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Leveraging emerging technologies for deep industry electrification in an energy system model

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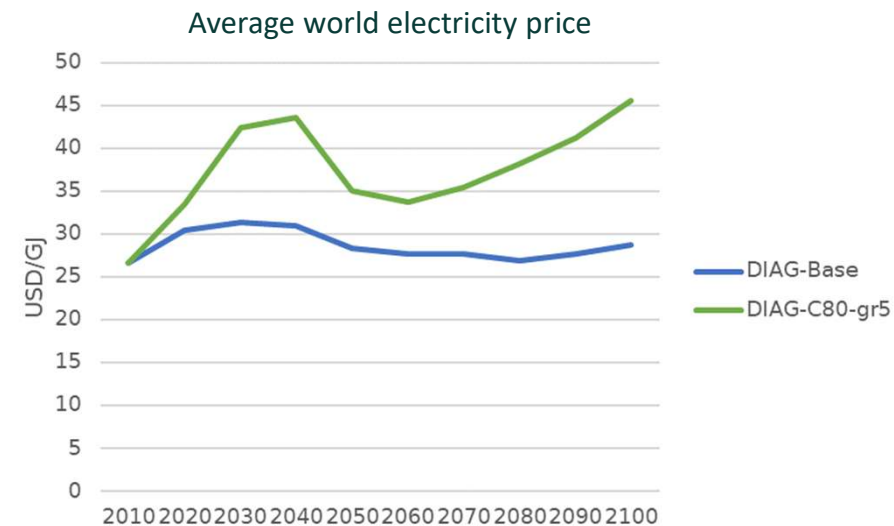
IAMC conference, Venice, 14 November 2023

Adrien Bidaud, LPSC

Silvana Mima, GAEL

Challenges for industry electrification

- Historically, electricity has been expensive
→ fossil fuels chosen over electricity
- Large amounts of low-CO2 electricity: at what cost? At which speed?
→ rate of deployment of low-CO2 capacities should increase significantly
- Electricity pricing for industry:
 - Total electricity price: increasing cost due to residual emissions, peaking plants and storage
 - Industrial processes: need for baseload (little flexibility)
 - Dedicated fixed-rate contracts for zero-emissions electricity: unlikely to offer lower rates with high shares of VRE
→ Industry likely to experience increasing electricity prices (especially mid-term)



Source: NAVIGATE database, 8 models average

New electric technologies

- *Established technologies: electric boilers, electric furnaces*
- Electrolysis for the conversion of iron ore into steel:
 - Large amount of electricity needed
 - ULCOS, SIDERWIN projects: → TRL 6; TRL 9 expected by 2030
- Electric kiln for the conversion of limestone to clinker:
 - Decarbonate project: → TRL 5 (small-scale prototype)
- Heat pumps:
 - Low/mid-temperature compression heat pumps (<100 °C): common (TRL 9+)
 - Higher-temperature heat pumps (mechanical vapour recompression (MVR), up to 200 °C): in use in specific applications, prototypes for large-scale (TRL 4-5)



Source: <https://www.siemens-energy.com/>



Source: <https://www.siderwin-spire.eu/>



Source: <https://www.decarbonate.fi/>

→ costs uncertainty

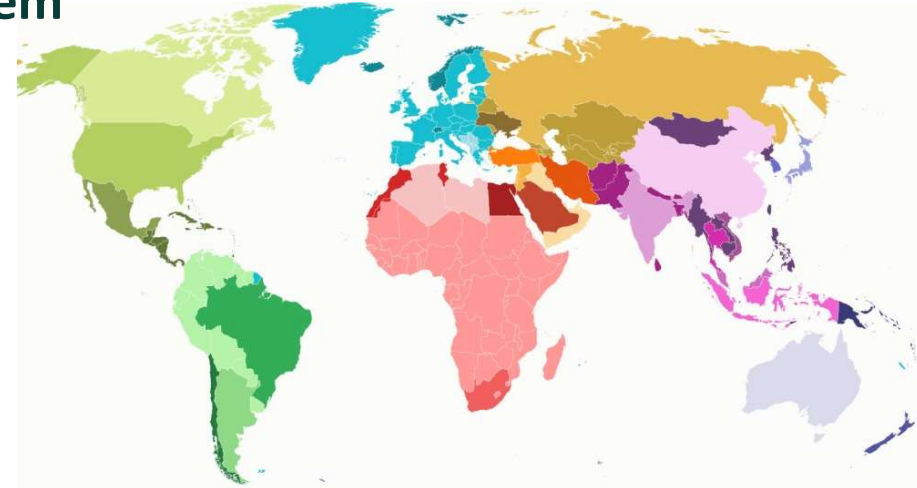
POLES: Prospective Outlook on Long-term Energy Systems

Projections of the evolution of the world energy system

- Long-term model (to 2050-2100)
- EU + 39 countries / regions (OECD, G20)
- Partial equilibrium, simulation

Output

- International energy prices & trade
- All energy sources and vectors
- All GHG emissions (linkage with specialist tools for non-energy)

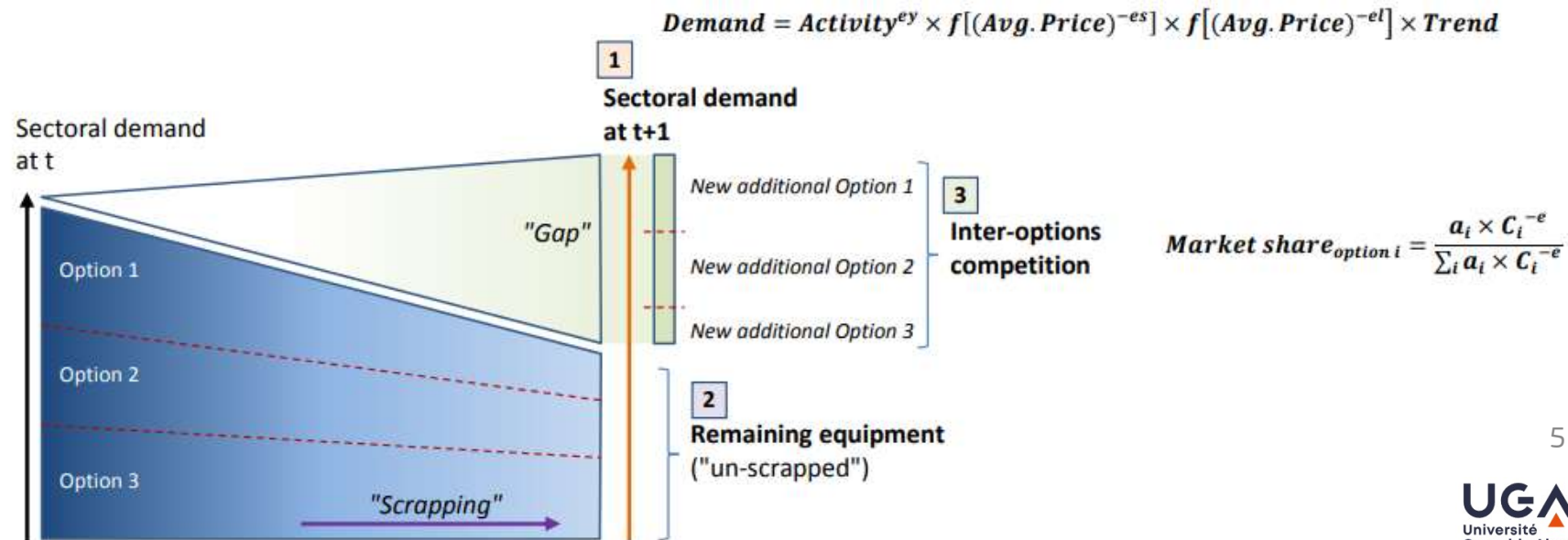


https://joint-research-centre.ec.europa.eu/poles_en

Methodology: modelling

“Old” approach: separate equations for elec, other fuels

- FEC elec = f(VA, Price)
- FEC fuels = f(VA, AvgPrice)
 - Fuels = oil, gas, coal, solid biomass
 - Logit distribution between fuels



Methodology: modelling

“New” approach:

• Steel, Cement:

- FEC all fuels = $f(\text{Tons, Processes})$
- Processes vintage, logit distribution between processes
- Within each process: logit distribution between relevant fuels
- Physical trade of goods

• Chemicals, Other Industry:

- FEC all fuels = $f(\text{VA, AvgPrice})$
- Logit distribution between fuels
- Elec parameters (cost, efficiency) = $f(\% \text{ in FEC})$

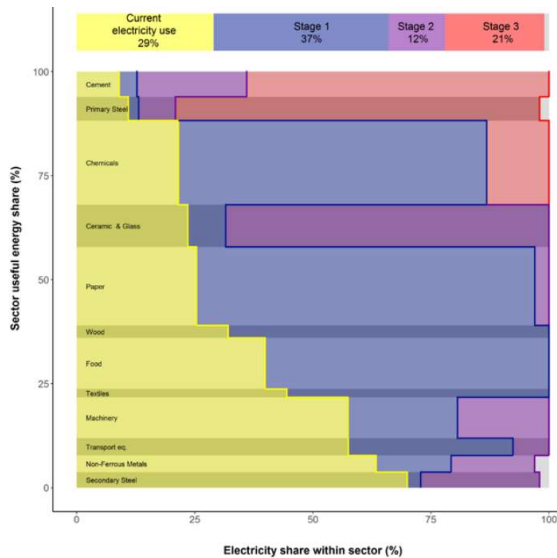
Electricity in:

- raw material preparation & finishing (fixed GJ/t)
- Steel: EAF, Electrolysis
- Cement: Pre-calciner, Electric kiln

Electricity in:

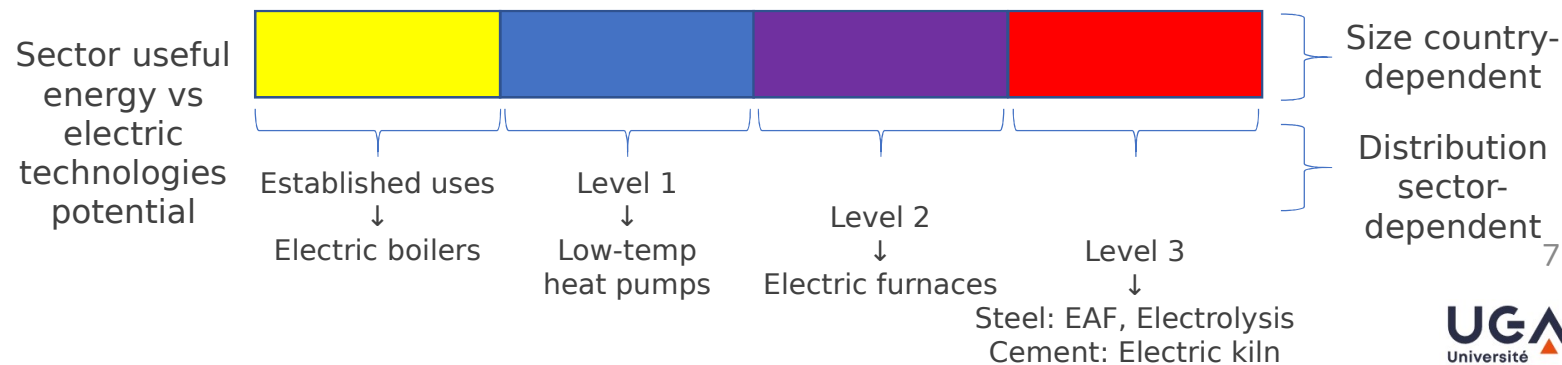
- established uses: boilers
- low-temp heat pumps
- electric furnaces

Methodology: electrification potentials



- By sub-sector: identification of potentials at several stages corresponding to different technologies
- Historical statistics position each country at a starting level of electrification by sub-sector
- Technologies described with:
 - overnight investment cost
 - efficiency or coefficient of performance
 - technology maturity (multiplicative factor from zero to one)

Source: Madeddu et al 2020
 (doi:10.1088/1748-9326)
 + JRC-IDEES 2018 (doi:10.2905/JRC-10110-10001)



Methodology: technologies and potentials

Sub-sector	Product within sub-sector	Current (2021) electrification level	Technology level 1	Achievable potential level 1	Technology level 2	Achievable potential level 2	Technology level 3	Achievable potential level 3
Iron & Steel	Primary routes (tons in 4 processes)	10%	Heat pumps	13.3%	Electric furnaces	21.4%	Electrolysis	100%
Iron & Steel	Secondary route (tons in electric arc furnace, subject to scrap availability)	71%	Heat pumps	74.5%	Electric furnaces	100%	-	-
Non-Metallic Minerals	Cement	11%	Heat pumps	13.0%	Electric pre-calciner (resistance kiln)	36.5%	Electric kiln	100%
Non-Metallic Minerals	Other (driver: value added)	25%	Heat pumps	31.5%	-	-	-	-
Chemicals	All (driver: value added)	24%	Heat pumps	87.0%	-	-	-	-
Other manufacturing	All (driver: value added)	36%	Heat pumps	98.4%	Electric furnaces	99%	-	-

Note: electrification share refers to sectoral electricity consumption over total sectoral final energy consumption; final energy needs exclude non-energy uses (chemical feedstocks).

Methodology: techno-economic parameters

Sub-sector	Electric technology	CAPEX (2020)	Efficiency (2020)	Comparison technology	CAPEX (2020)	Efficiency (2020)
Steel	Electric Arc Furnace	370 \$/t steel	2.9 GJ/t steel			
Steel	Electrolysis	730-1090 \$/t steel	11.9 GJ/t steel	<i>BF-BOF</i>	<i>1180 \$/t steel</i>	<i>16.7 GJ/t steel</i>
Cement	Electric pre-calciner	3780 \$/kW	95%	<i>Coal-fuelled pre-calciner</i>	<i>1160 \$/kW</i>	<i>70%</i>
Cement	Electric kiln	480-720 \$/t cement	3.3 GJ/t cement	<i>Long dry kiln with pre-heater and pre-calciner</i>	<i>350 \$/t cement</i>	<i>3.3 GJ/t</i>
All	Electric boiler	620 \$/kW	99%	<i>Gas boiler</i>	<i>1030 \$/kW</i>	<i>80%</i>
All	Low-temperature heat pump	1780 \$/kW	200%			
All	Electric furnace	620 \$/kW	85%			

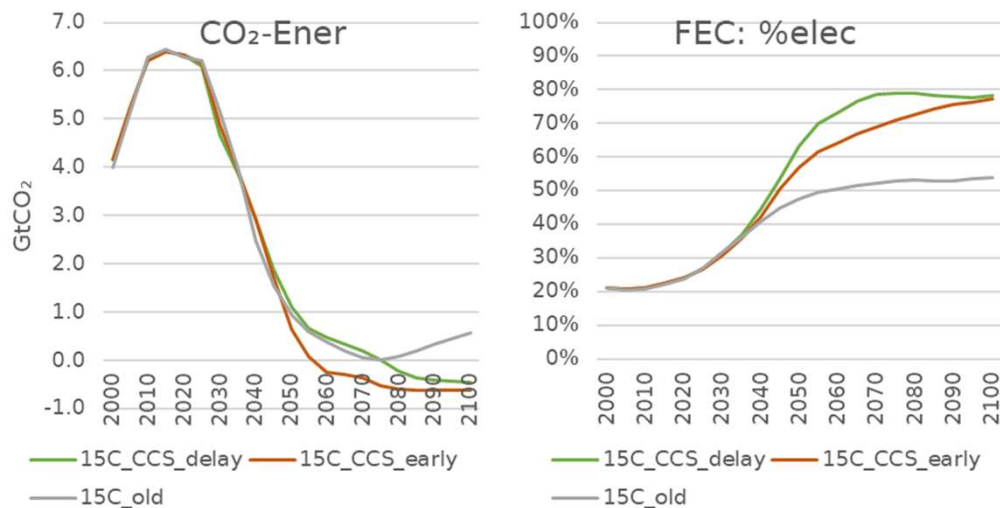
See: JRC-CETO https://setis.ec.europa.eu/publications/clean-energy-technology-observatory-ceto_en

Scenarios

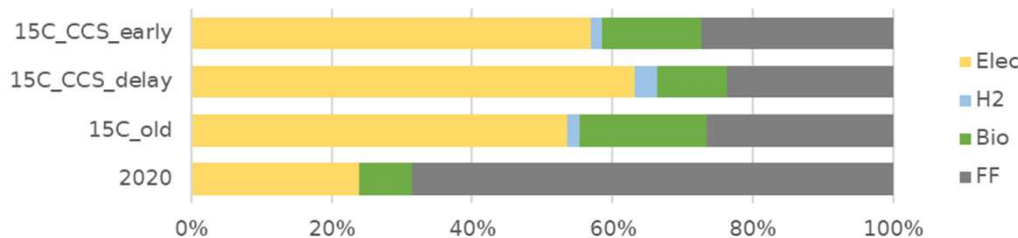
<i>15C_old</i>	1.5°C scenario with old modelling	GECO 2021
<i>15C_CCS_early</i>	1.5°C scenario with early CCS availability - To assess the competitiveness of the electric technologies compared to a competitor that allows a prolonged use of combustion-based technologies at relatively low cost	Derived from GECO 2022
<i>15C_CCS_delay</i>	1.5°C scenario with delayed CCS availability (by 30 years), optimistic cost assumptions for new electric technologies - To assess the potential of the electric technologies with more friendly conditions for in-depth changes	Derived from GECO 2022

Global Energy and Climate Outlooks 2021, 2022:
see JRC: https://joint-research-centre.ec.europa.eu/geco_en

Results: Total industry

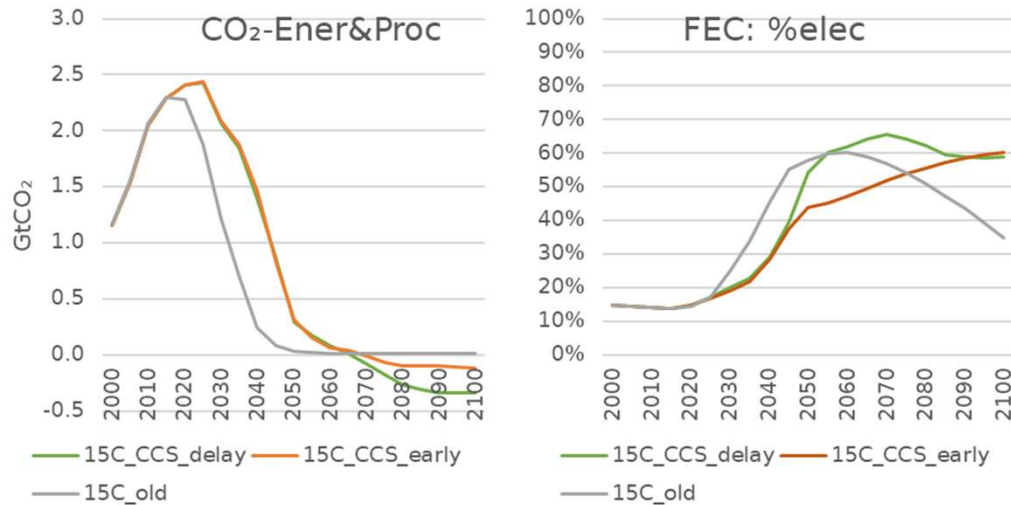


2050 Energy mix

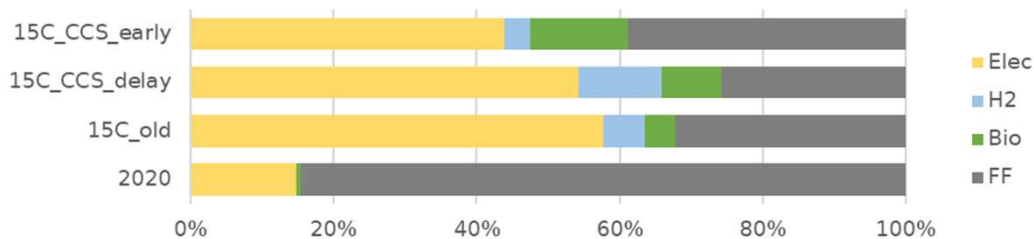


- Strong increase of electrification over time
- Effect of new modelling noticeable after 2040
- Delayed CCS development: higher electrification, lower biomass use
- Overall emissions trajectory similar

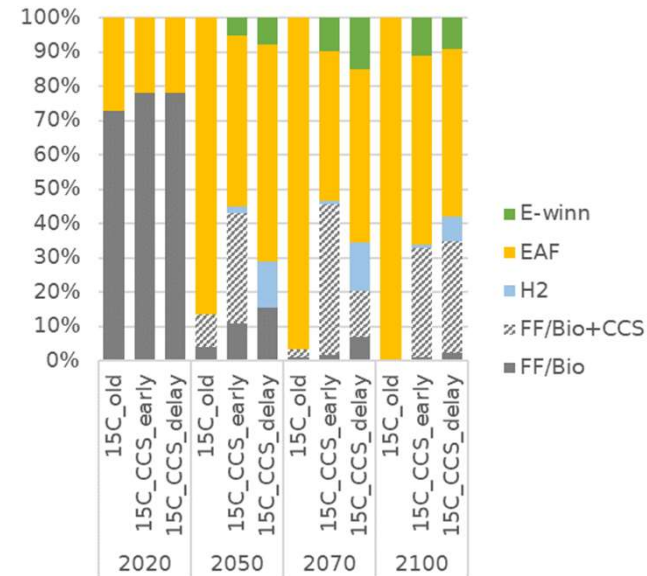
Results: Iron & Steel



2050 Energy mix



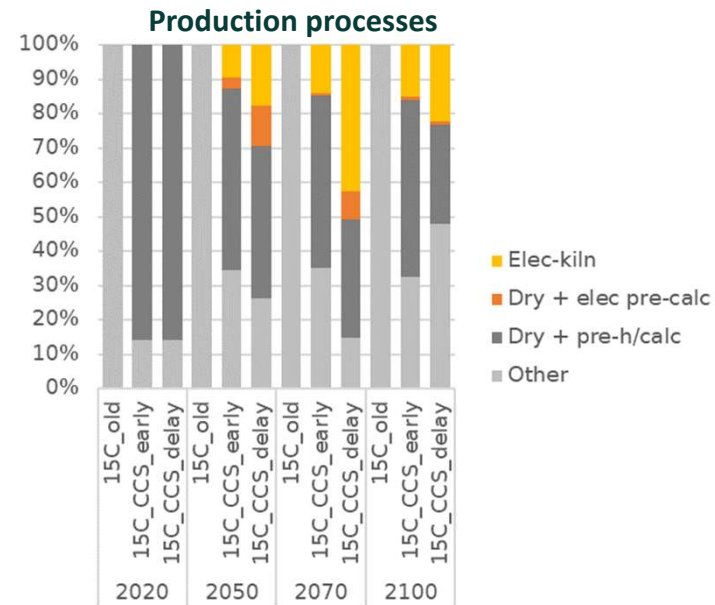
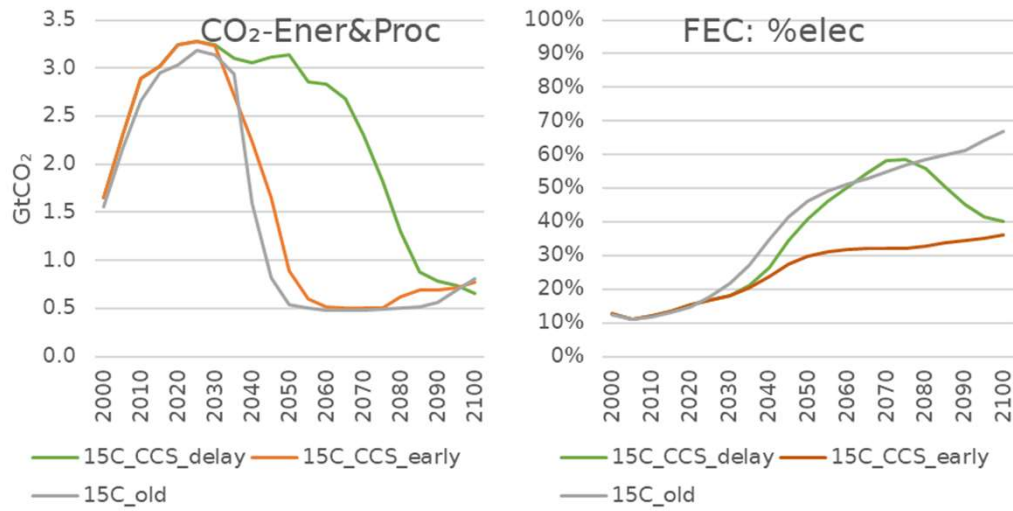
Production processes



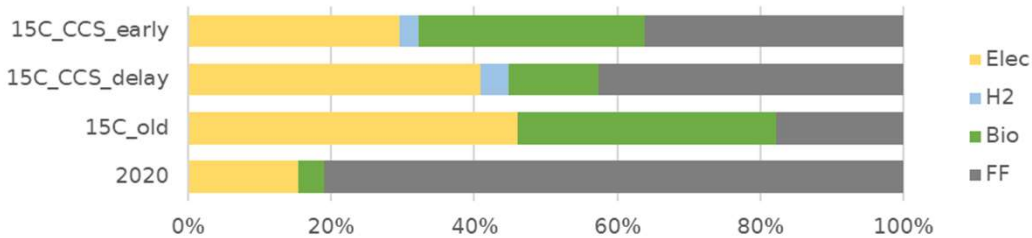
Representation of specific production processes & steel scrap flows

- Steel demand: recycling potential, growth of EAF
- Higher CCS uptake, lower electrification
- Higher electrification reached with delayed CCS

Results: Cement & Non- Metallic Minerals



2050 Energy mix

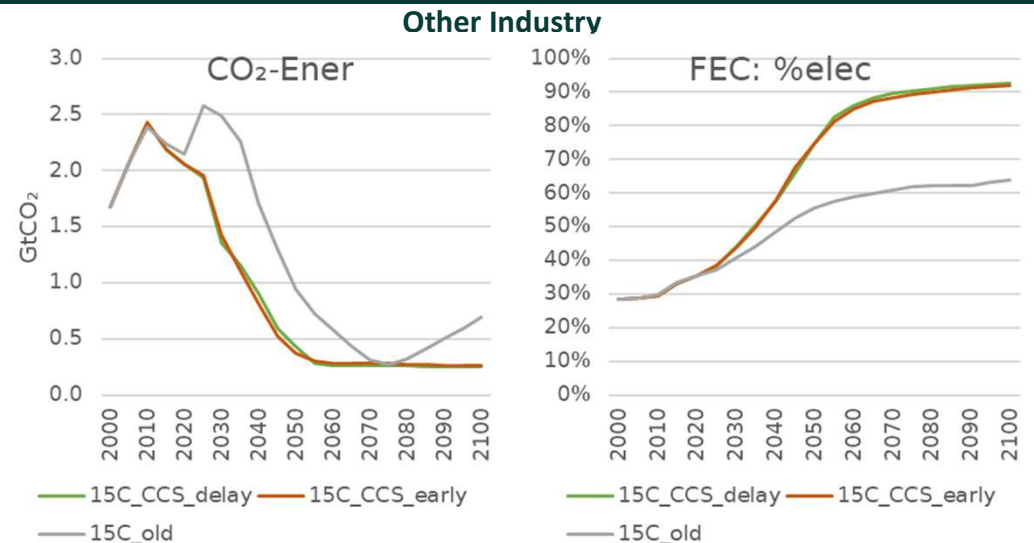
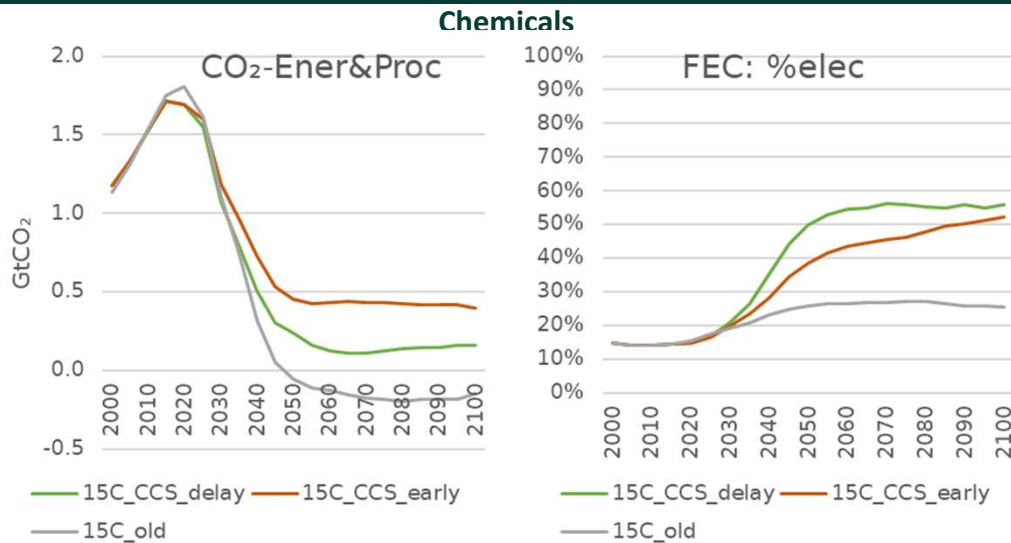


Representation of physical tons demand + specific production processes:

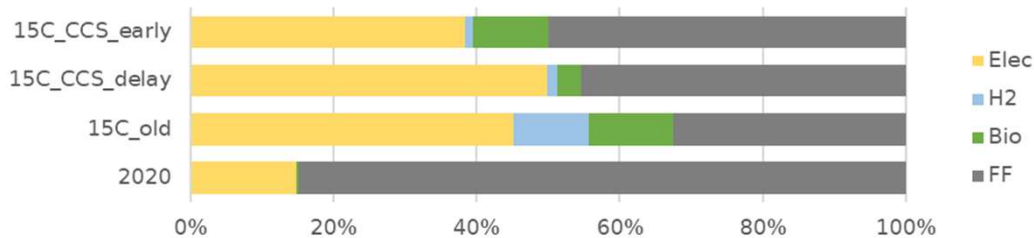
→ Higher levels of total energy demand, lower potential for electrification

→ Higher electrification reached with delayed CCS

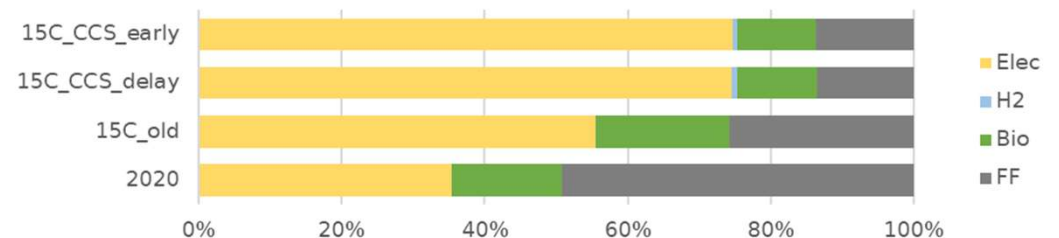
Results: Chemicals & Other Industry



2050 Energy mix



2050 Energy mix



Higher effect of inclusion of new electrification technologies

Chemicals: lower potential, trade-off with CCS; Other Industry: near-total electrification

Conclusions

- Model improvements: balancing detail with complexity
- Untapped potential for higher electrification in industry: from $\frac{1}{4}$ to $\frac{1}{2}$ of FEC in 2050
- Higher electrification is possible using proven technologies
- Result in lower reliance on options with trade-offs (e.g. BECCS)
- Dependent on cost and timeliness of providing large amounts of low-CO₂ electricity
- Role of emergent technologies for further electrification: high-temperature heat pumps, electrochemistry, roto-dynamic heaters, plasma arc furnace, microwave...

Thank you!



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