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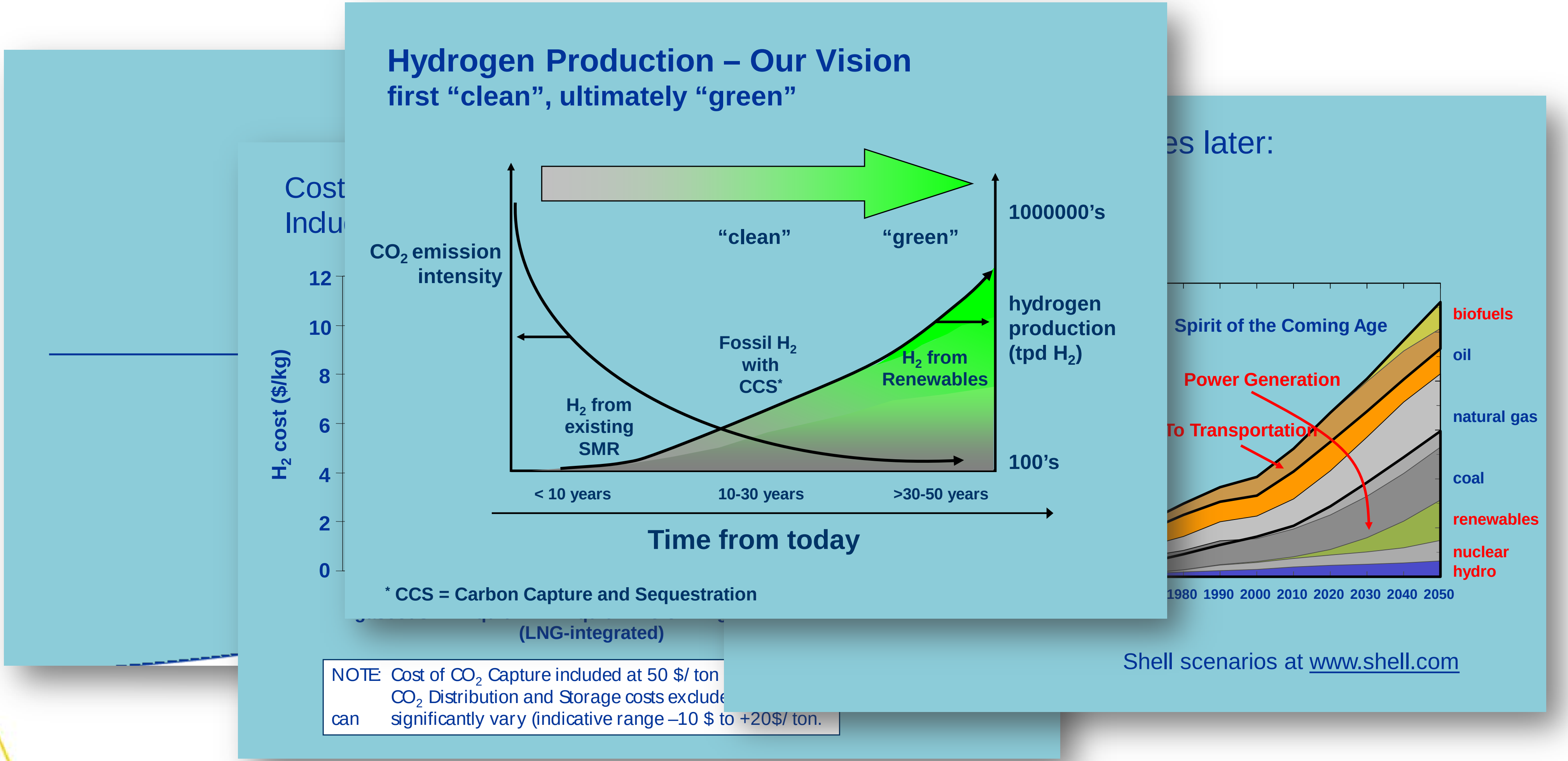
Electrochemical Conversion, Energy Storage and Future Fuels - assessing the options

Gert Jan Kramer

ECCM conference, The Hague, 29 June 2018

Green or Clean Hydrogen; Green or Blue Hydrogen

A flashback to the 00s



See: G.J. Kramer, J. Huijsmans and D. Austgen, *Clean and Green Hydrogen*, WHEC 16 (2006)

Green or Clean Hydrogen; Green or Blue Hydrogen

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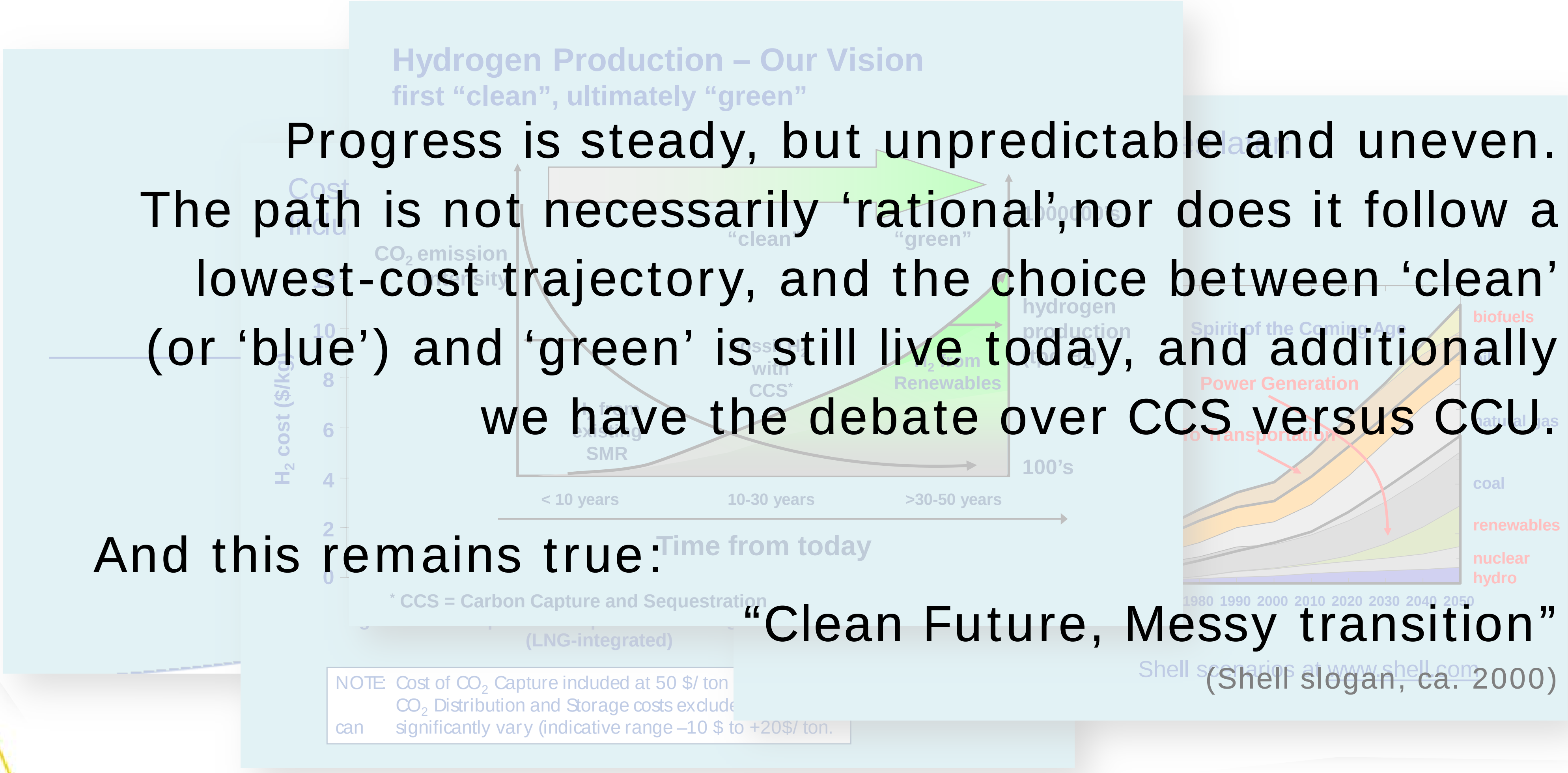


Progress is steady, but unpredictable and uneven. The path is not necessarily 'rational', nor does it follow a lowest-cost trajectory, and the choice between 'clean' (or 'blue') and 'green' is still live today, and additionally we have the debate over CCS versus CCU.

And this remains true:

"Clean Future, Messy transition"

(Shell slogan, ca. 2000)

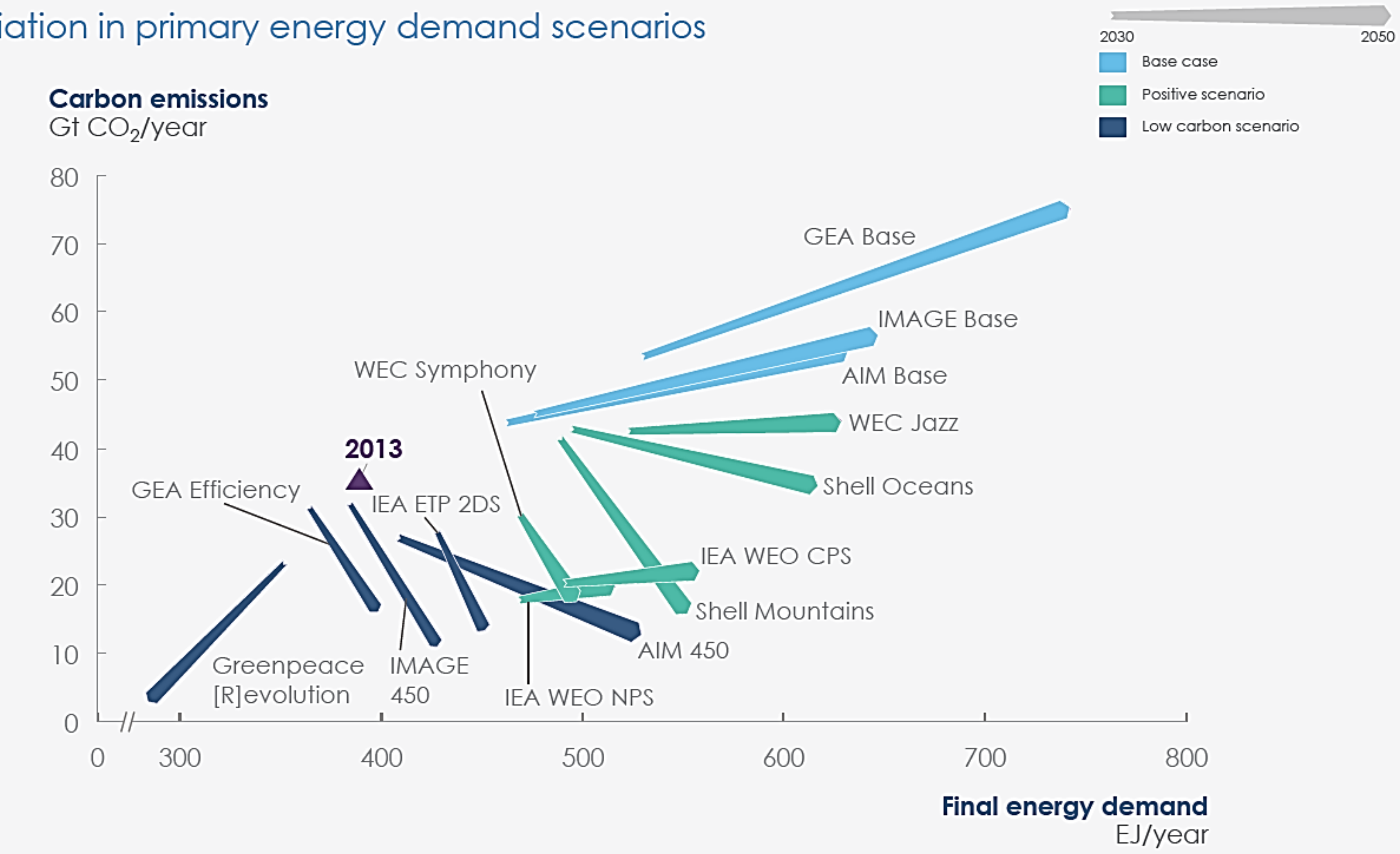
What has changed in those eleven years?

2007	2018
• Targets: 2 °C, ~550 ppm	• Targets: 1.5-2 °C, ≤450 ppm
• “carbon constrained” outlook	• “net-zero emission” outlook
• PV and Wind in their commercial infancy	• PV and Wind both >100 $billion industries
• CCS for the Power sector	• CCS for Industry
• Biofuels and Hydrogen for Transport	• Electric Mobility for Transport
	• Negative emissions
• Hydrogen:Clean vs Green	• Hydrocarbons: CCS vs CCU

Where are we headed? Energy and emissions

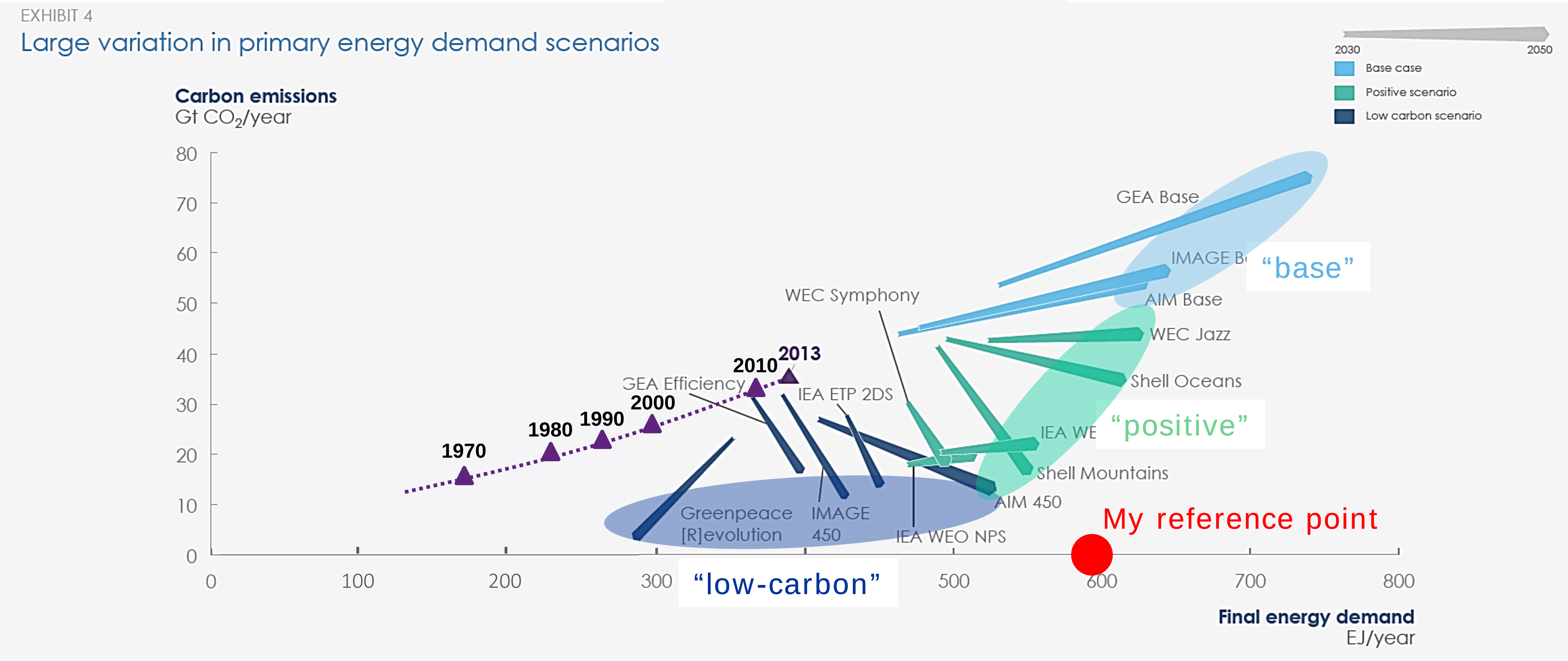
EXHIBIT 4

Large variation in primary energy demand scenarios



Source: Energy Transitions Commission, *Shaping Energy Transitions* (April 2016)

Where are we headed? Energy and emissions



It takes decades for new energy technologies to mature

Will Electrochemical Conversion follow this pattern?

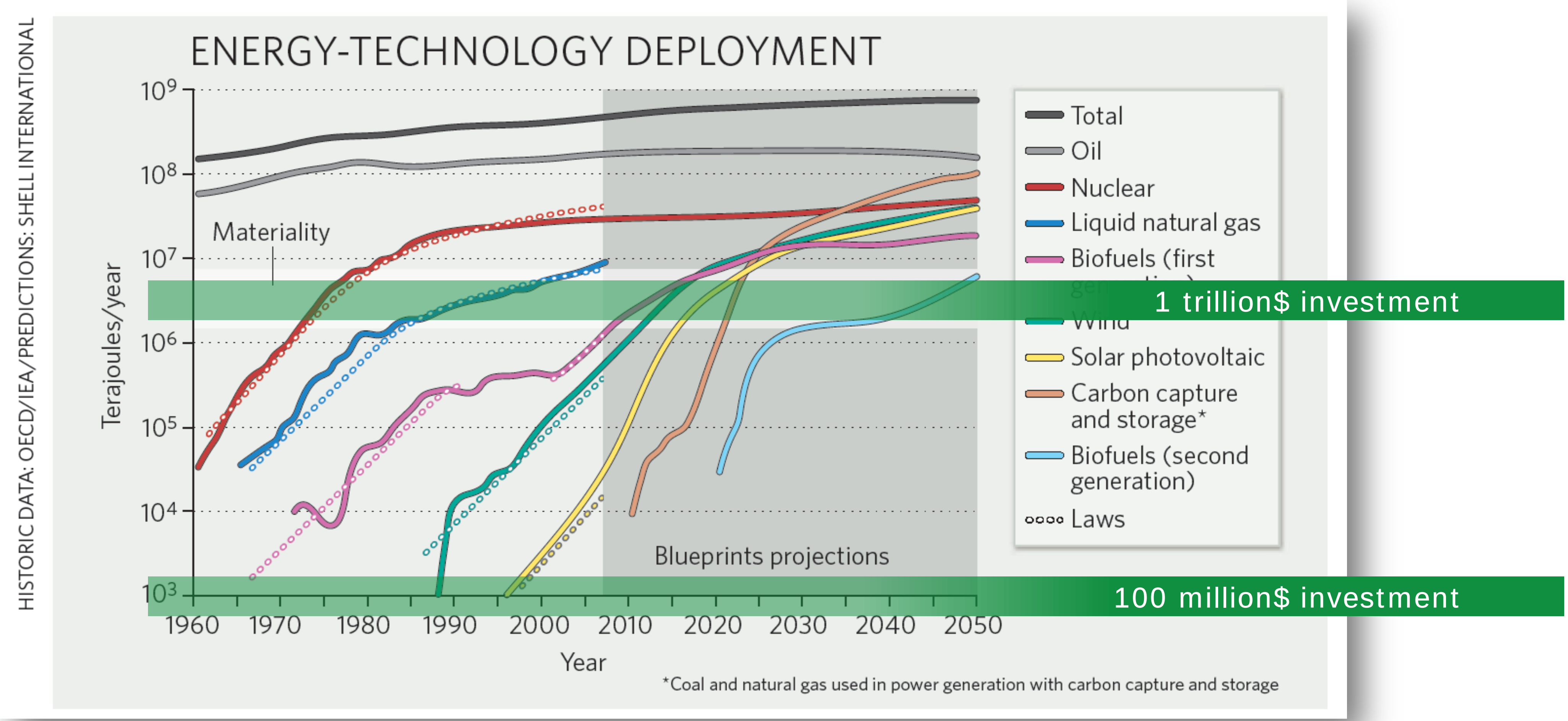
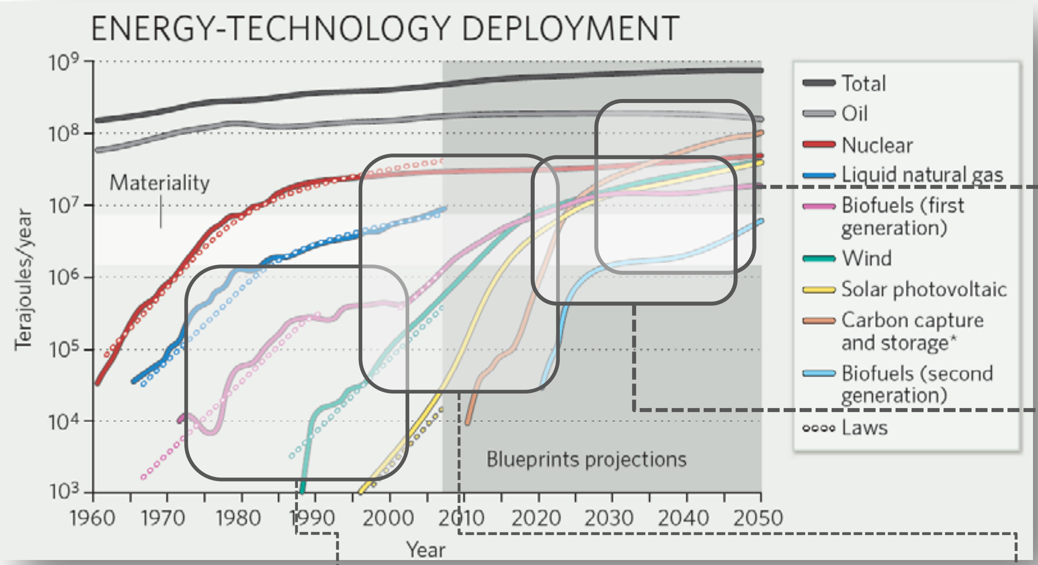


Figure: G.J. Kramer and M. Haigh, *Nature*, **462**, 568 (2009)

… but we started in the 1970s



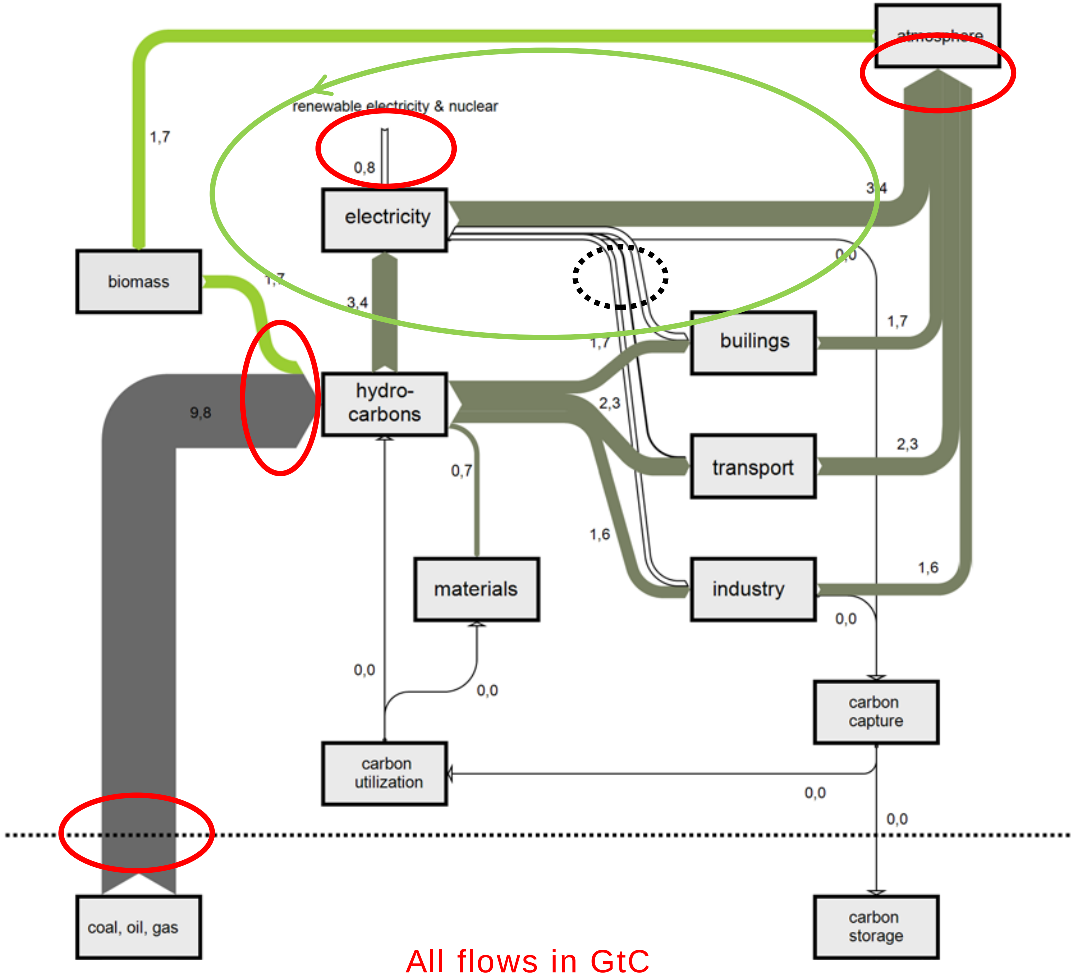
Dealing with fuels and irreplaceable carbon

1970s to 2000 – Creating the Technologies

Ca. 2000 to 2030 – Technologi

Post 2025 – Making the RE *system* work

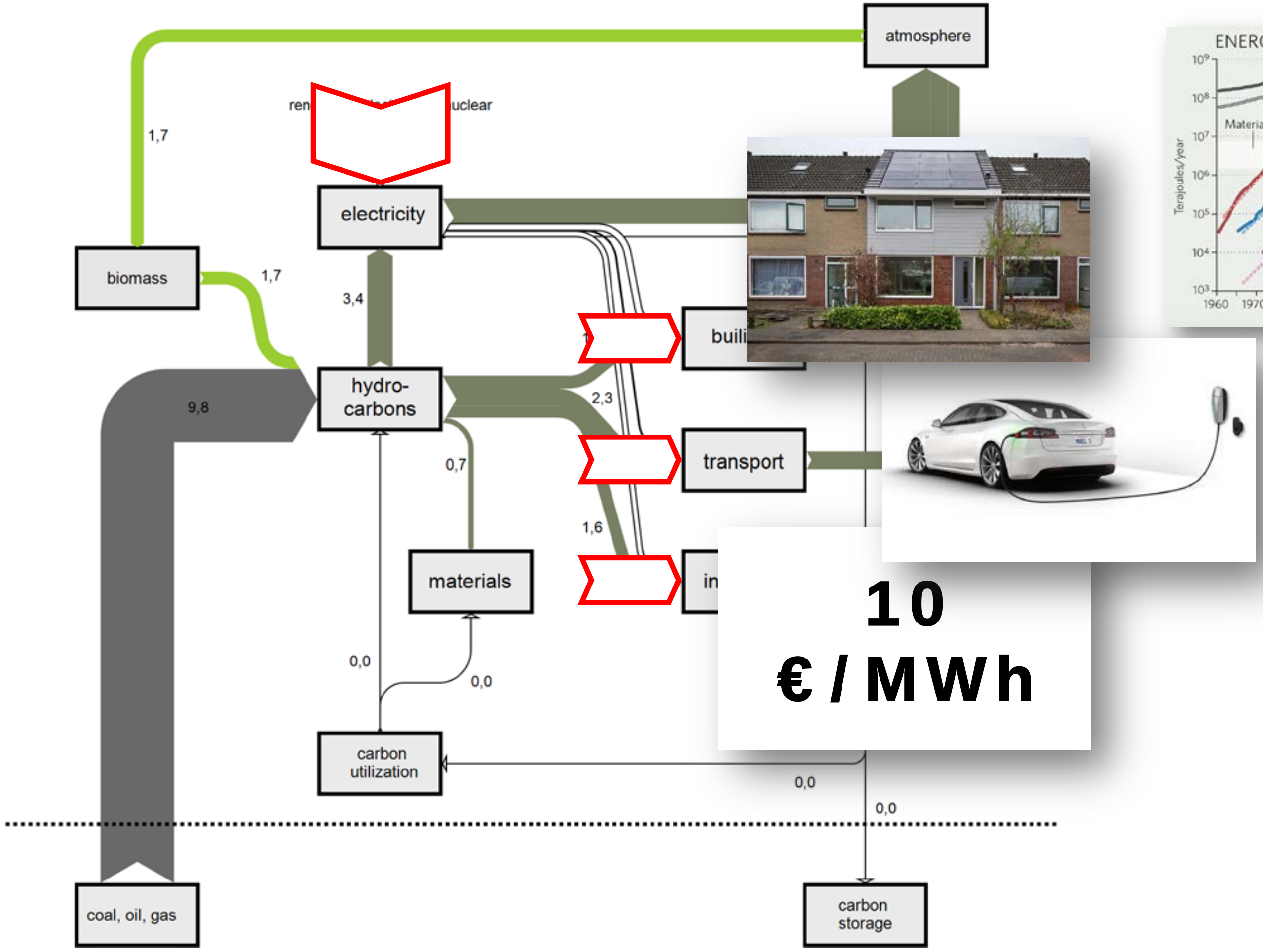
The world's carbon-energy balance (2015)

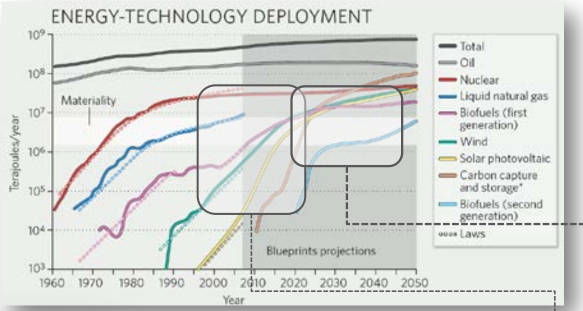


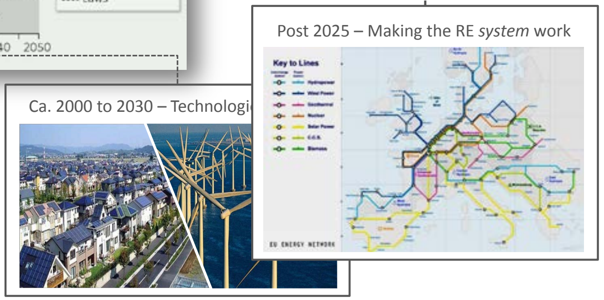
- 90% of primary energy is hydrocarbons;
  10% is electric (nuclear, hydro, PV, wind)
- Fossil hydrocarbons:
  80% of primary energy (470 EJ/year)
  10 Gt/year carbon, or 36 Gt embodied CO_2
- Biomass energy:
  10% of primary energy (55 EJ/year)
  1.7 Gt/year carbon, or 6 Gt embodied CO_2
  NB: 30 EJ/year is "traditional biomass"
- Electricity is 20% of final energy consumption
  (represented in the graph by virtual carbon flows scaled to the hydrocarbon energy equivalent)

Source: G.J. Kramer, based on IEA data

Renewable electricity and electrification will drive change







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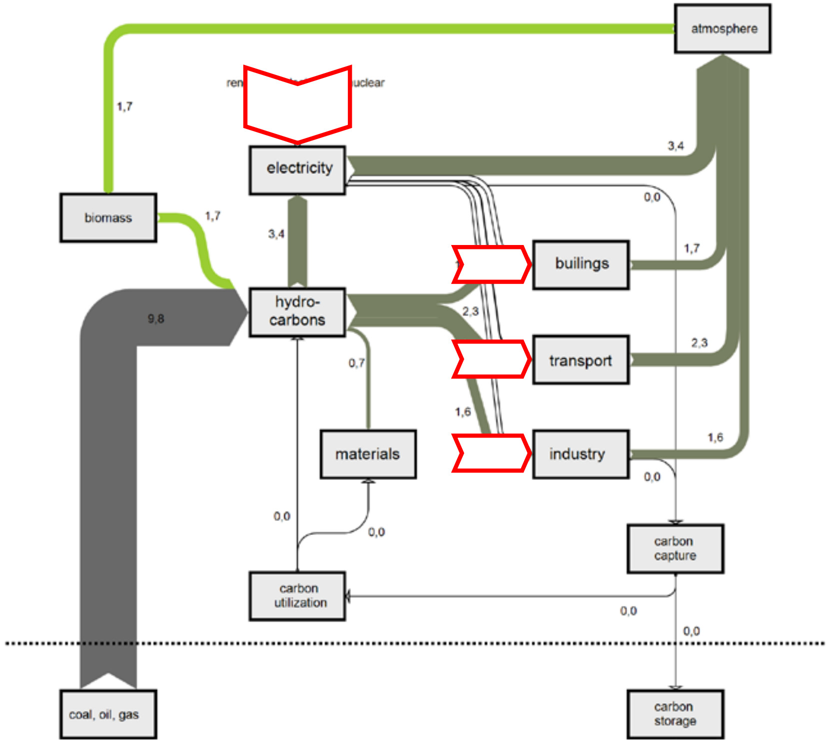

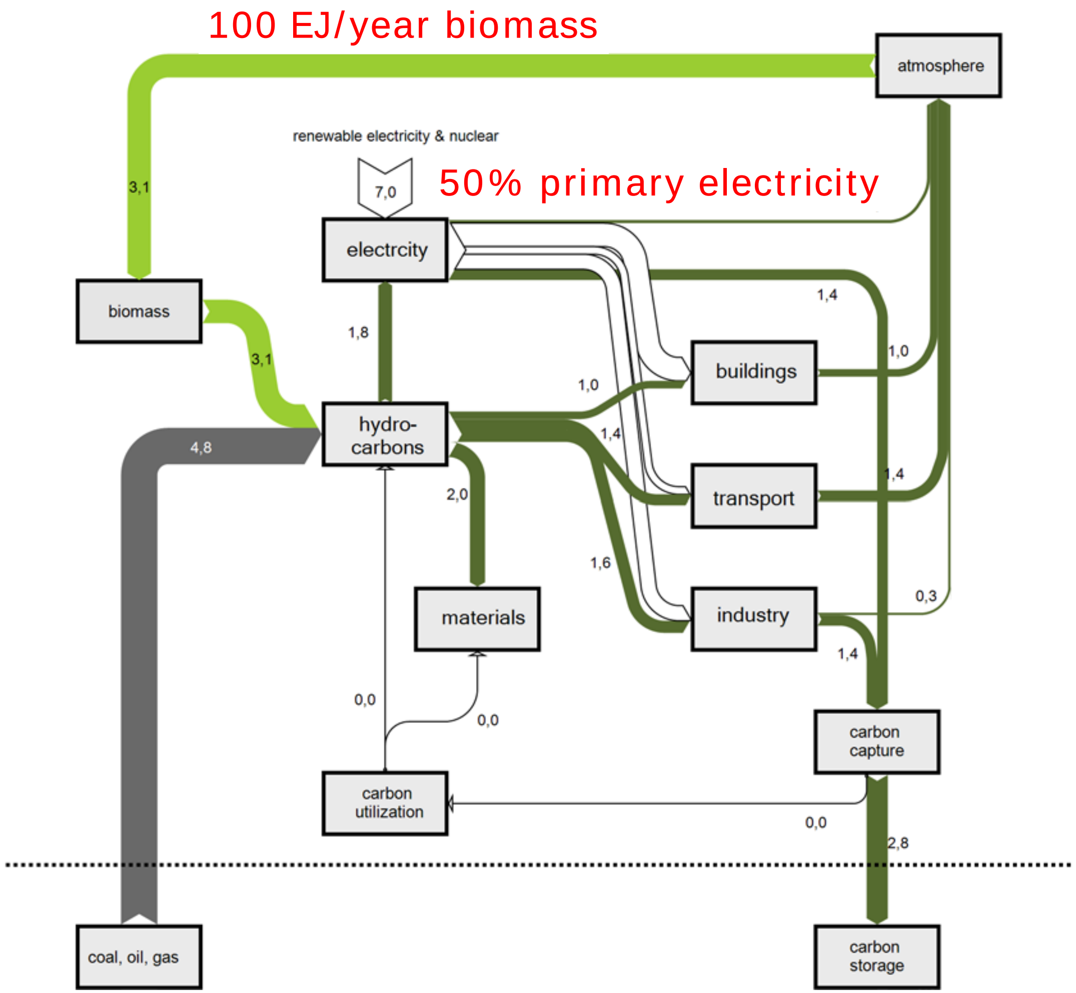

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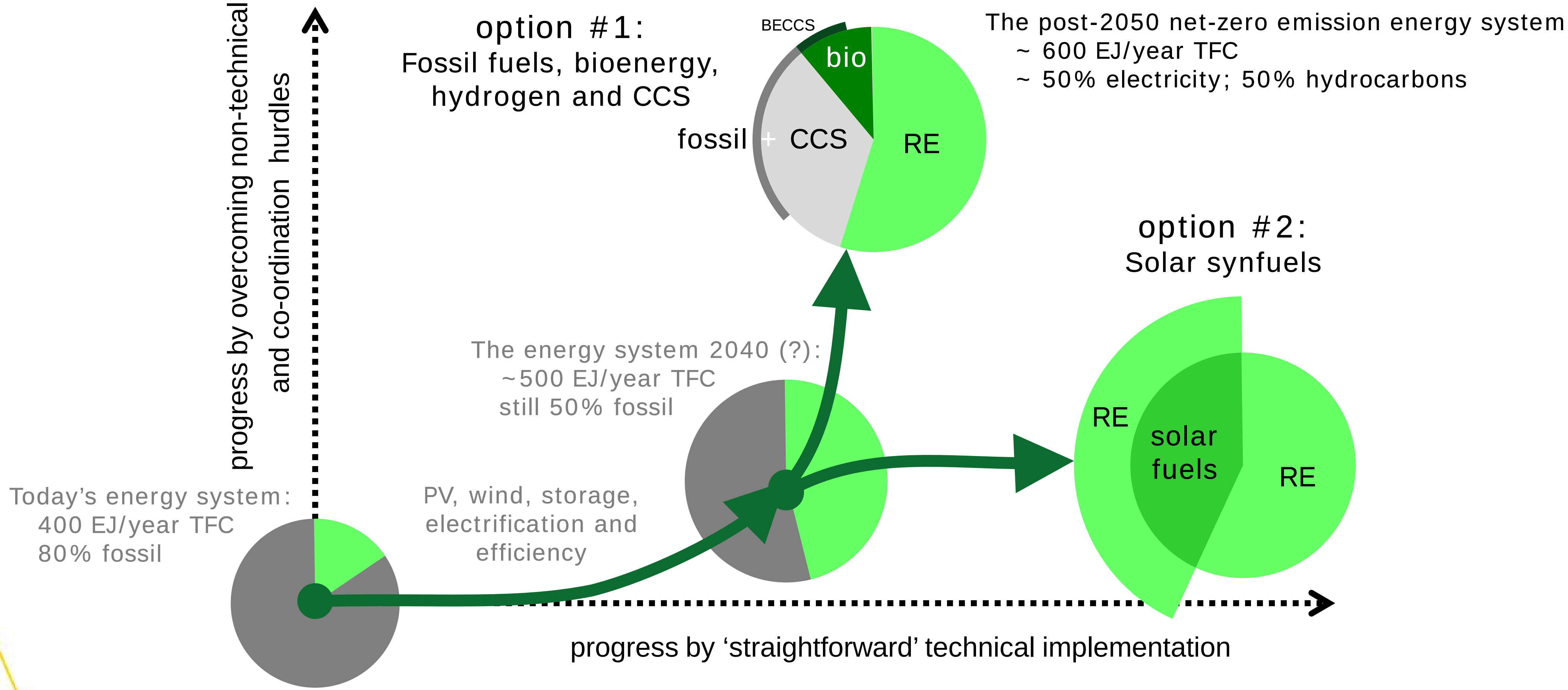
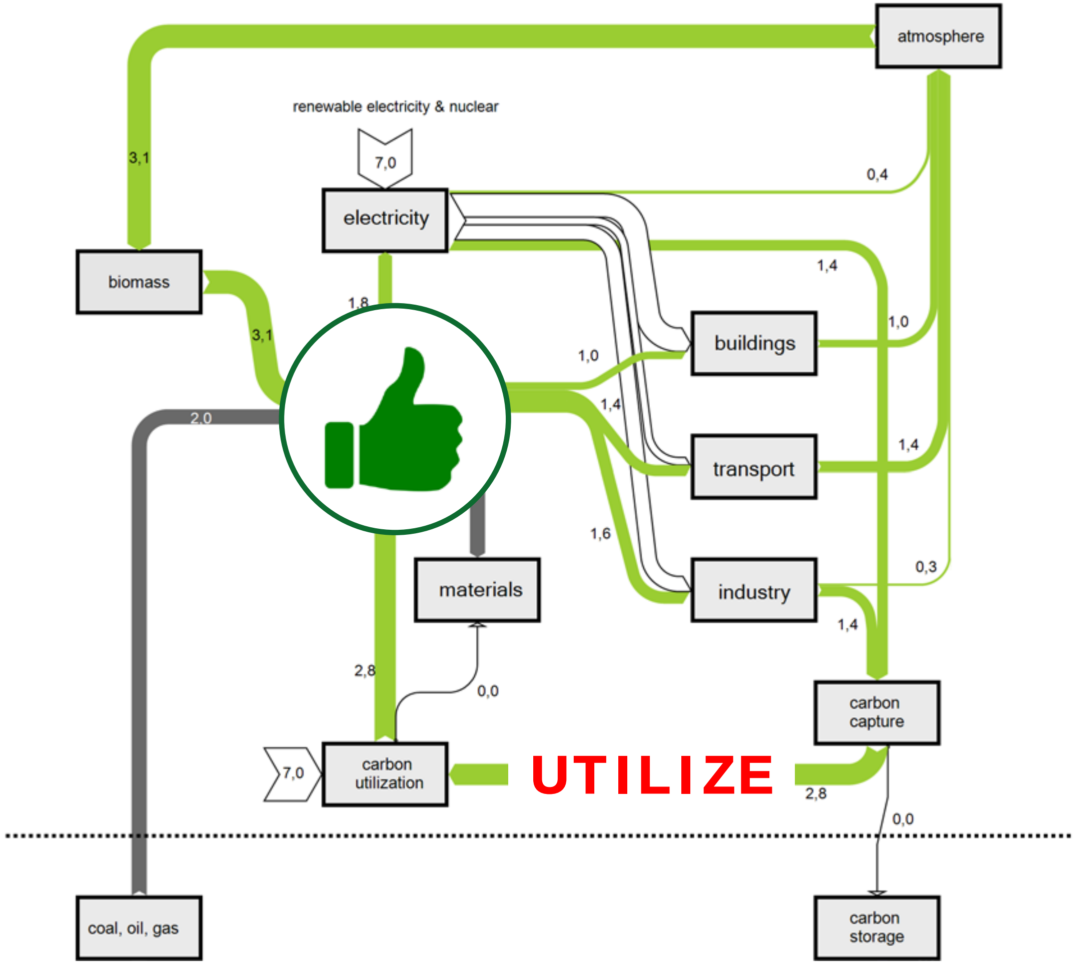
The Unfolding Energy Transition

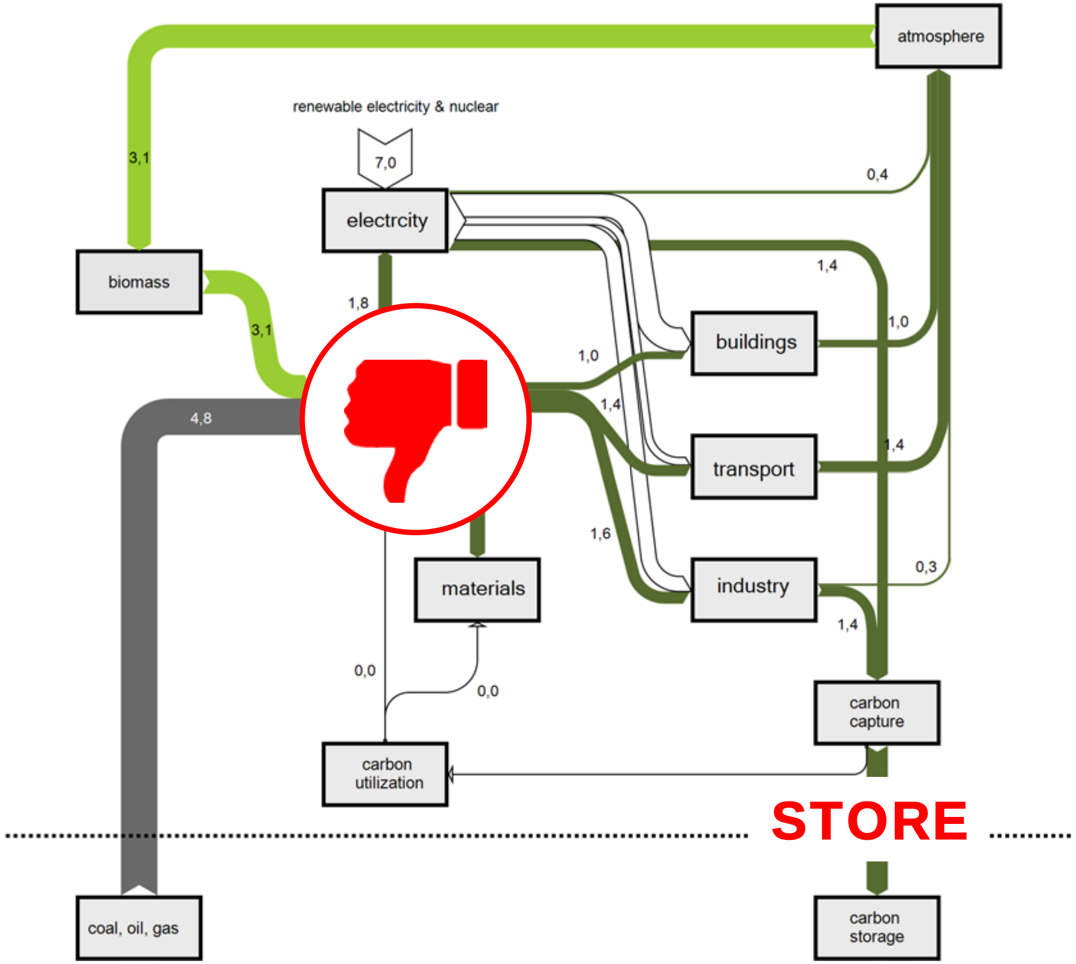
A model based on current realities and future optionalities



O.D.E. Kraan, G.J. Kramer & M. Haigh, in preparation

Carbon Capture and … then what?



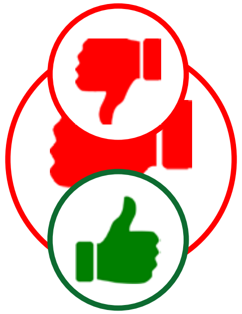


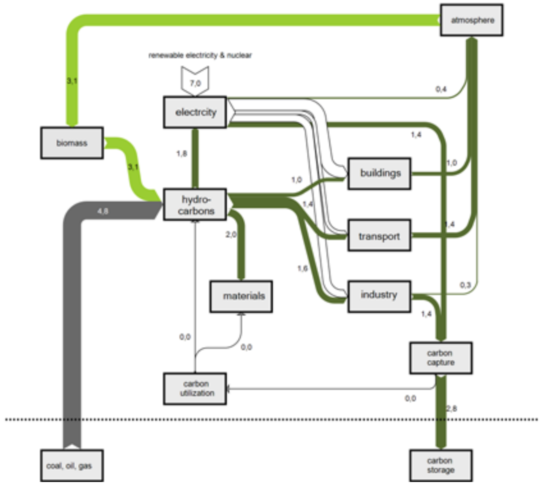
CCS versus CCU

firm

Option #1: Fossil Fuels plus CCS

- 2.8 GtC fossil fuels, requiring circa 10 Gt CO_2 storage
- Equivalent to 20 billion barrels of oil, 50 \$ + 25\$ CCS = 75 \$/bbl is **1.5 trillion\$**

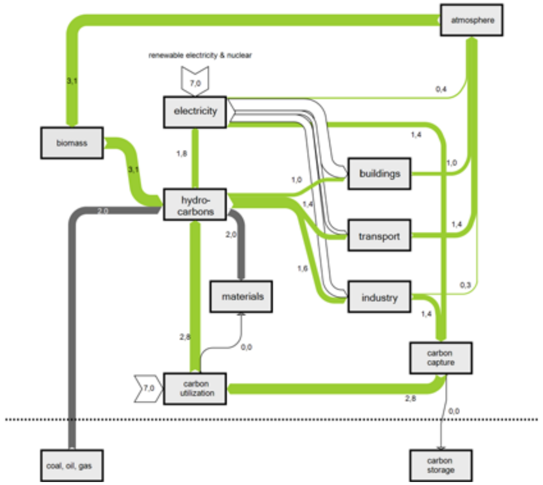




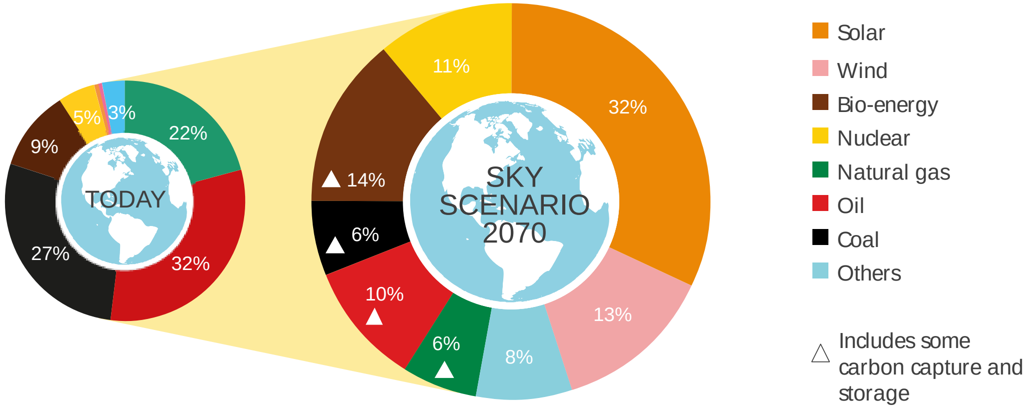
"future"

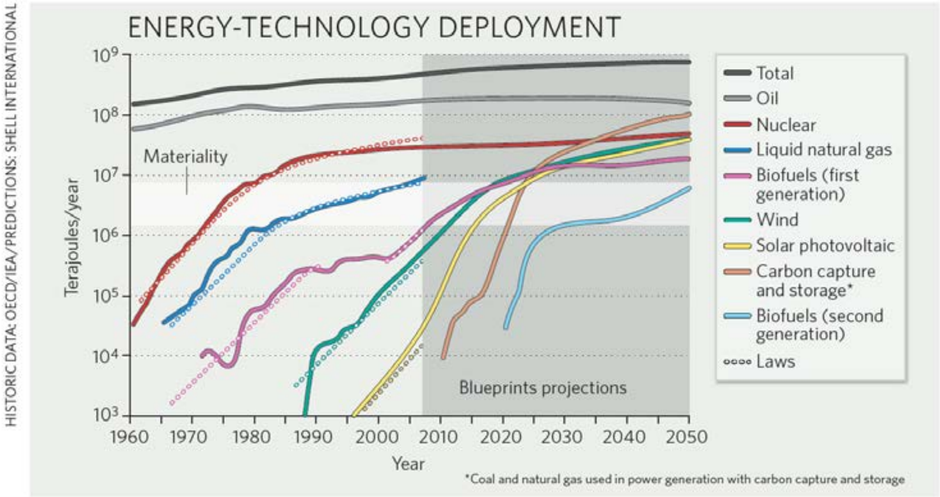
Option #2: Synfuels from CO_2 (CCU)

- 2.8 GtC synfuel (10 Gt CO_2), requiring ca. 300 EJ renewable electricity
- That is 20 billion barrels of synfuel; if electricity is 1¢/kWh, synfuel will be ca. 200 \$/bbl, so **4 trillion\$** in total



Towards a Conclusion of the Future Role of Electrochemical Conversion





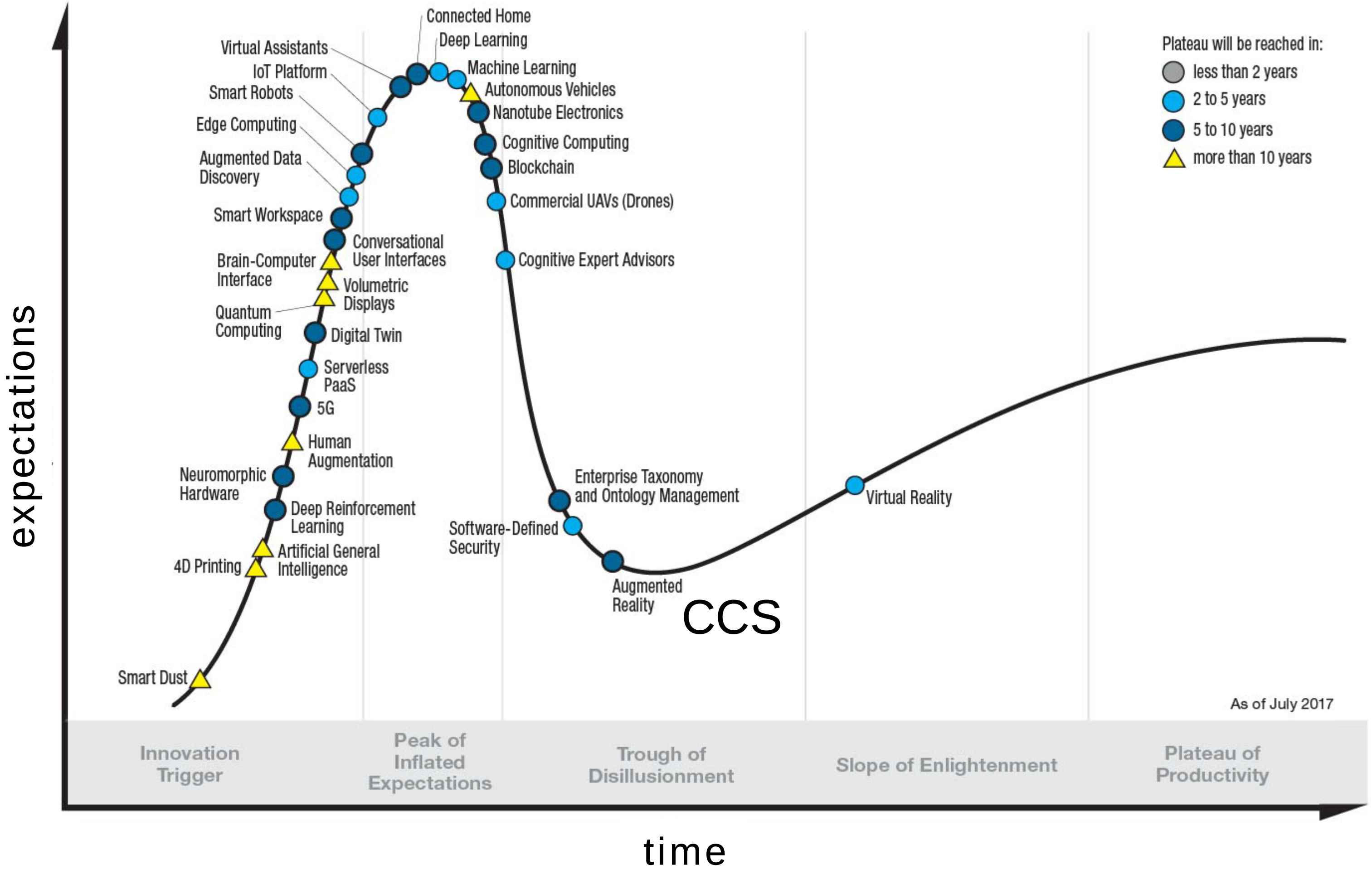
Intermittent renewables will be the backbone of the future energy system, so electrolysis will become a key technology – and Green Hydrogen a future energy vector.

I.E. it services non-power sectors more than that it provides power storage

The question is not if electrochemical conversion will be important. It will be.

The question is *when* it will come to scale and what its *ultimate scope* will be

Final thought: Hype Cycles



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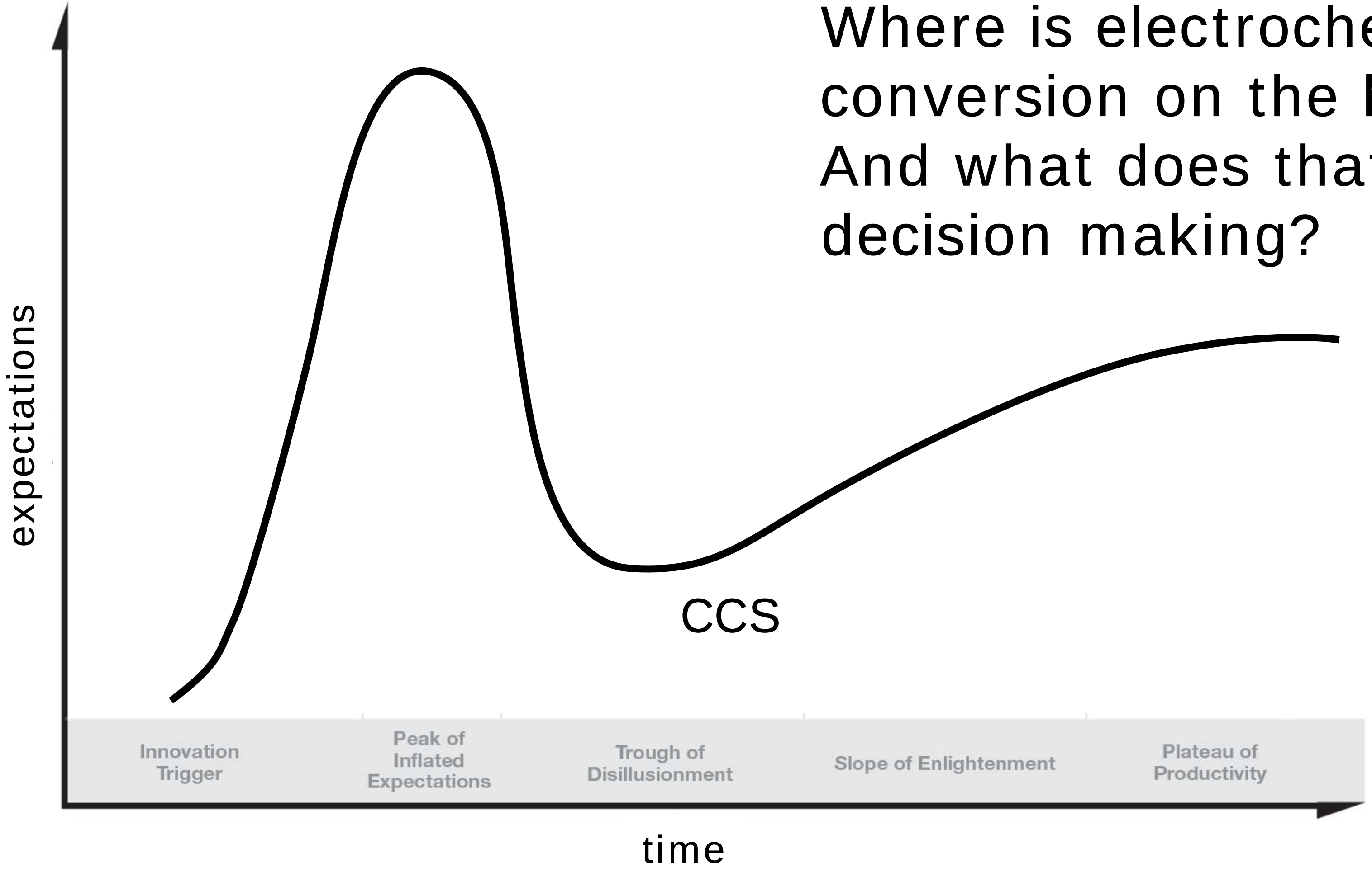
My Conclusion is to leave you with Questions



Where is electrochemical conversion on the hype cycle? And what does that imply for decision making?

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Thank you for your attention

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