulverized coal boiler
  - Gas boiler
  - Combined Cycle Gas Turbine (CCGT)
  - High Temperature Gas-cooled Reactor
- Scaled to deliver 165 MWt net

Table with standard model assumptions

Variable	Value
Discount rate	5%
Load factor	90%
Operational lifetime	60 years for HTR 30 years for gas units 40 years for other technologies
Construction time	5 years for HTR 3 years for other technologies
Electric efficiency	61,0% for CCGT 43,3% for other technologies

- Hydrogen production methods considered:
  - High Temperature Steam Electrolysis (HTSE)
  - Steam Methane Reforming (SMR)
  - Sulphur-Iodine cycle (SI)
  - Electrolysis
- Exceptions apply to gas boilers in combination with SMR, HTSE and conventional electrolysis

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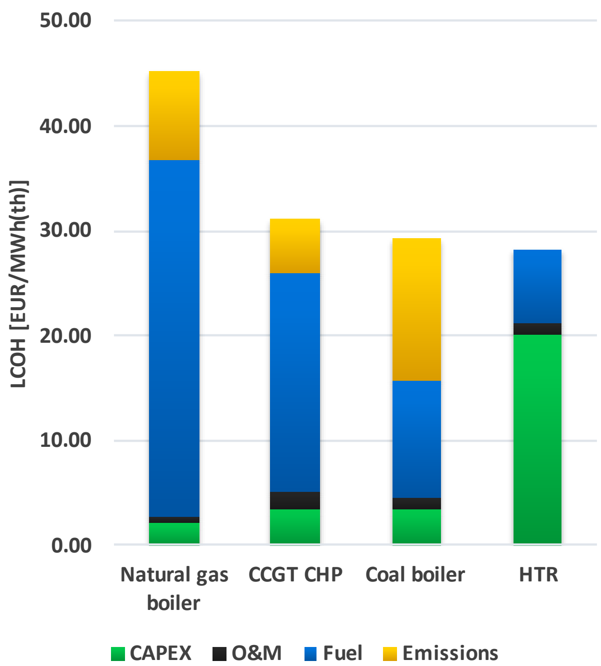
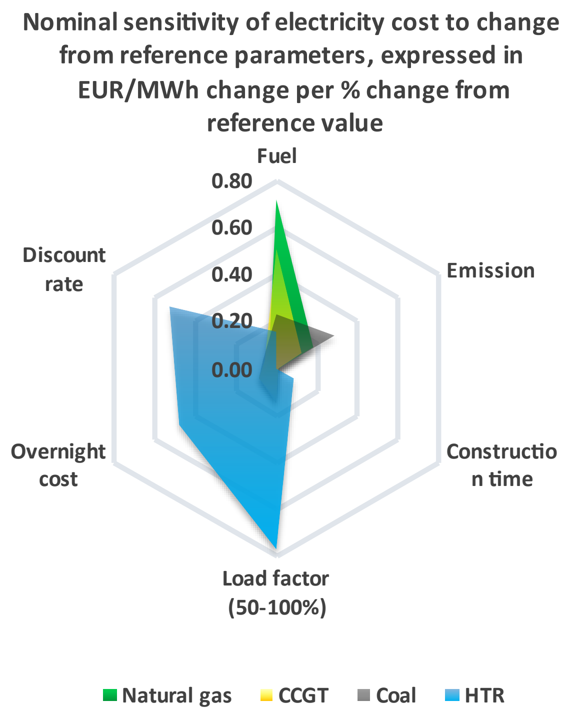
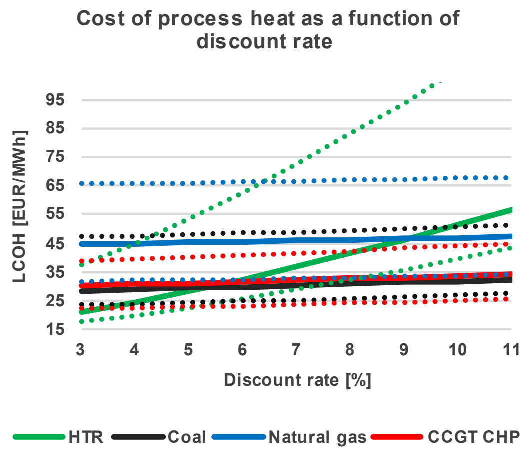
Sensitivity of CHP





- HTRs depend almost exclusively on CAPEX factors
- Coal is equally fuel- and emission-dependent
- Gas is extremely sensitive to fuel price, somewhat dependent on emissions
- HTRs must operate as baseload



- Gas and coal affected by external factors – fuel, emissions
- HTRs affected by internal factors – CAPEX, construction time, discount rate
- Favorable financing is necessary for HTRs

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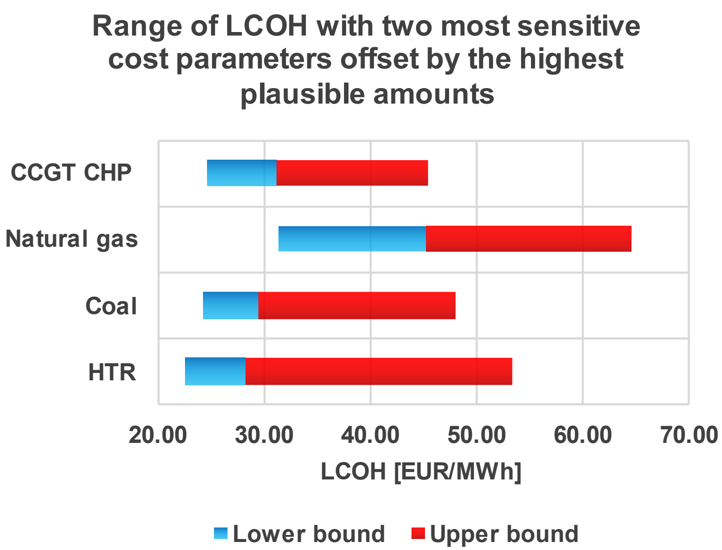
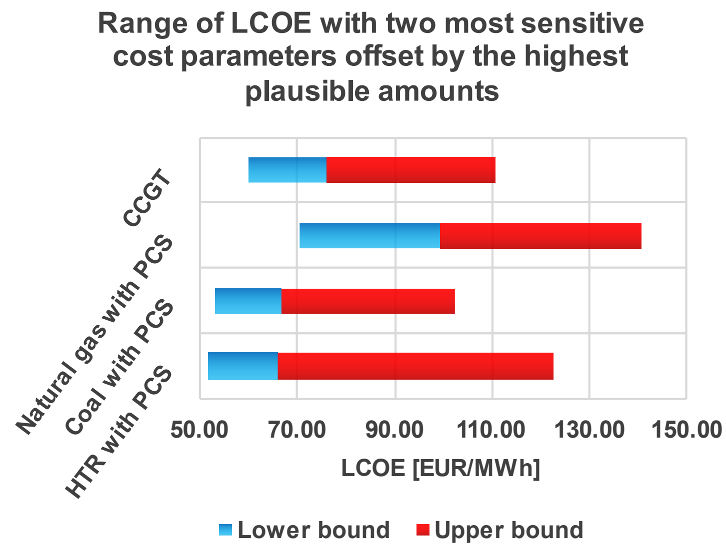
Ranges of levelized CHP cost





Offset for HTRs on the graphs is -20% to +50% of overnight cost and 60-99% load factor
Gas and coal have emissions and fuel price offset as stated in slide 3

- Worst- and best- case scenarios with similar ranges for all technologies except gas boilers
  - HTRs compete with other technologies in favorable scenarios
  - Profitability will be determined by financing and construction time
  - Due to cost, no flexibility of HTRs on load factor, contrary to gas and coal

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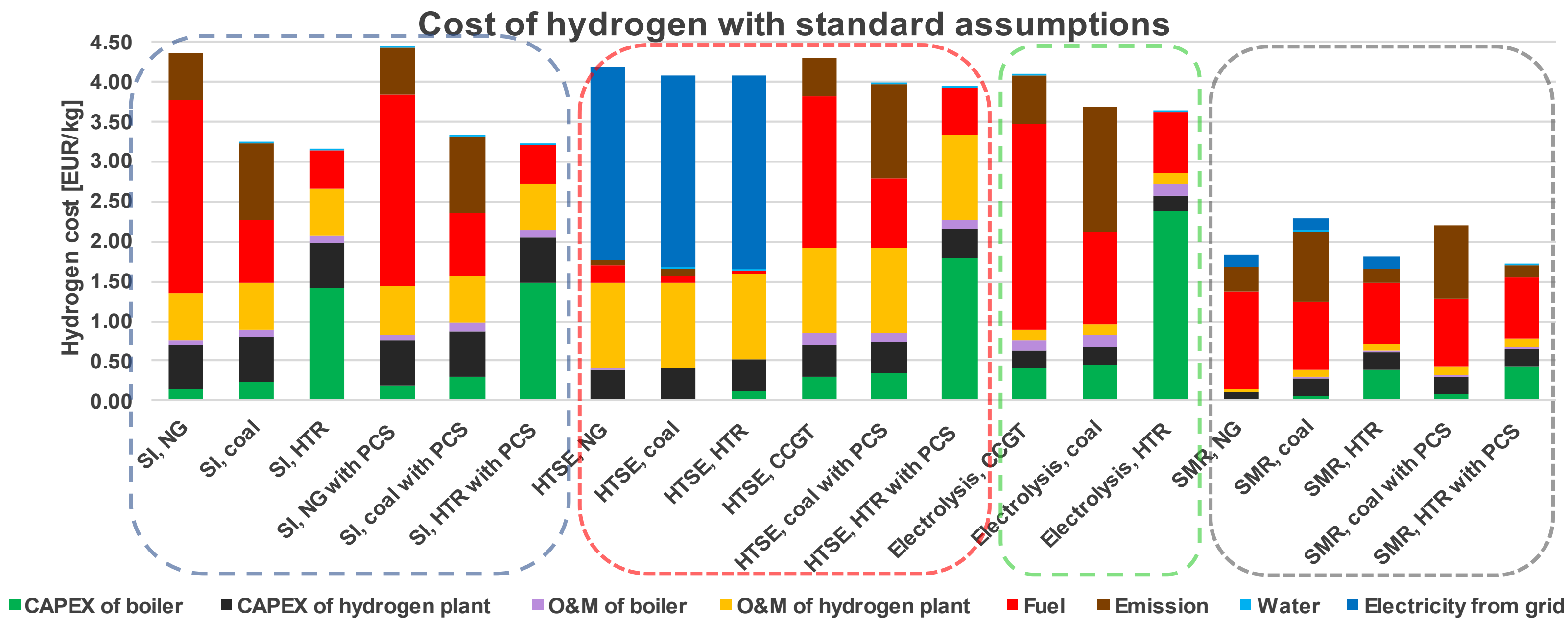
Levelized hydrogen costs



- Sulphur-Iodine can be the most affordable green hydrogen
- HTSE is hindered by O&M and electricity costs
- Electrolysis has low CAPEX but very high electricity consumption
- Steam Methane Reforming is overall the most affordable

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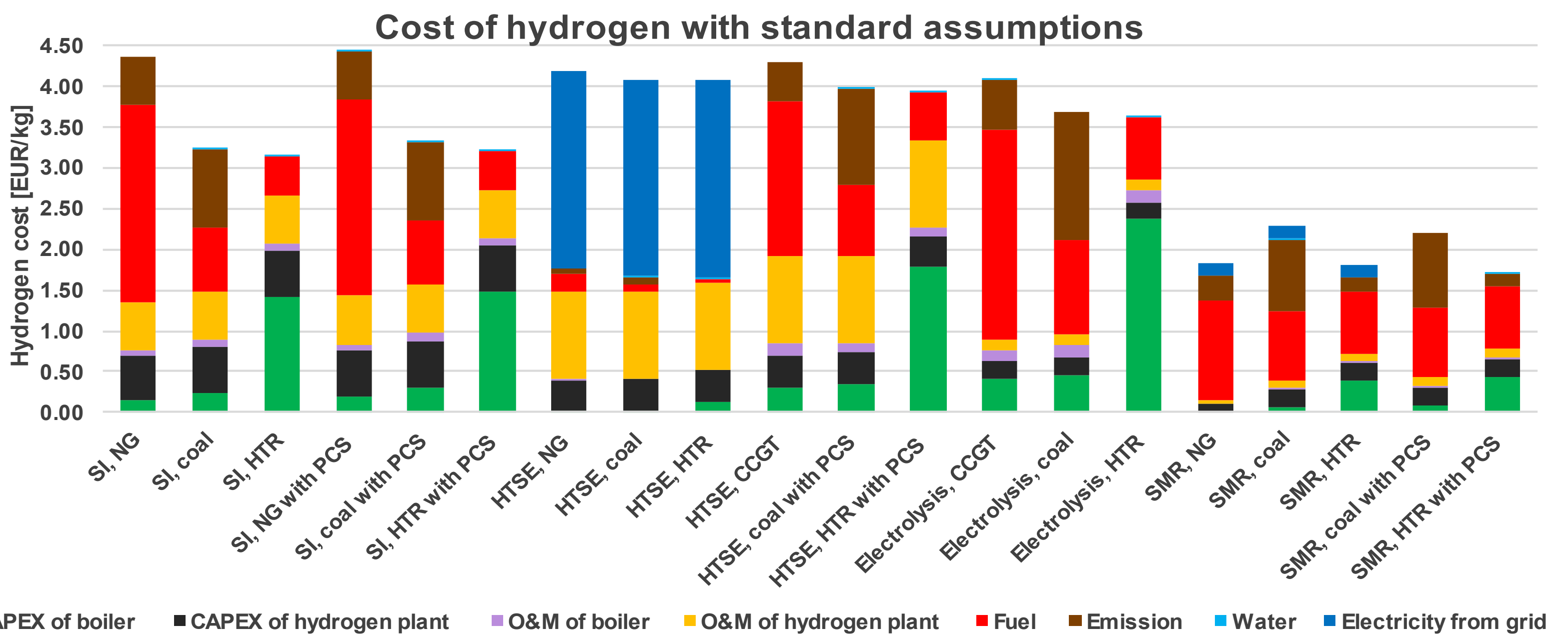
Levelized hydrogen costs

- Steam Methane Reforming is the only sensible way of producing hydrogen using fossil fuels
- Economics of green hydrogen suffer from either high energy cost, capital cost, O&M cost, or all the above



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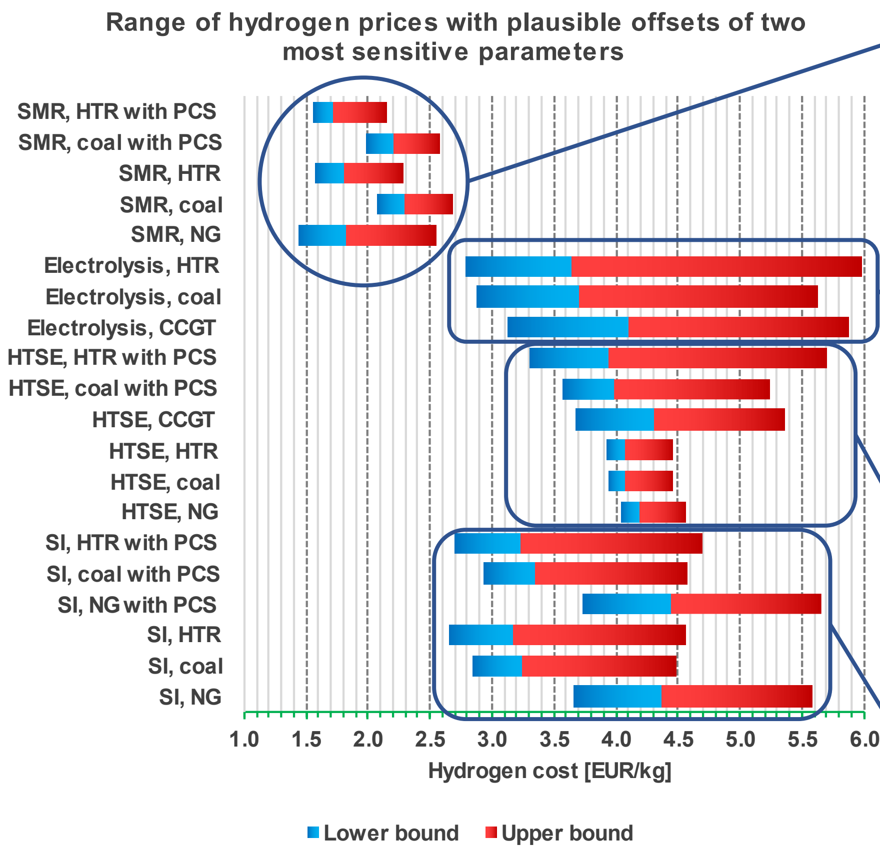
Ranges of levelized hydrogen costs



- SMR is the most competitive in every case
  - High thermodynamic efficiency
  - Low CAPEX

- Electrolysis most expensive for baseload production
- Low overnight cost enables opportunistic hydrogen production during cheap electricity

- High O&M and CAPEX of HTSE make it currently prohibitively expensive

- SI could compete with SMR if:
  - Efficiency was higher
  - CAPEX and O&M were lower

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Summary

- Poland will be a representative example of the EU market
  - Growing dependence on gas from phaseout of coal
  - High emission costs, similar objectives across EU
  - Not applicable outside EU
- Fuel, emission and electricity prices are expected to rise
- Methodology based on comparison of levelized cost, with focus on impact of most important parameters
- Hybrid Energy Systems consider coal, gas and HTRs as energy sources and Sulphur-Iodine, Steam Methane Reforming, low- and High-Temperature Electrolysis as hydrogen production methods
- HTRs can compete for heat and electricity production with gas and coal in favorable conditions
  - High utilization factor, favorable financing and timely construction
  - Rising fuel and emission prices
- Hydrogen from HTRs needs to become more cost competitive
- SMR is the most affordable hydrogen production method for the near future
- SI and HTSE need development, lower CAPEX and O&M or higher efficiency
  - SI with HTR can be the most affordable green hydrogen
- Electrolysis is the most expensive as baseload hydrogen production
  - Relatively low CAPEX allows to make installations which take advantage of excess electricity

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Thank you for your attention

Questions?

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