Pathways to Clean and Green Hydrogen

Roger Cracknell

Gert Jan Kramer

Joep Huijsmans

Dave Austgen

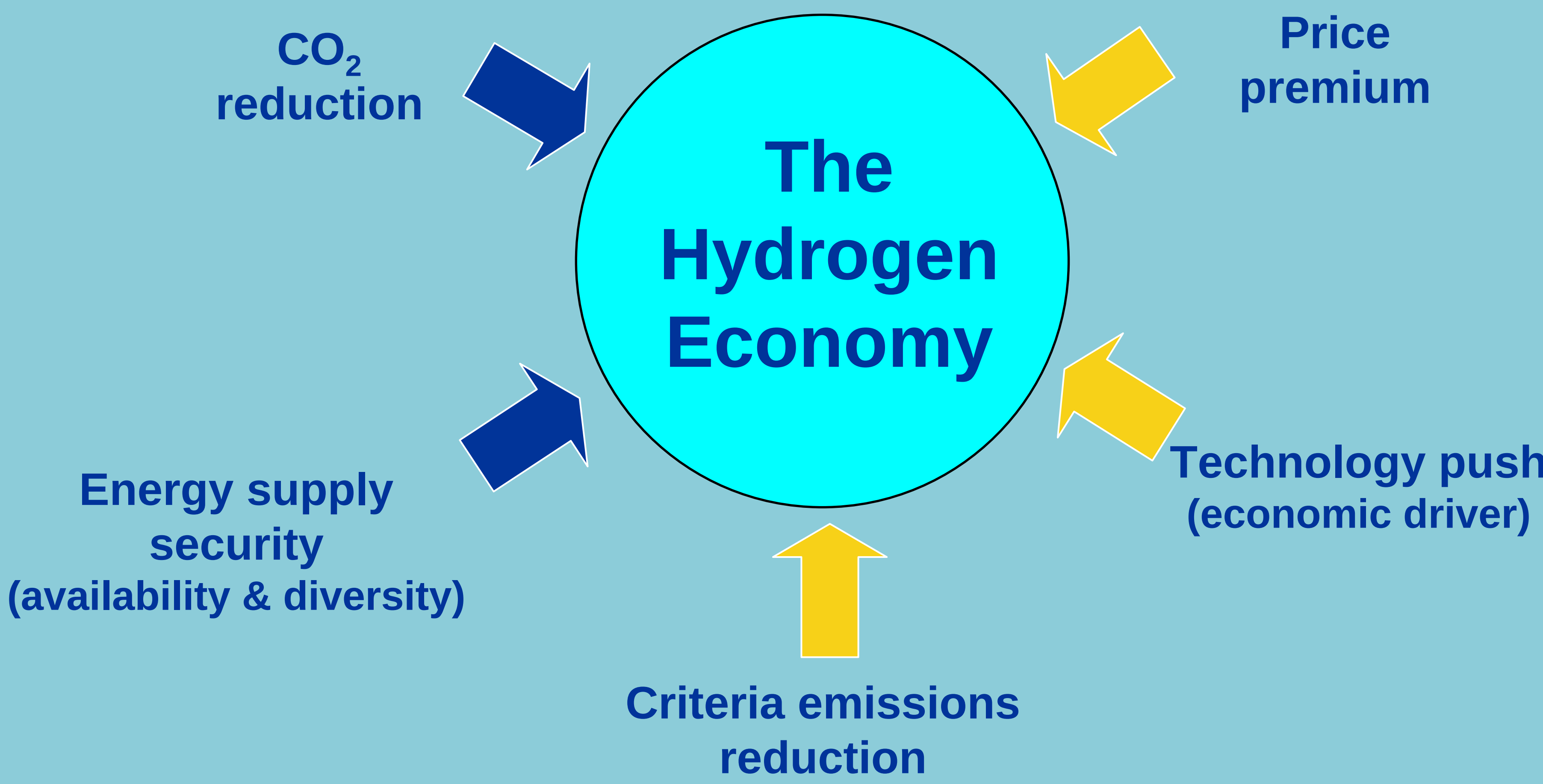
Combustion Technologies for reducing emissions of CO_2 to the atmosphere

Cambridge

18/12/06

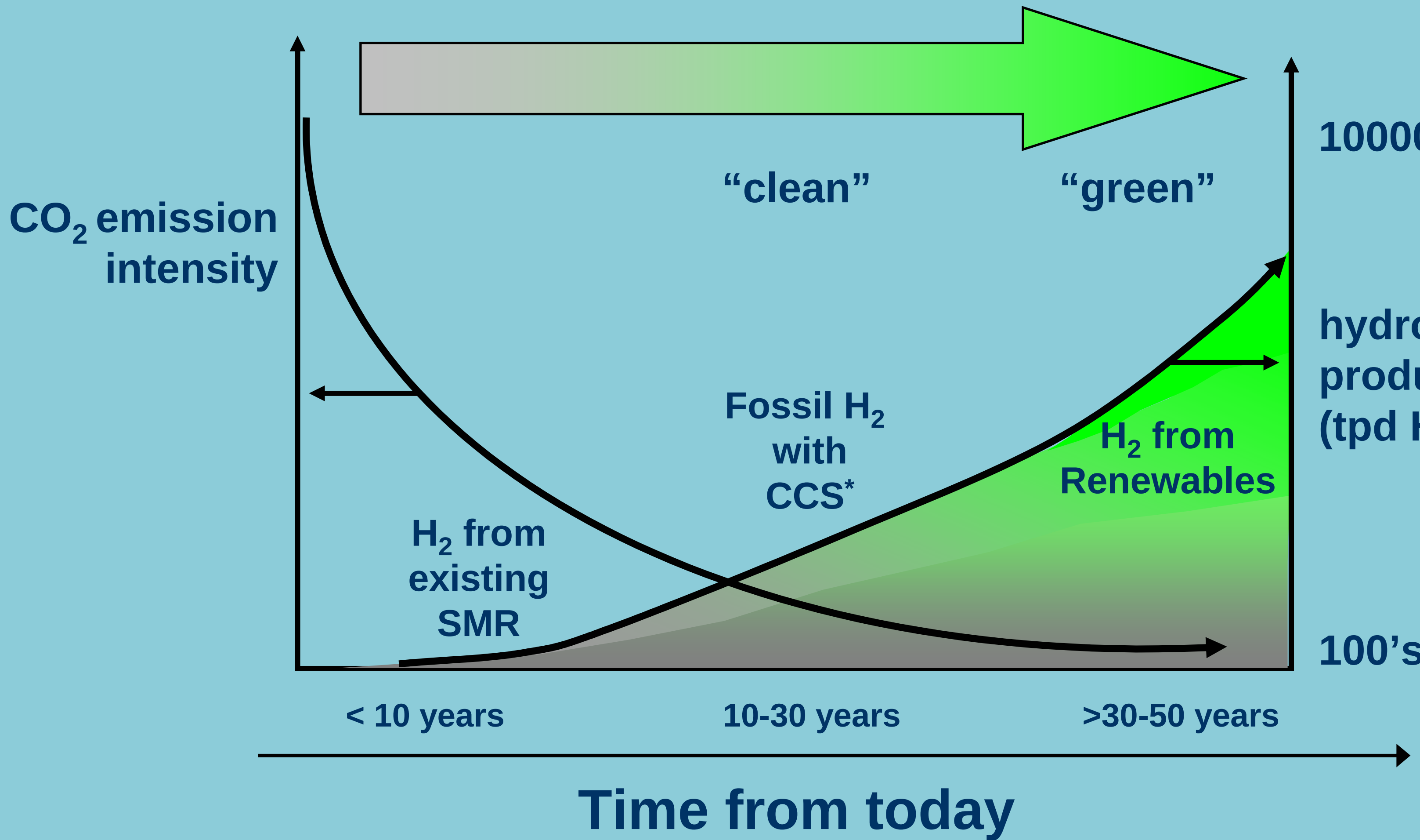
Shell Hydrogen

Drivers for the Hydrogen Economy
Energy supply security and CO_2 are key



Hydrogen Production – Our Vision

first "clean", ultimately "green"



* CCS = Carbon Capture and Sequestration

Public Drivers for the Hydrogen Economy

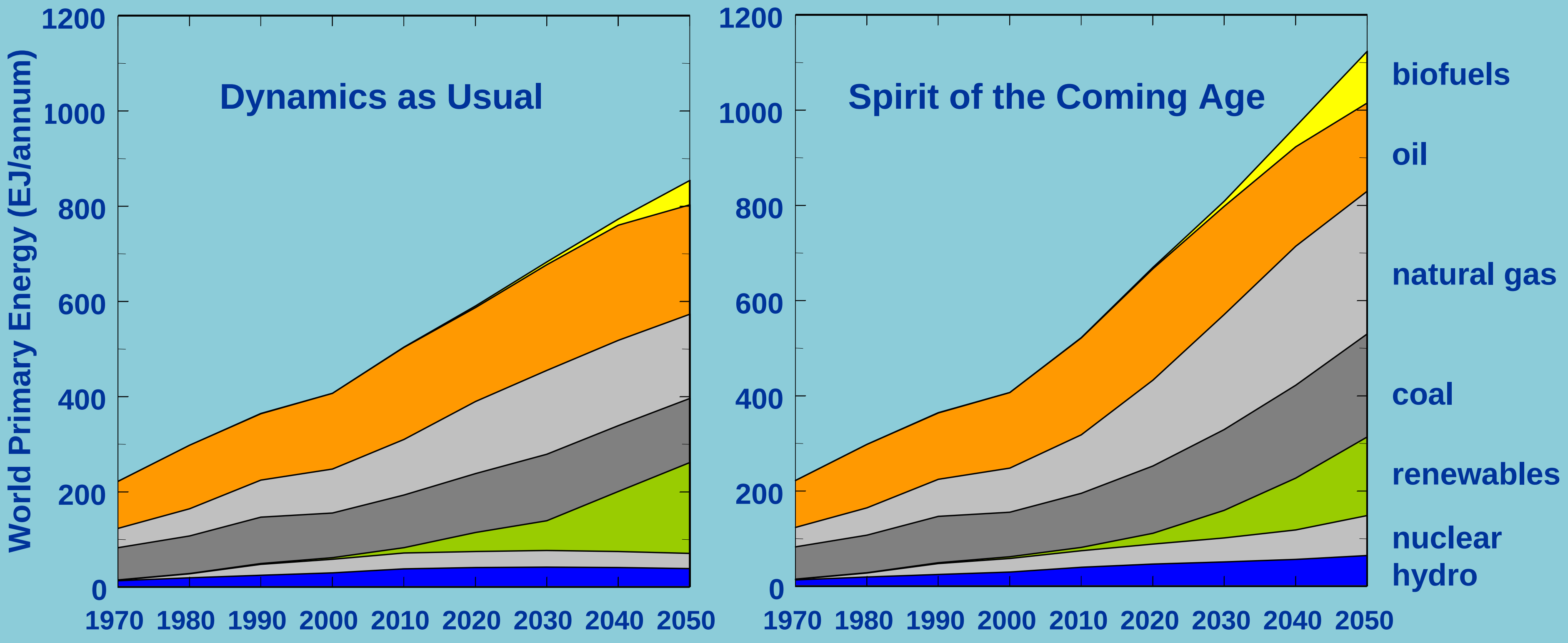
CO_2 reduction

- Renewables offer greatest CO_2 reduction when used as replacement to current fossil fuel electricity generation
- Fossil fuel-derived hydrogen, with Carbon Capture and Sequestration, offers scope for affordable, low-carbon hydrogen

Security of supply

- Renewables do not provide sufficient supply levels in short timeframe to move beyond best use in electricity generation
- Through 2025 we must look at the broad range of fossil fuels (*e.g.*, Natural Gas, Coal) and biomass feedstock for hydrogen production

Why “green” hydrogen comes later: Resource Availability



Shell scenarios at www.shell.com

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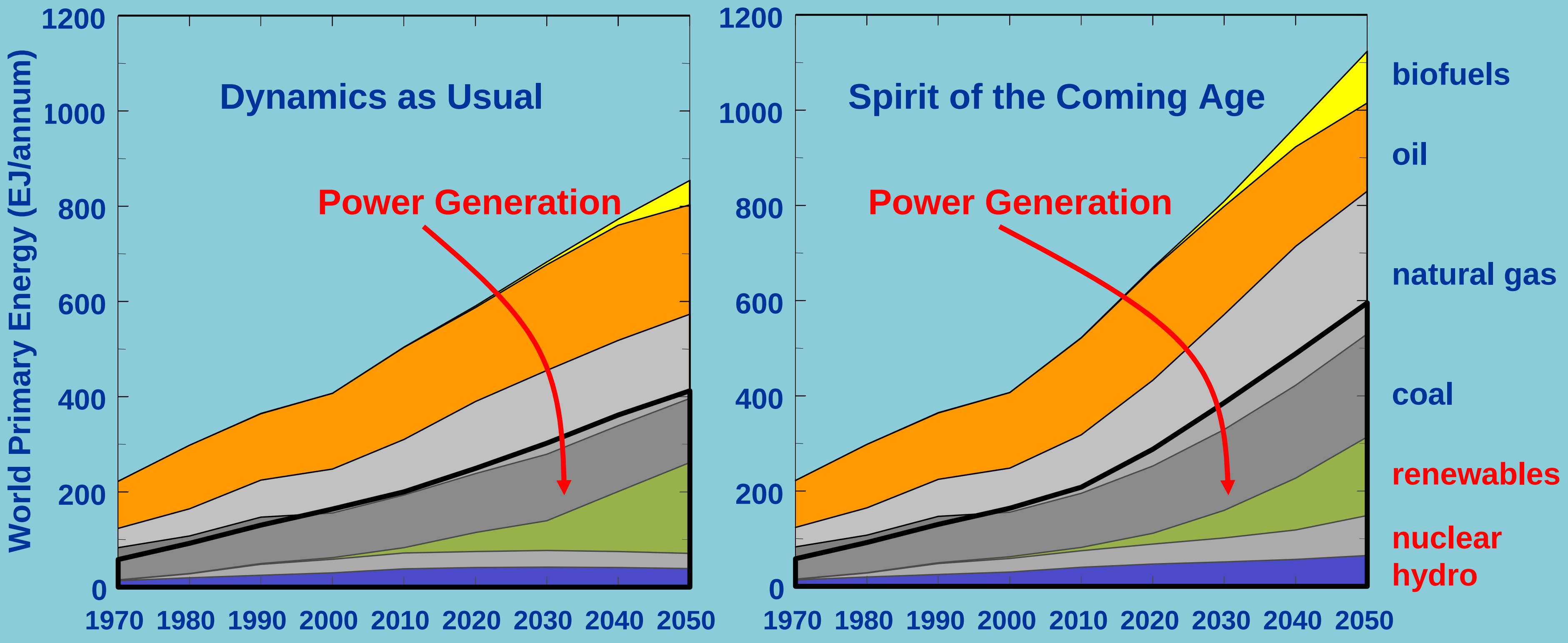

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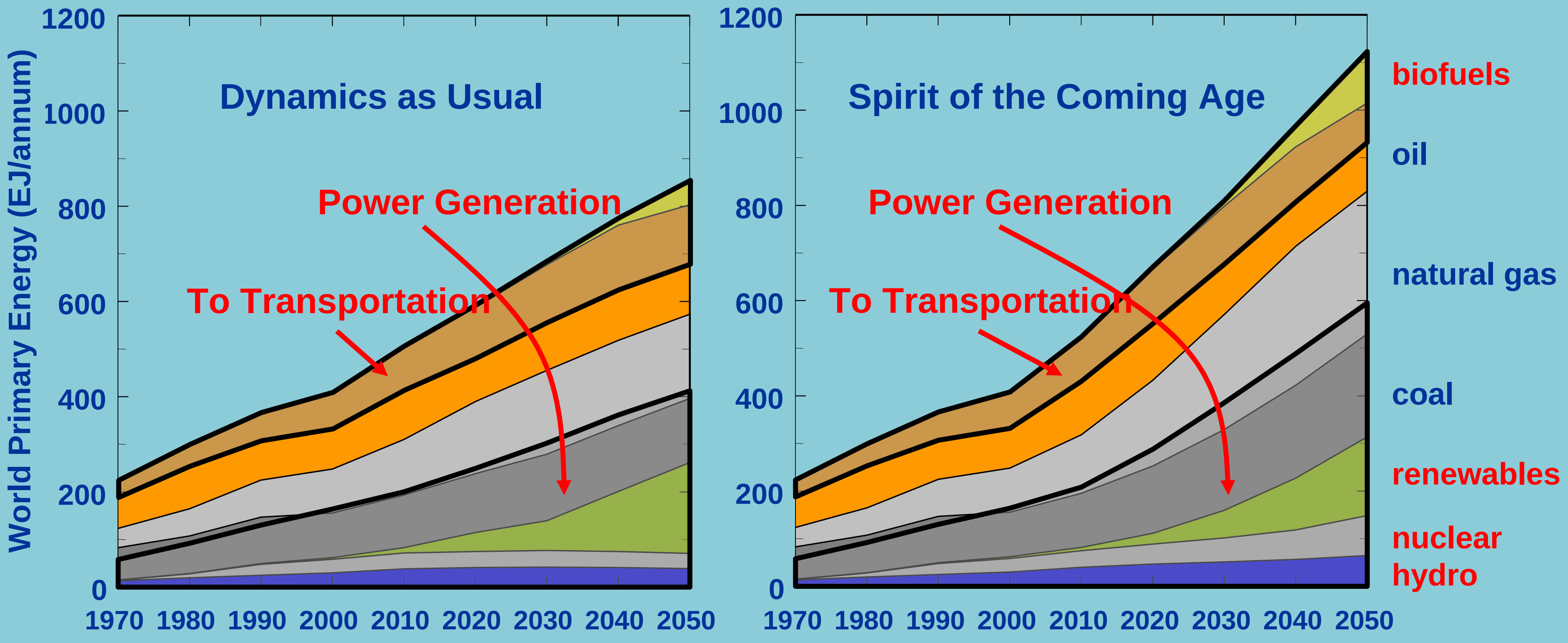

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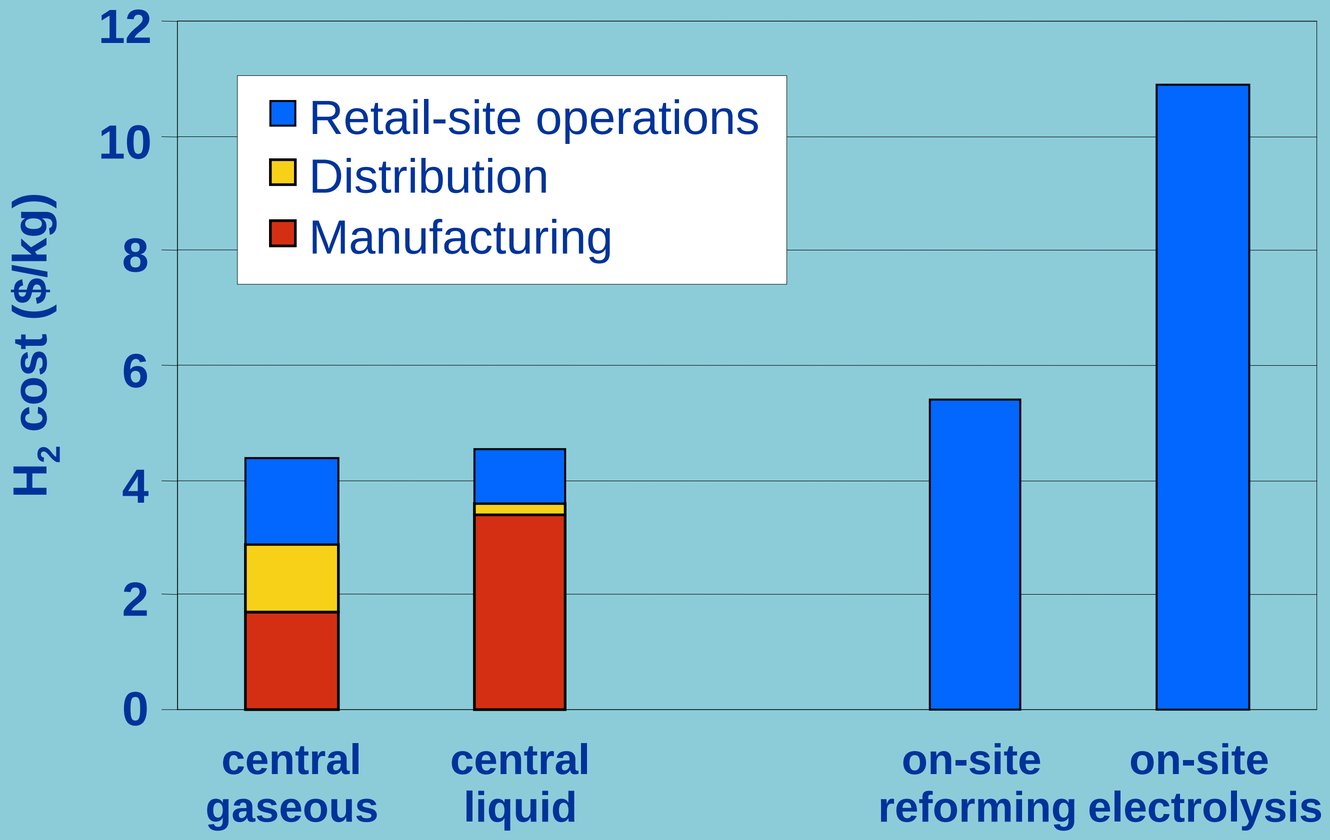
Cost of Hydrogen at the Retail Site Excluding CCS (Carbon Capture and Storage)



<u>Financial assumptions</u>

IRR: 10%; tax rate: 35%
Non-fuel O&M: 5% of capital
Electricity: 0.11 $/kWh
NG: 7 $/MMBtu

<u>Technical assumptions</u>

All current technology
NG-based SMR
World-scale Liquefaction

<u>Distribution & Retail</u>

US case study
75 km trucking
Retail mode: 350 bar GH_2

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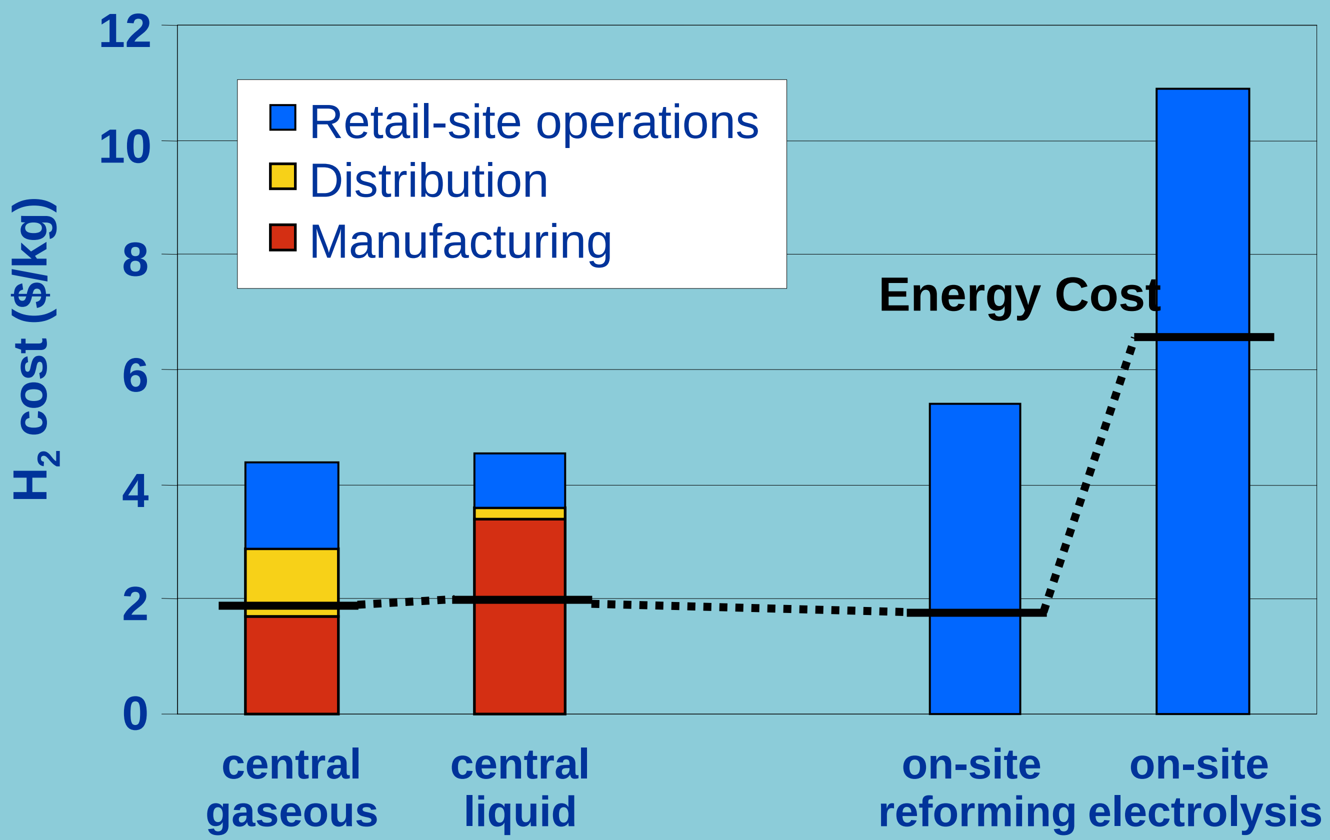

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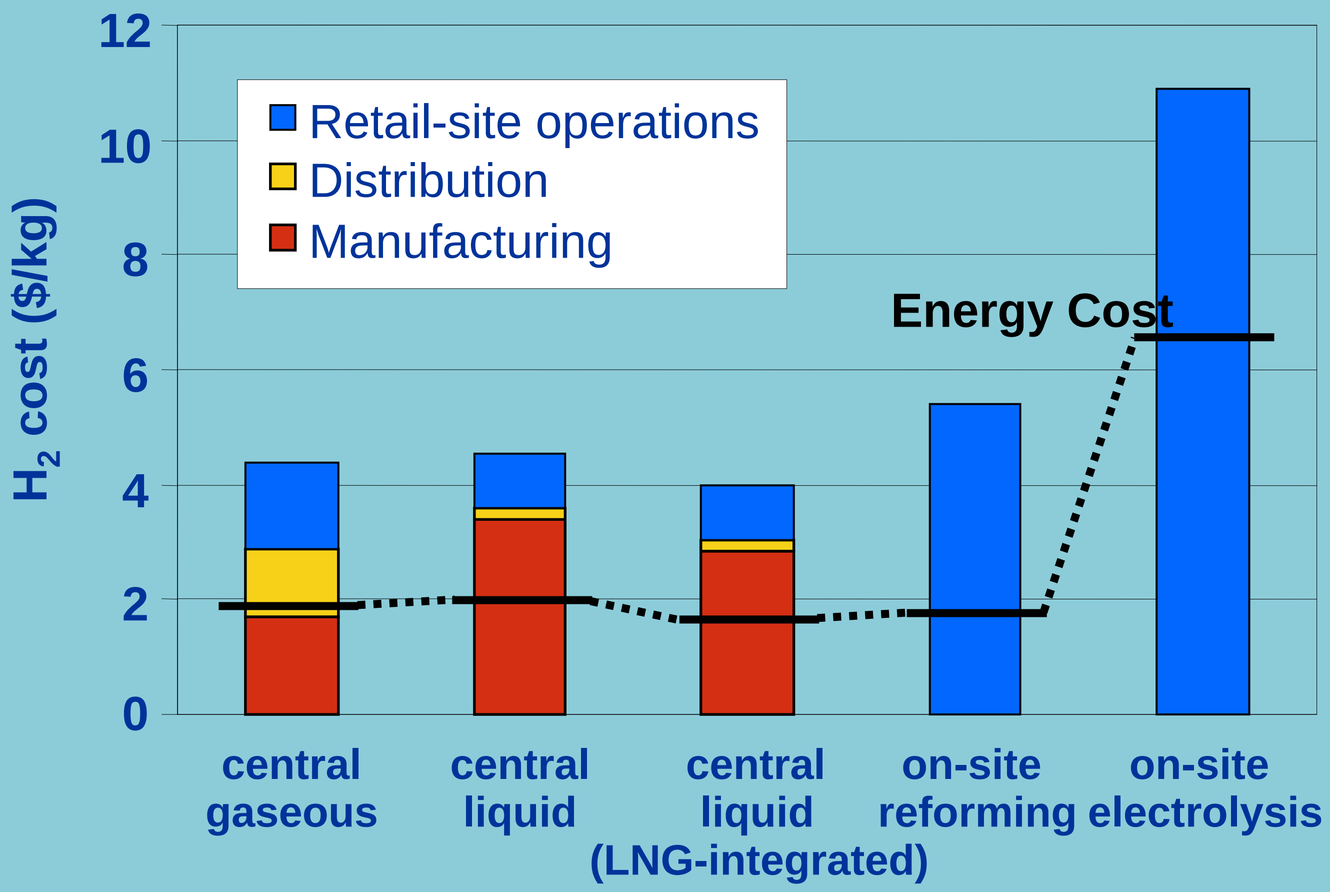

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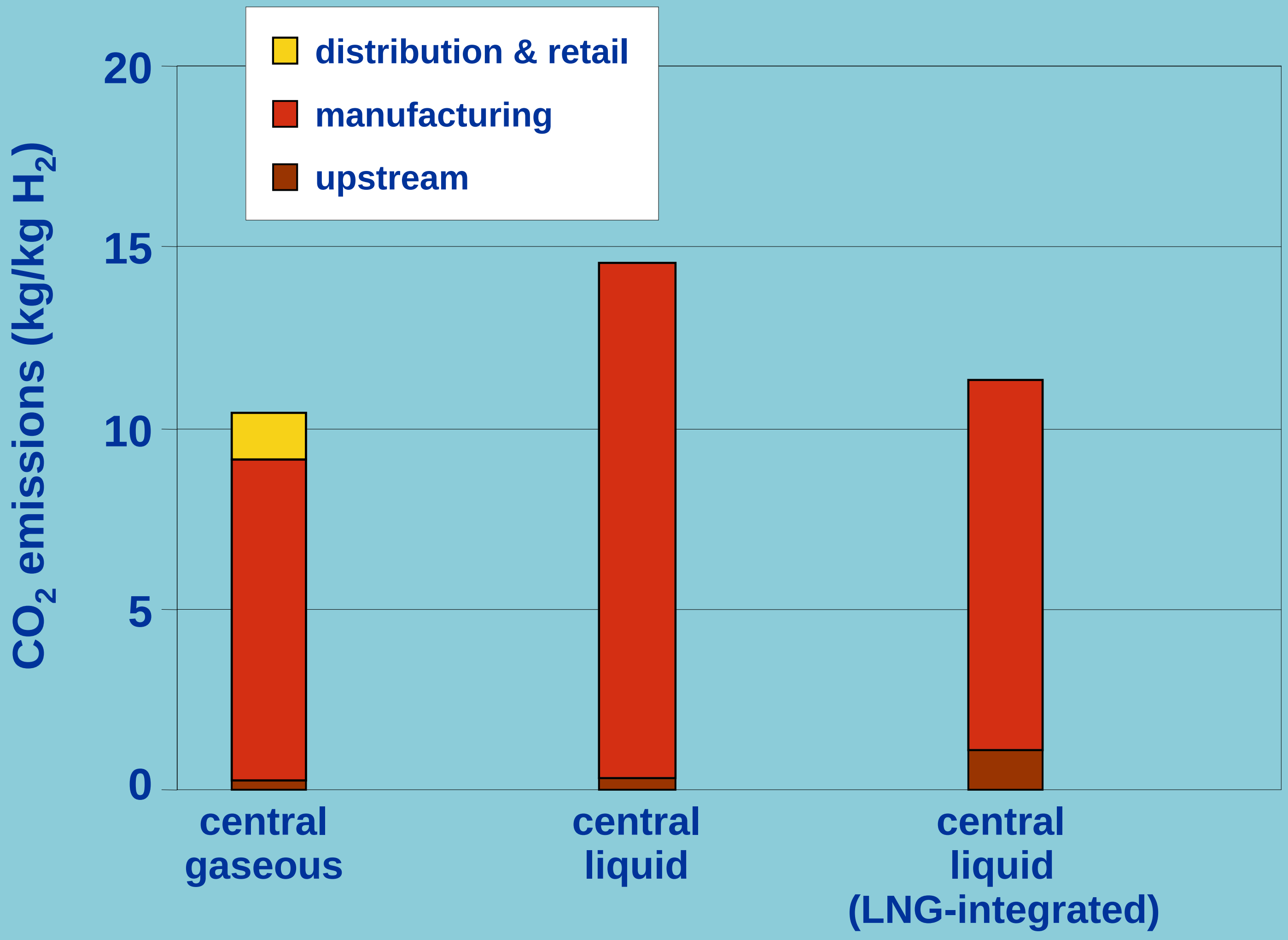
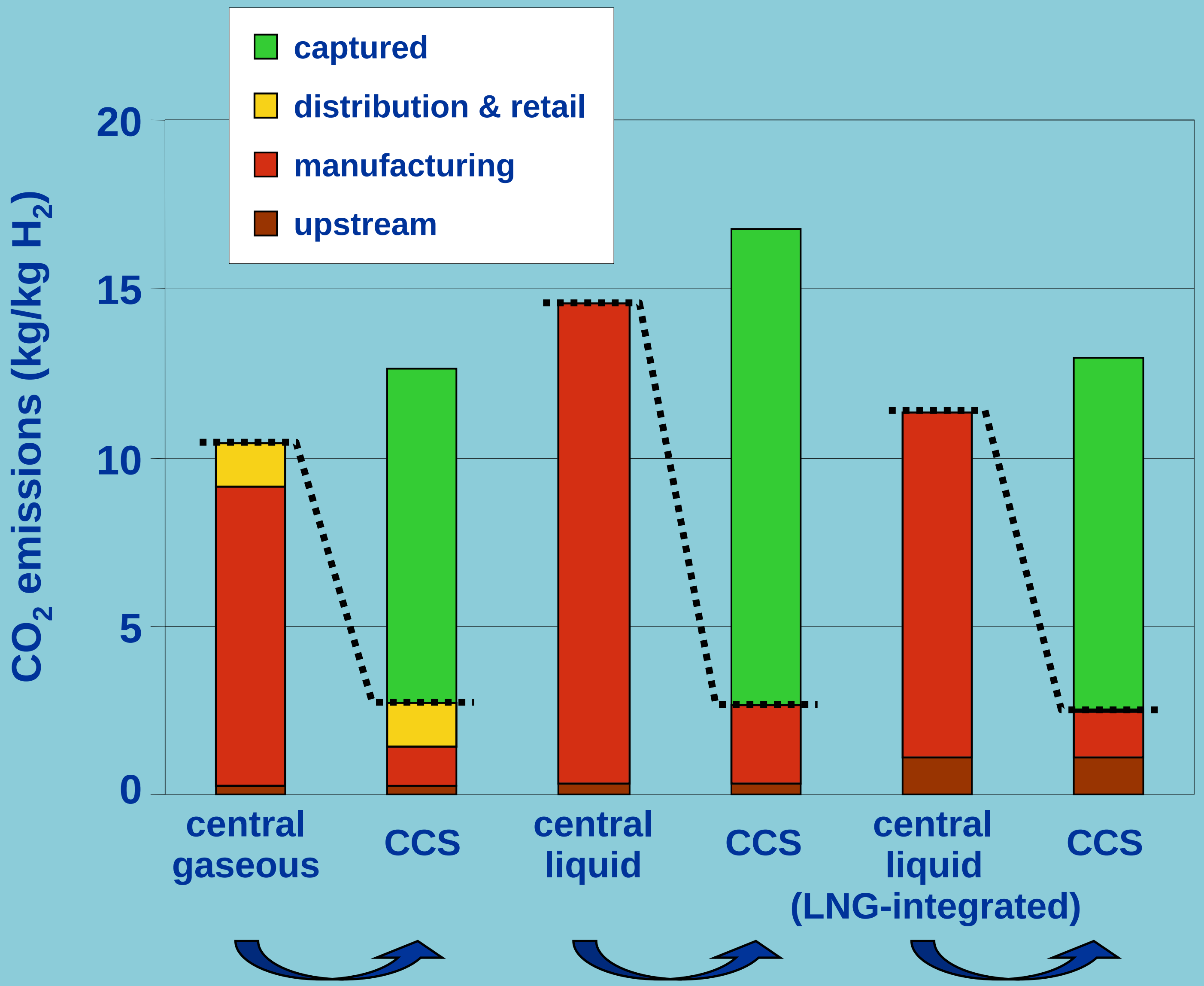
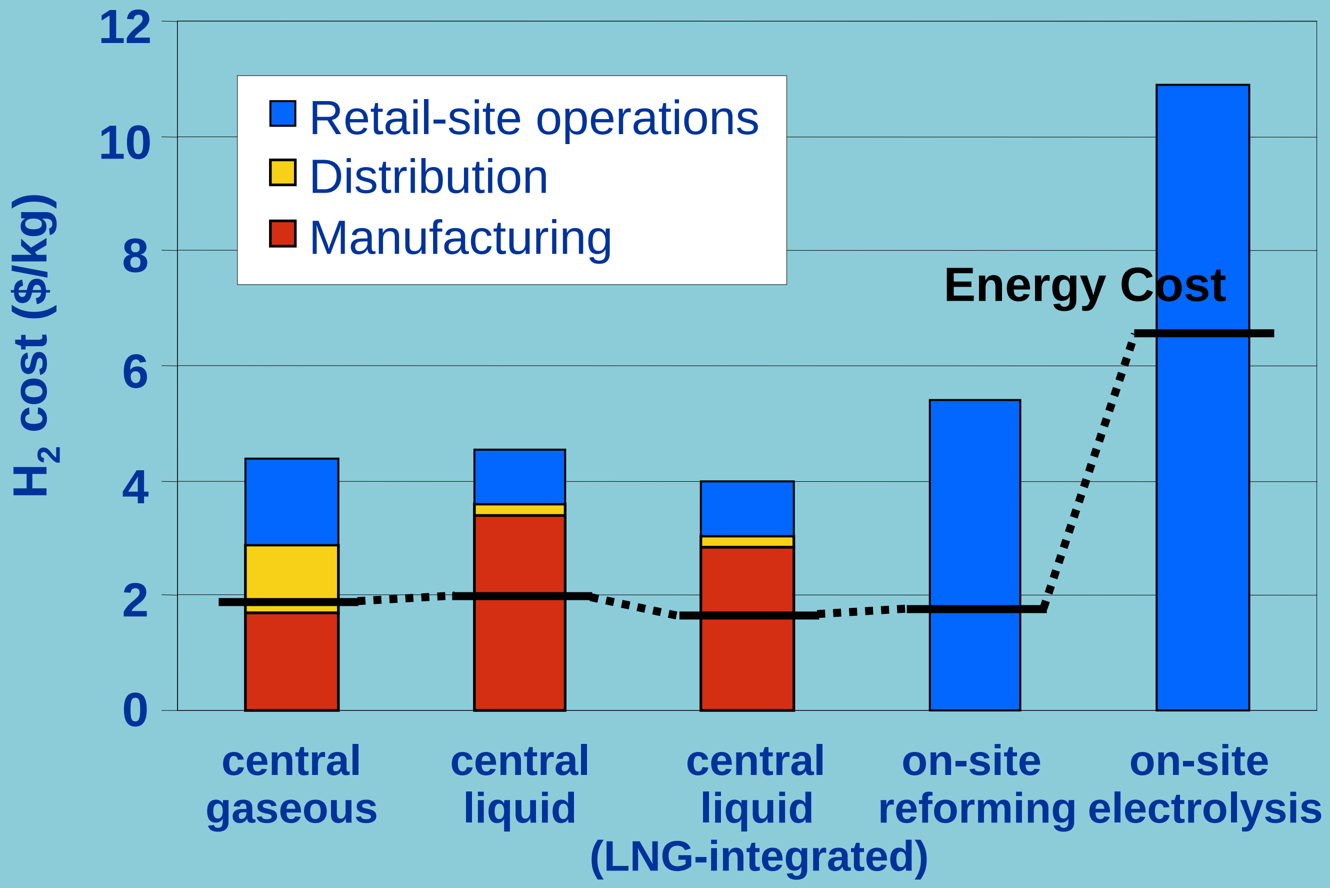
Breakdown of CO2 emissions



Breakdown of CO2 emissions
90% CO_2 capture at Central Production Facility



Cost of Hydrogen at the Retail Site Excluding CCS (Carbon Capture and Storage)



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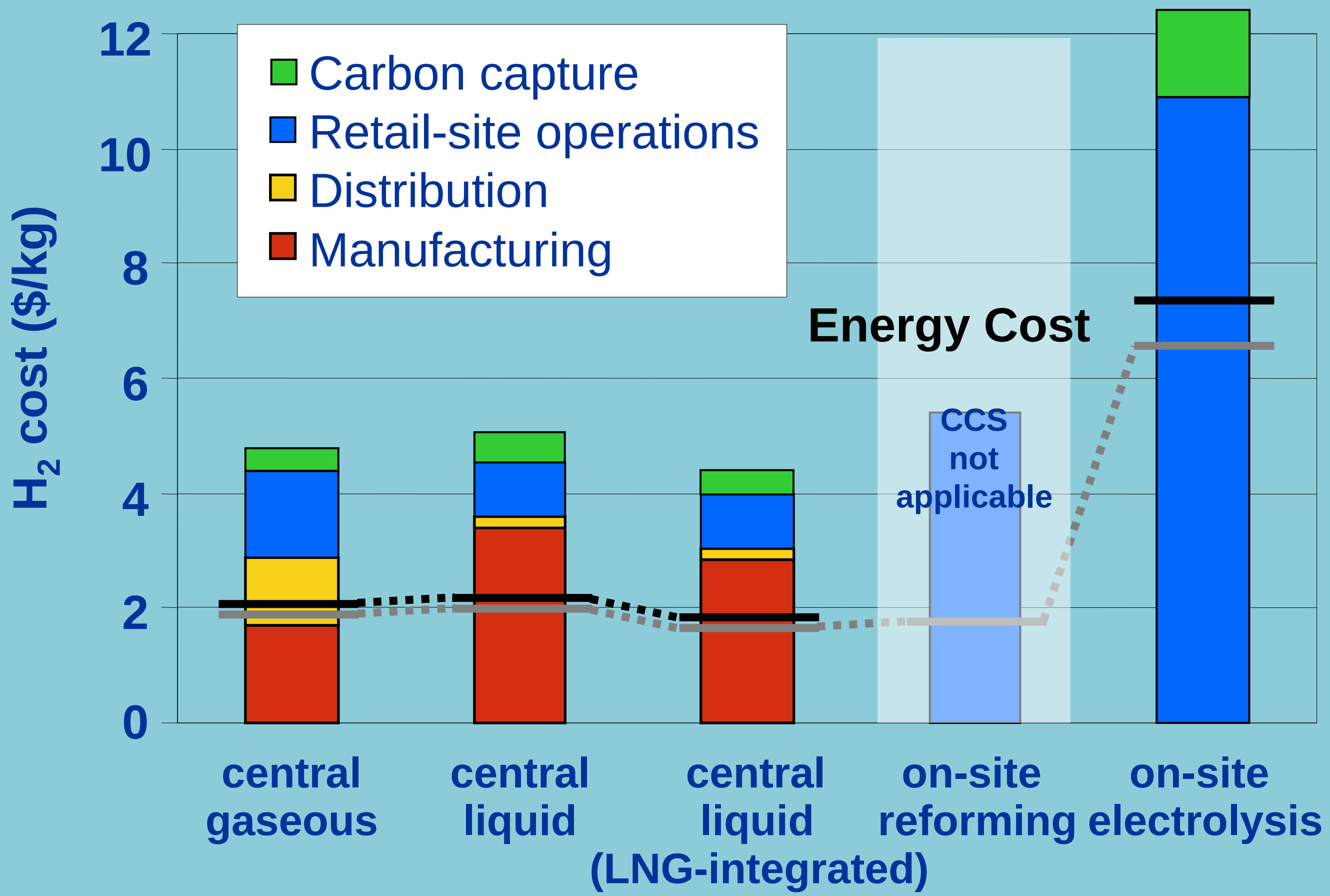

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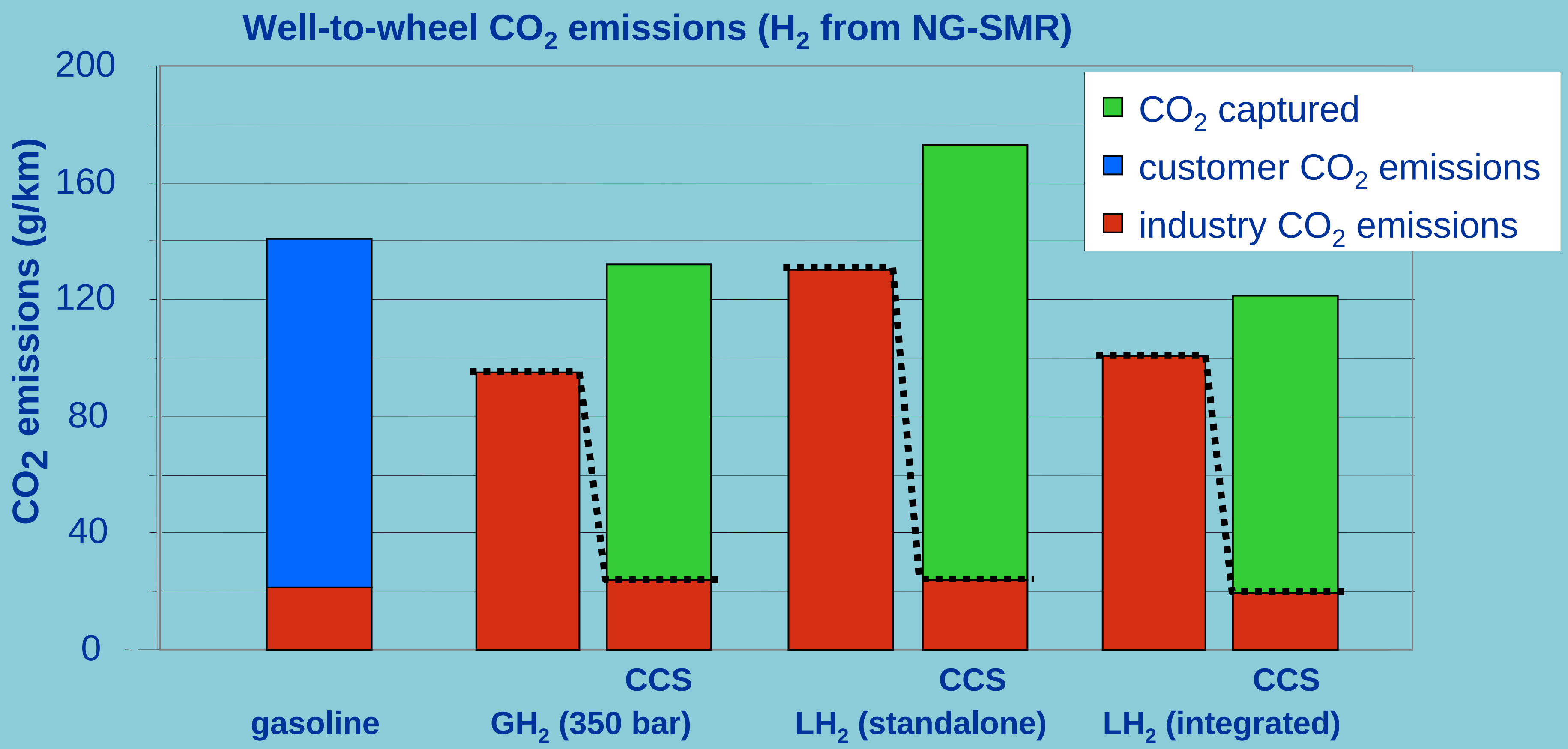
NOTE: Cost of CO_2 Capture included at 50 $/ton avoided; CO_2 Distribution and Storage costs excluded, as this can significantly vary (indicative range –10 $ to +20$/ton.

Clean Hydrogen for Transportation
The impact for the end-user & manufacturer



Vehicle assumptions
Hydrogen-FCV, 3.3 liter goe/100 km = 0.9 kg H2/100 km
Gasoline DI HEV, fuel consumption 5.2 liter/100 km
Based on GM-LBST European WtW study (Sept 2002)

Well-to-tank analysis:
Shell assessment, 90% CO_2 capture at H_2 manufacturing and liquefaction site

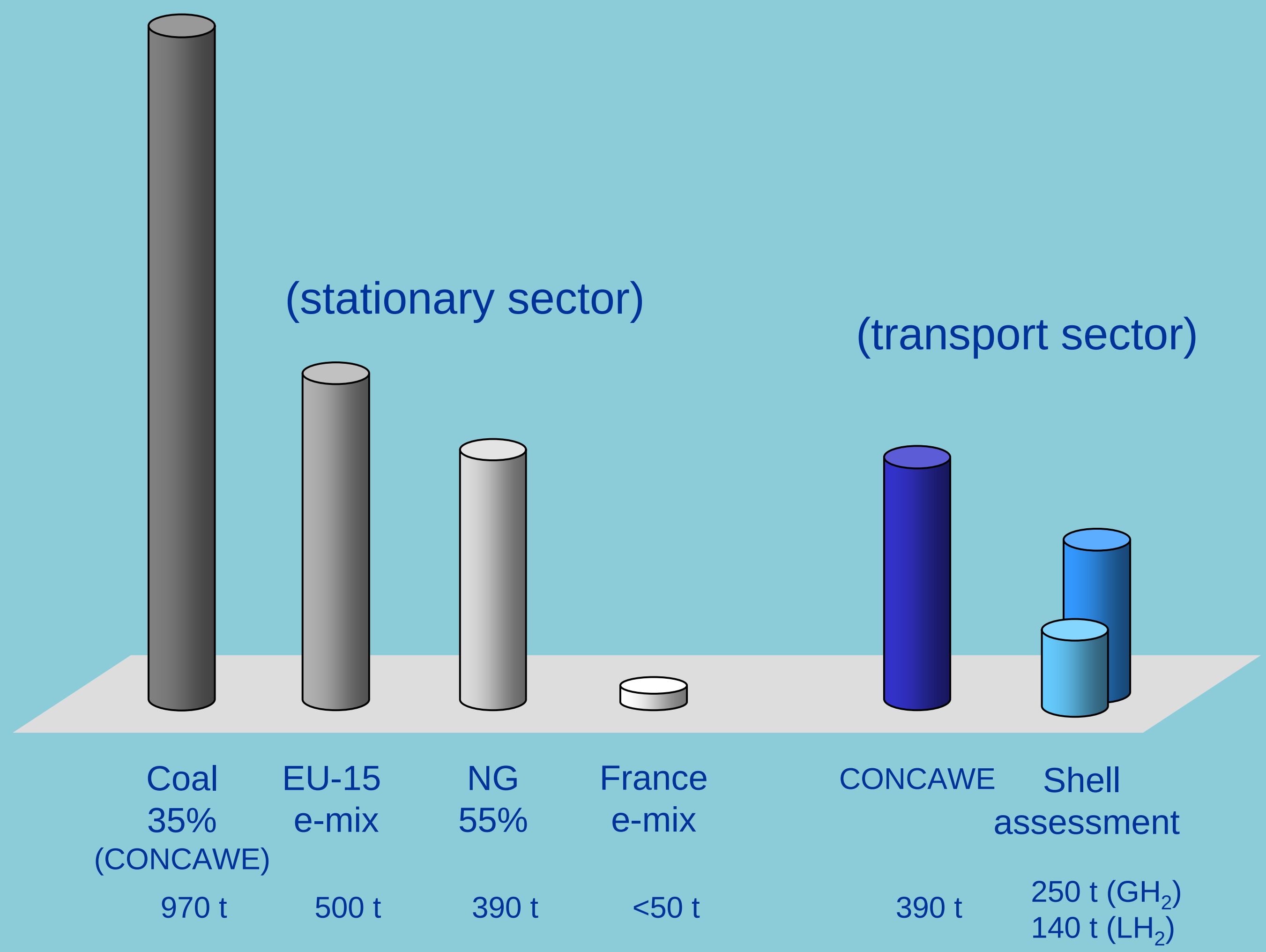
Conclusion – The Case for Clean Hydrogen

- Key public drivers for supporting the Hydrogen Economy are reducing carbon emissions and ensuring security of supply;
- At present, renewables are most effective in replacing stationary power sources;
- Hydrogen made from a range of fossil fuels, notably NG and coal, can alleviate transport-sector dependence on imported oil;
- Hydrogen delivery is more cost-effective via larger-scale production than e.g. Forecourt production;
- Larger-scale Hydrogen production allows cost-efficient Carbon Capture and Sequestration;
- Distribution and Retail of both Gaseous Hydrogen and Liquid Hydrogen offer promise, being comparable in terms of cost and environmental performance;
- “Clean Hydrogen” will reduce transport WtW emissions by some 80% compared to gasoline/diesel hybrids.

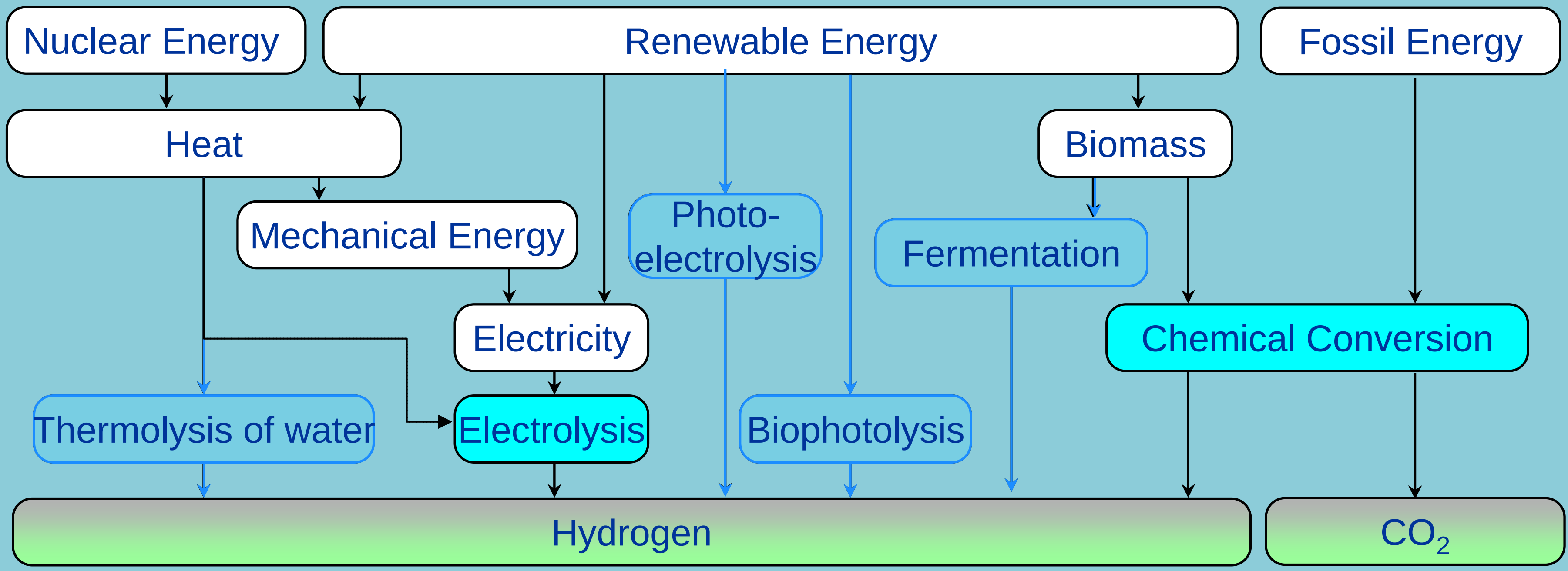
www.shell.com/hydrogen

Why “green” hydrogen comes later:

Carbon Savings: 1 GWh Renewable Electricity replacing ..



Hydrogen Production – Technology options



Adapted from John A. Turner, *Science*, **285**, 687 (1999) for EU-HFP-SRA