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Atoms for Peace and Development

Modelling of hydrogen production technologies in an integrated energy system at different carbon constraints

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Introduction

- Deep decarbonisation
- Increase of electricity demand
  - Electrification of sectors like energy, transportation and industrial processes

Hydrogen

→ For hard to abate sectors

→ Flexibility for systems with high VRE share

Research questions

Power sector

- Impact of carbon constraint?

Introducing hydrogen

1. How is hydrogen produced at different carbon constraints?
2. In which way does the hydrogen system change the power generation mix?
3. Under which conditions is hydrogen burnt for electricity?

Methodology – System & Model

System

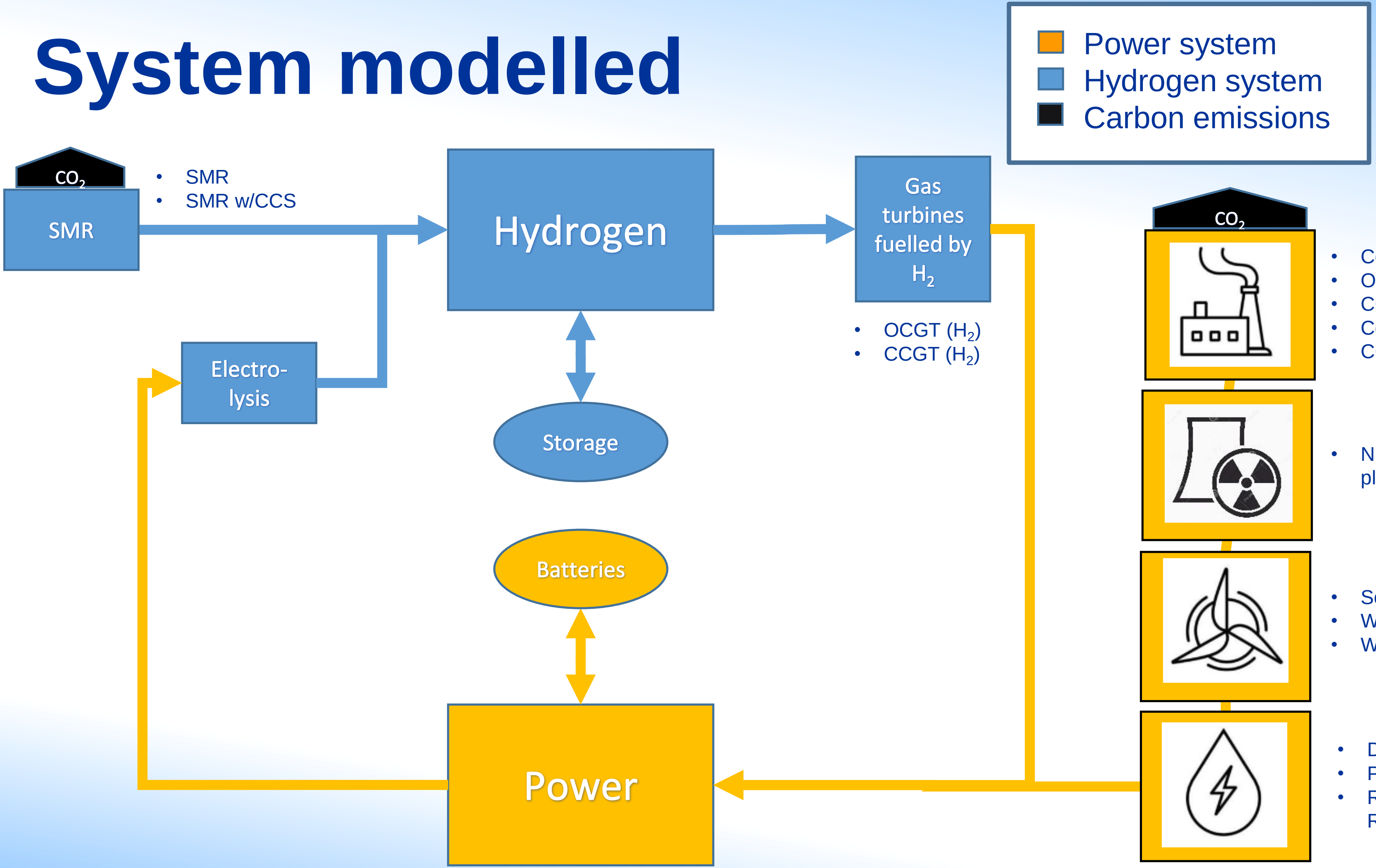
- Single region
- Greenfield approach for 2050
  - Existing capacities are not taken into account
  - Only brownfield capacities: hydroelectric plants
- One year with hourly resolution
  - Hourly data from real countries
- “Copper plate” approach

Model

- PowerInvest
  - Linear

		Country „France“	Country „UK“
El. demand [TWh]		500	
H_2 demand [TWh]		0, 100, 250	
Load factors	solar PV	15%	10%
	wind on-shore	24%	28%
	wind off-shore	41%	44%
Brownfield capacities [GW]	pumps	3	3
	dams	10	-
	run-of-the-river	12	-

System modelled

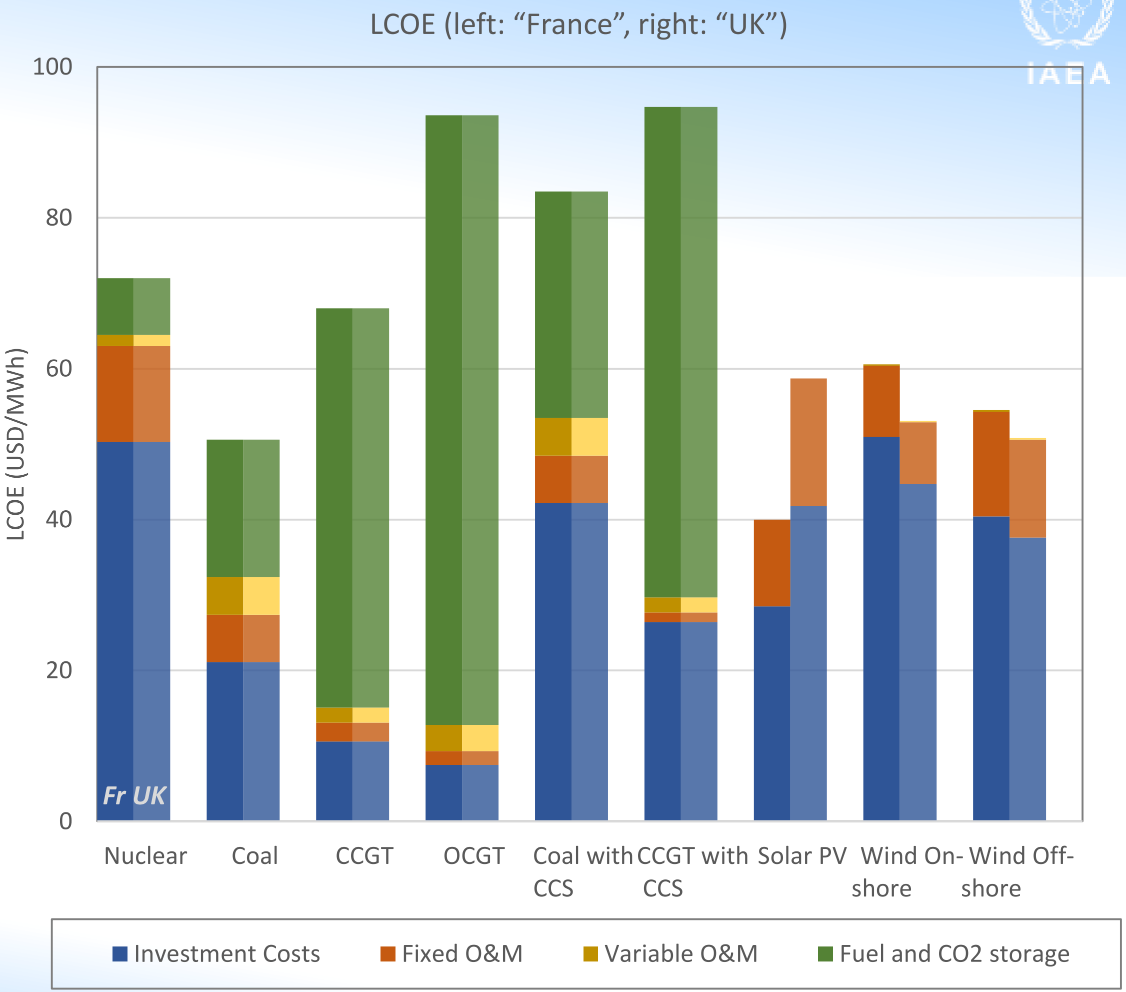


Levelised cost of electricity (LCOE)

- Method to compare different electricity generators
- All discounted costs over the lifetime divided by a discounted sum of produced electricity
- Economic data from IEA WEO 2022 Ed. (estimates for 2050)

Observations

- Coal has the lowest LCOE
- Renewables have similarly low LCOE
- Without fuel costs: nuclear has the highest LCOE



Results

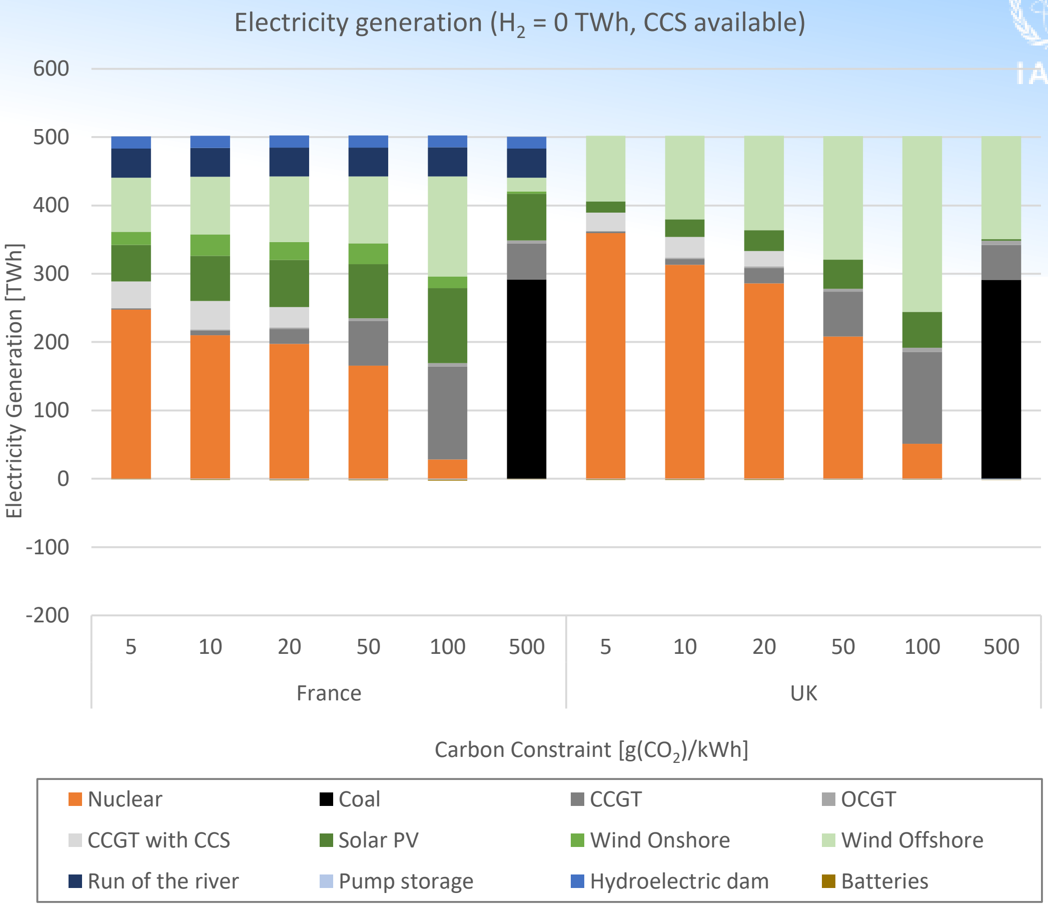
CASES WITHOUT HYDROGEN

Electricity Generation

- Electricity demand of 500 TWh
- „France“ vs. „UK“
- Six carbon constraints

Trends

- Coal at non-binding carbon constraint
- Shift to gas turbines at moderate carbon constraint
- Highest renewables share at 100 g(CO_2)/kWh
- Increase of nuclear at stringent carbon constraints
- Valid for both countries



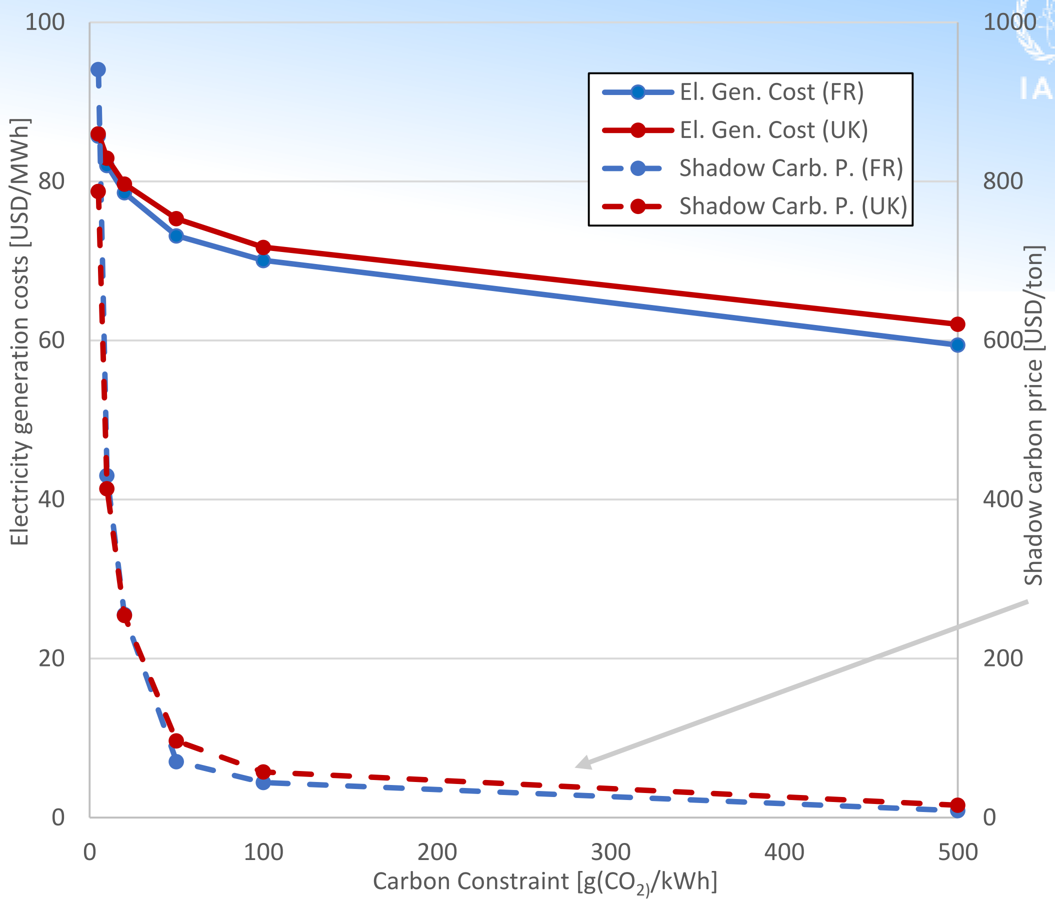
El. generation cost & shadow carbon price

Electricity generation cost [$/MWh]

- Increases as carbon constraints becomes more stringent
- ➢ Model will always fully utilize the carbon constraint

Shadow carbon price [$/ton]

- Results implicitly from imposing a carbon constraint
- When carbon constraint reached, more expensive technologies are used → increase of elec. price
- Increases over-proportionally when approaching 0 g(CO_2)/kWh
- ➢ Reducing carbon emissions from the energy system becomes increasingly more expensive



Results

CASES WITH HYDROGEN

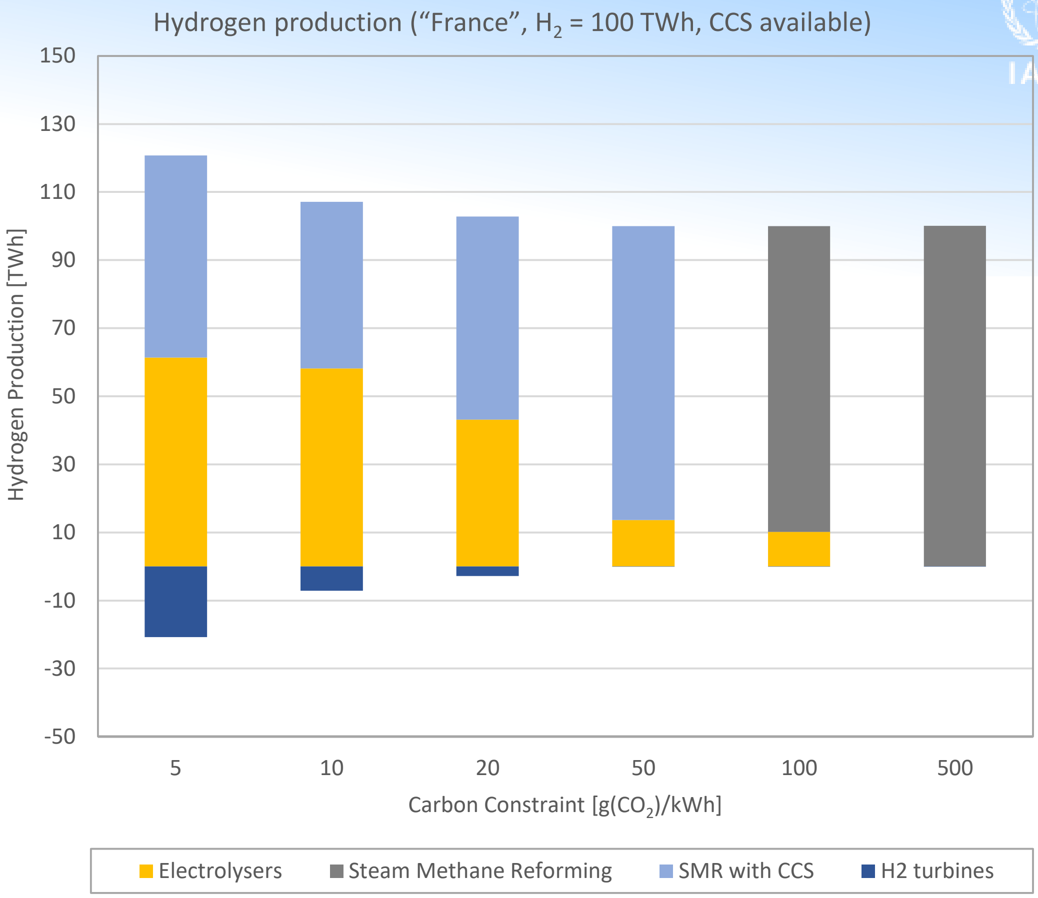
Hydrogen production

Trends

- Steam methane reforming (SMR) at non-binding carbon constraint
- Shift to SMR with CCS at moderate carbon constraint
- Electrolysis gains momentum and shares mix with SMR with CCS at stringent carbon constraint

Hydrogen to electricity

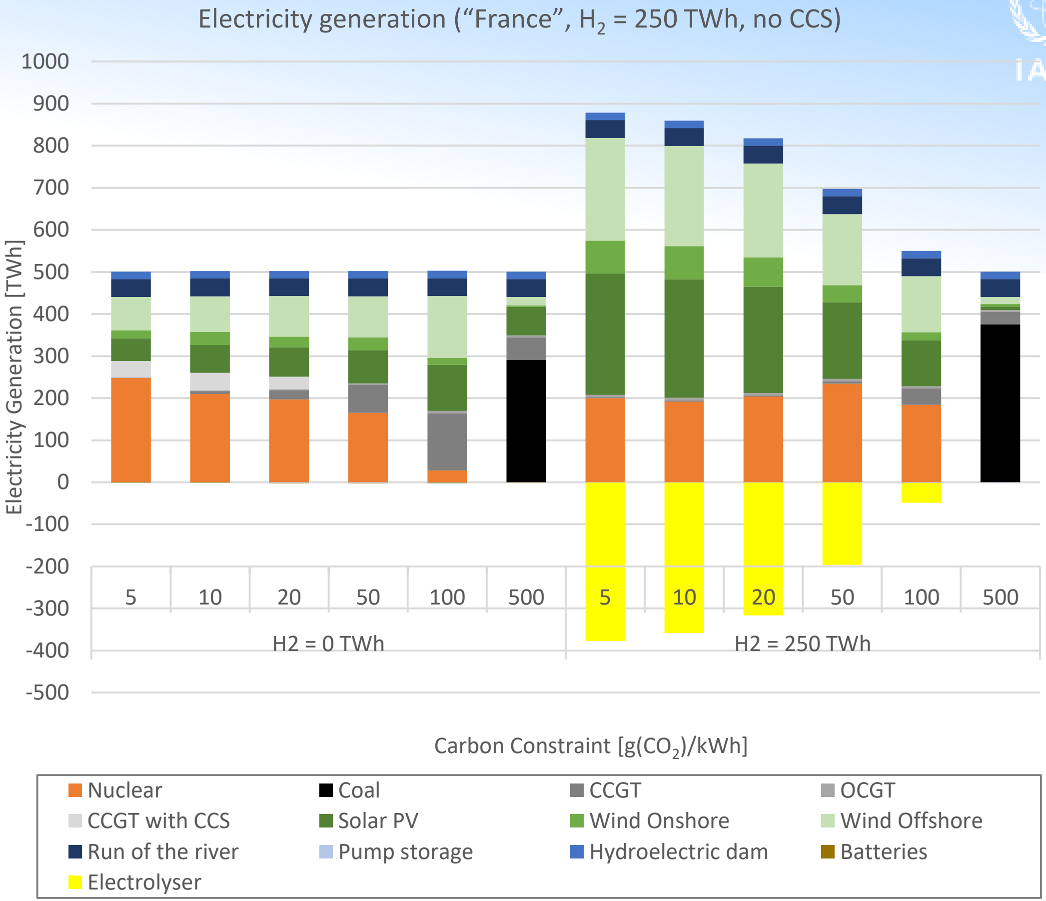
- Only at most stringent carbon constraint



Electricity generation - comparison

Trends

- Without CCS: electrolysis is the leading hydrogen production technology at stringent carbon constraints
  - More total electricity generation
- Higher renewables share
  - Due to additional flexiblity provided by electrolysis
- Lower use of gas turbines
- Less nuclear at stringent carbon constraint
- Valid for both “countries“



Results

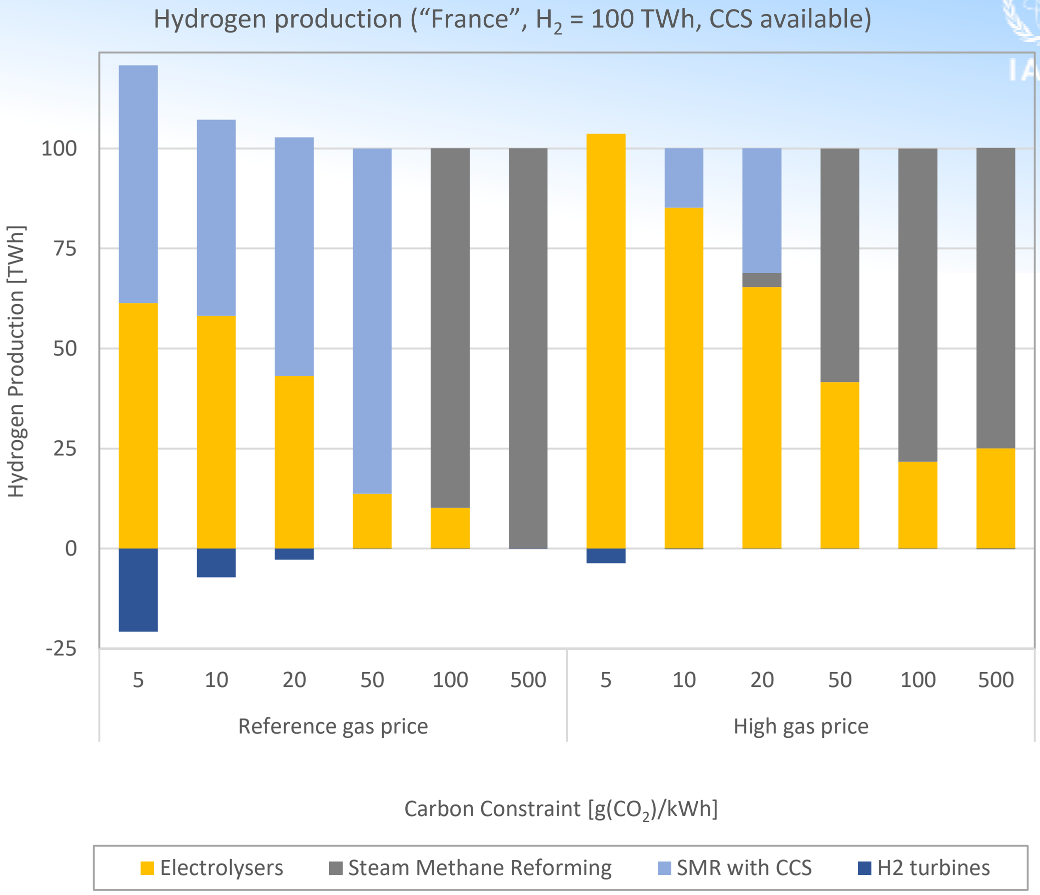
SENSITIVITY CASES

High gas price – hydrogen production

- Increase of the gas price from 9* to 12 $/MMBTU

Trends

- Steam methane reforming becomes less economic (both versions)
- Electrolysis increases across all carbon constraints
- Total hydrogen production decreases because hydrogen to electricity drops back

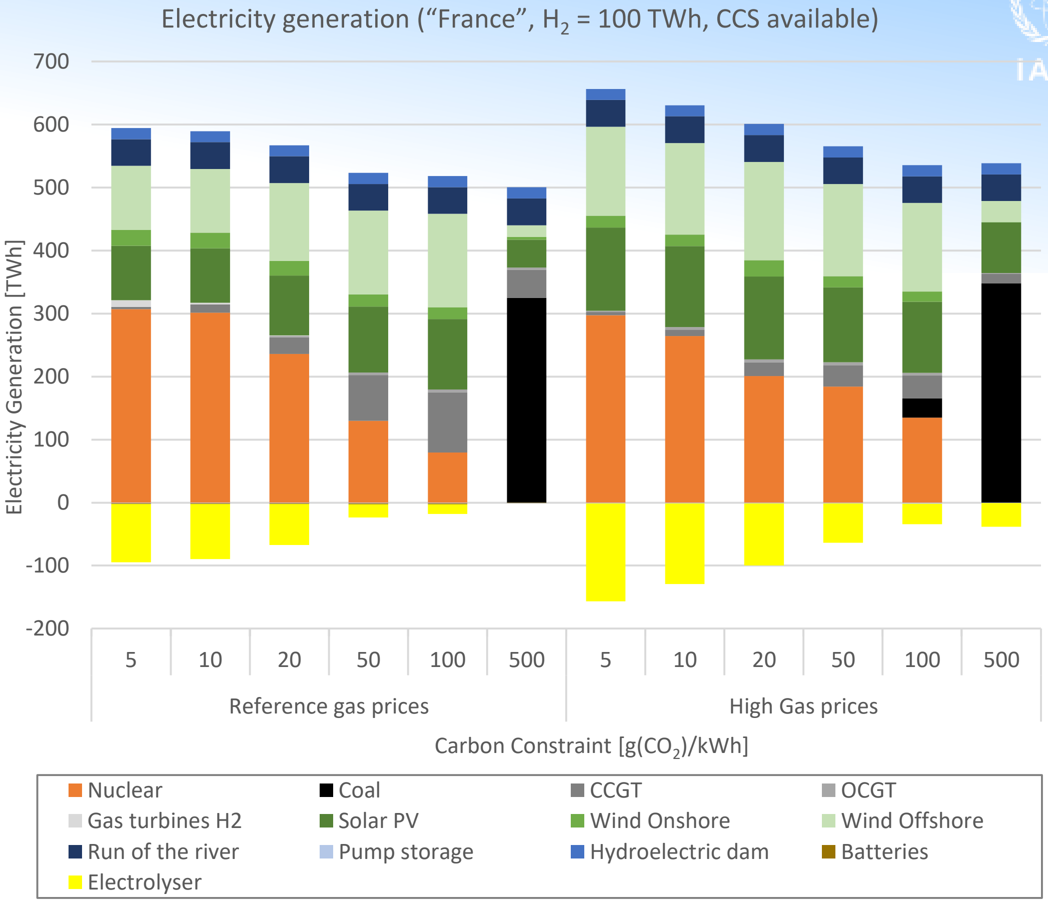


* Source: WEO (IEA, 2022)

High gas price – electricity generation

Trends

- Total electricity generation increases as electrolysis gains significance
- Gas turbines decrease across all carbon constraints
- Coal even at 100 $g(CO_2)/kWh$
- Nuclear increases at moderate carbon constraints
- Renewables share increases up to 50 $g(CO_2)/kWh$
- Flexibility from electrolysis

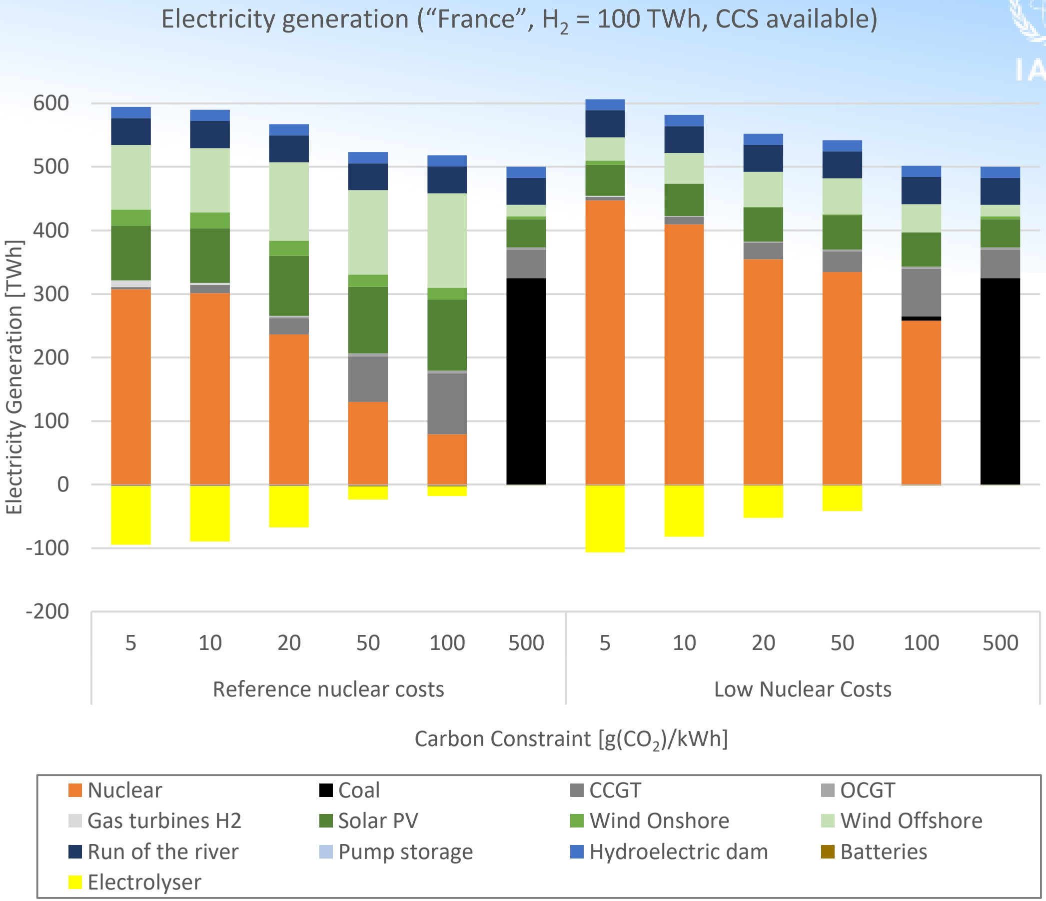


Low nuclear cost – electricity generation

- Construction costs from 4500* to 4000 $/kW
- Fixed operation and maintenance from 100 to 80 $/kW

Trends

- Significant increase of nuclear across all carbon constraints
- Decrease of gas turbines
- Decrease of renewables share
- Coal even enters at 100 g(CO_2)/kWh



* Source: WEO (IEA, 2022)

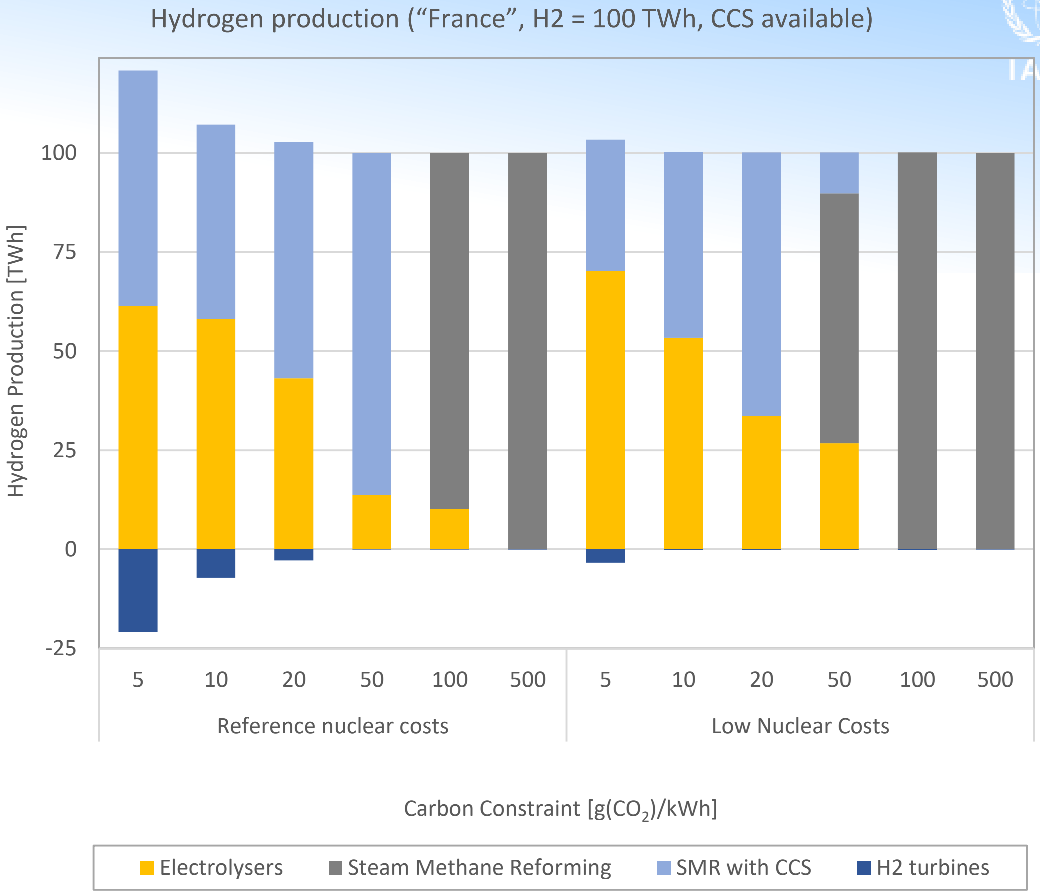
Low nuclear cost – hydrogen production

Trends

- Because of cheap electricity from nuclear:
  - Increase of electrolysis
  - Decrease of SMR

Hydrogen to electricity

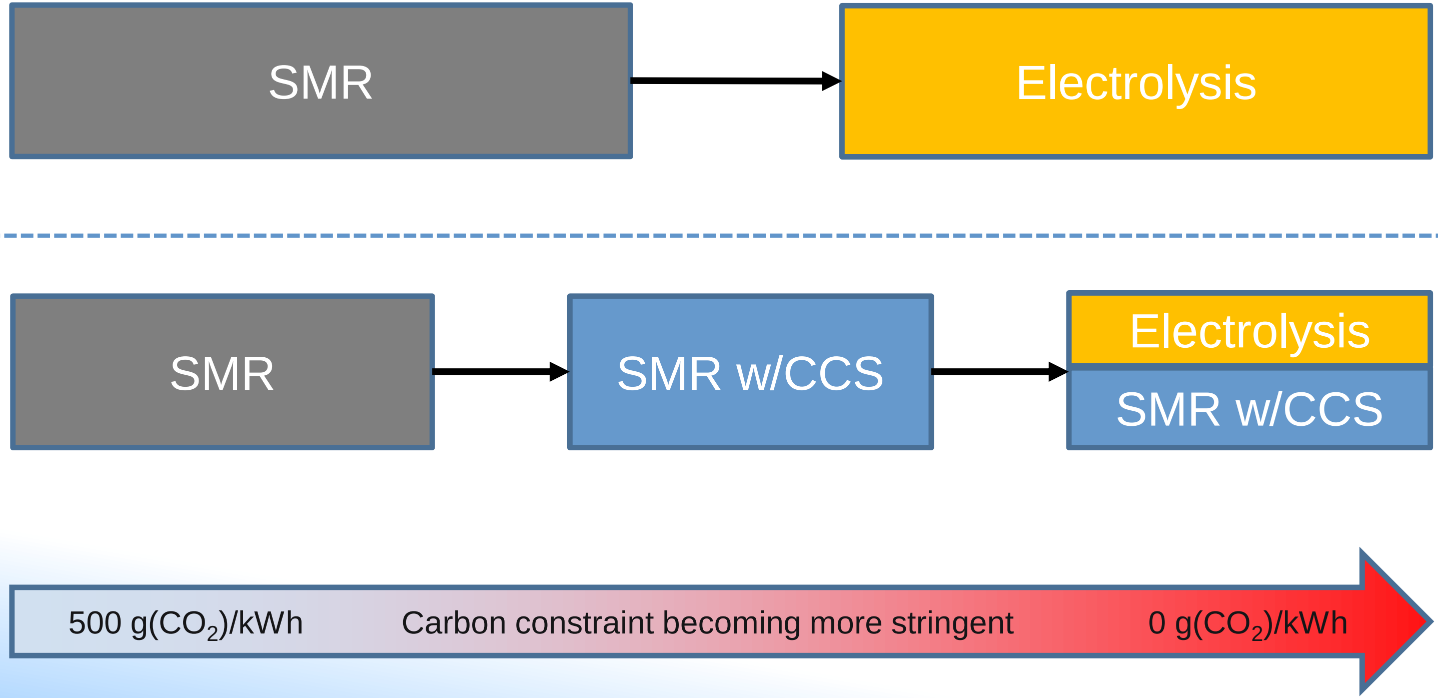
- Because of lower renewables share
  - Less flexibility is required
  - Therefore, decrease of hydrogen to electricity



CONCLUSION

Conclusion

1. How is hydrogen produced at different carbon constraints?



Conclusion

2. In which way does the hydrogen system change the power generation mix?
   - Hydrogen system (electrolysis) offers additional flexibility
   - Increase of renewables share across all carbon constraints
   - Decrease of nuclear at stringent carbon constraints

3. Under which conditions is hydrogen burnt for electricity?
   - Below 20 g(CO_2)/kWh
   - Hydrogen burning provides additional flexibility
   - Because of high energy losses only used as peaking technology
   - OCGT (H_2) dominates over CCGT (H_2)

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Thank you for your attention