The need for enabling infrastructure to move forward

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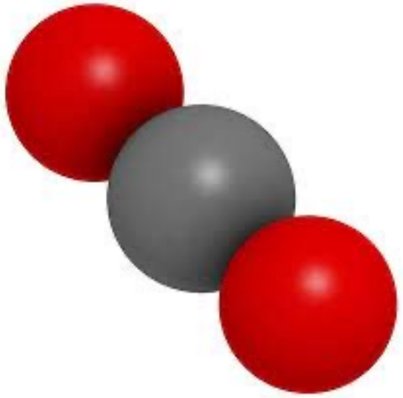
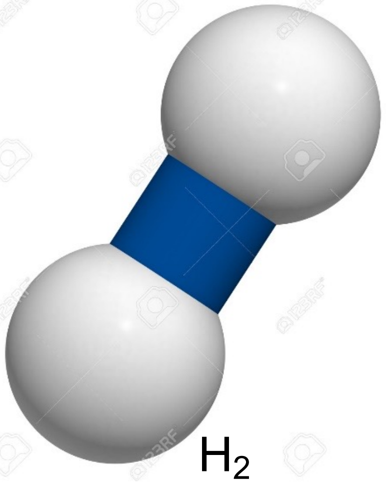
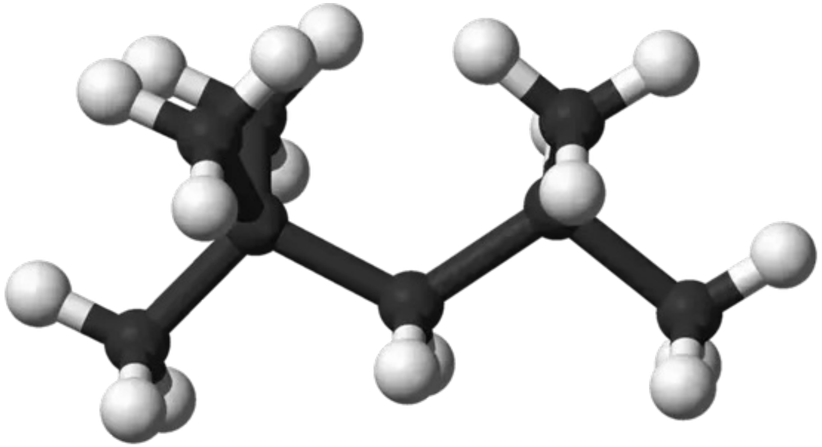
Enabling infrastructure



CO_2



H_2



- Capture of CO_2
- Transport of CO_2
- Temporal storage of CO_2

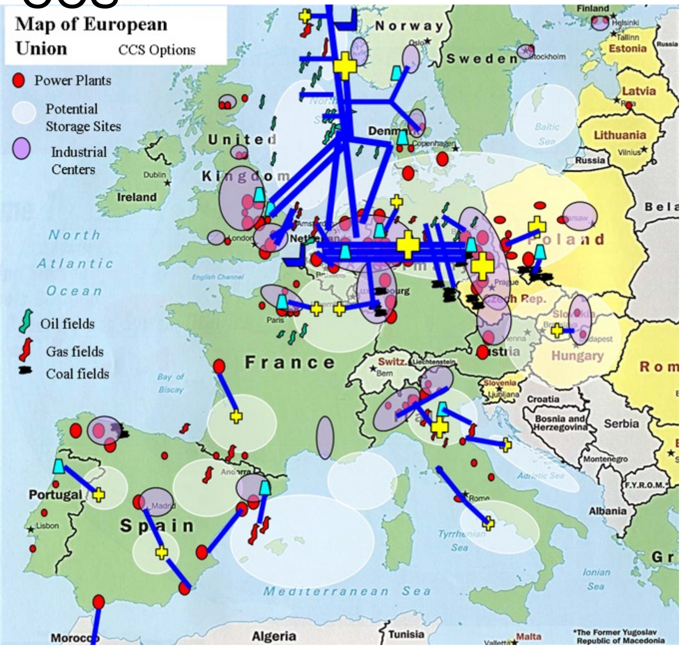
- Water
- Electricity
- Electricity storage
- Transport of H_2
- Temporal storage of H_2

- Fuel distribution

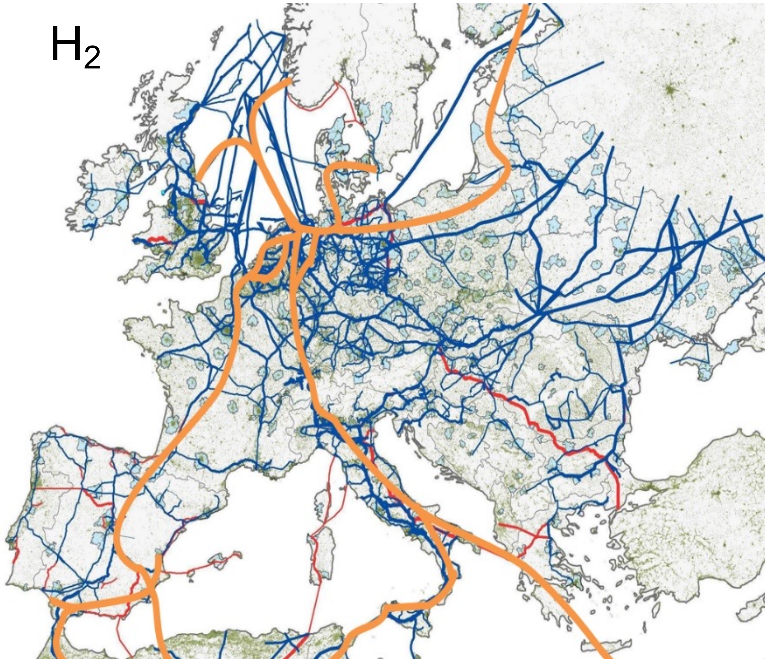
Centralized production (takes advantage of economies of scale) vs Decentralized production (takes advantage of economies of location/ number)

Infrastructure remains a basic requirement

CCS

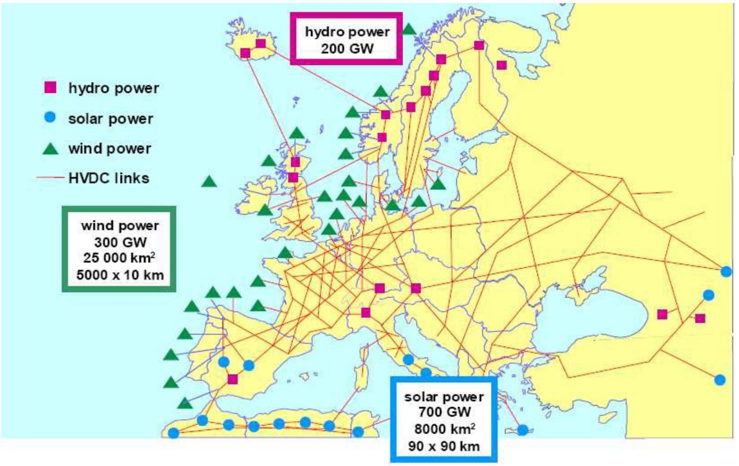


H_2

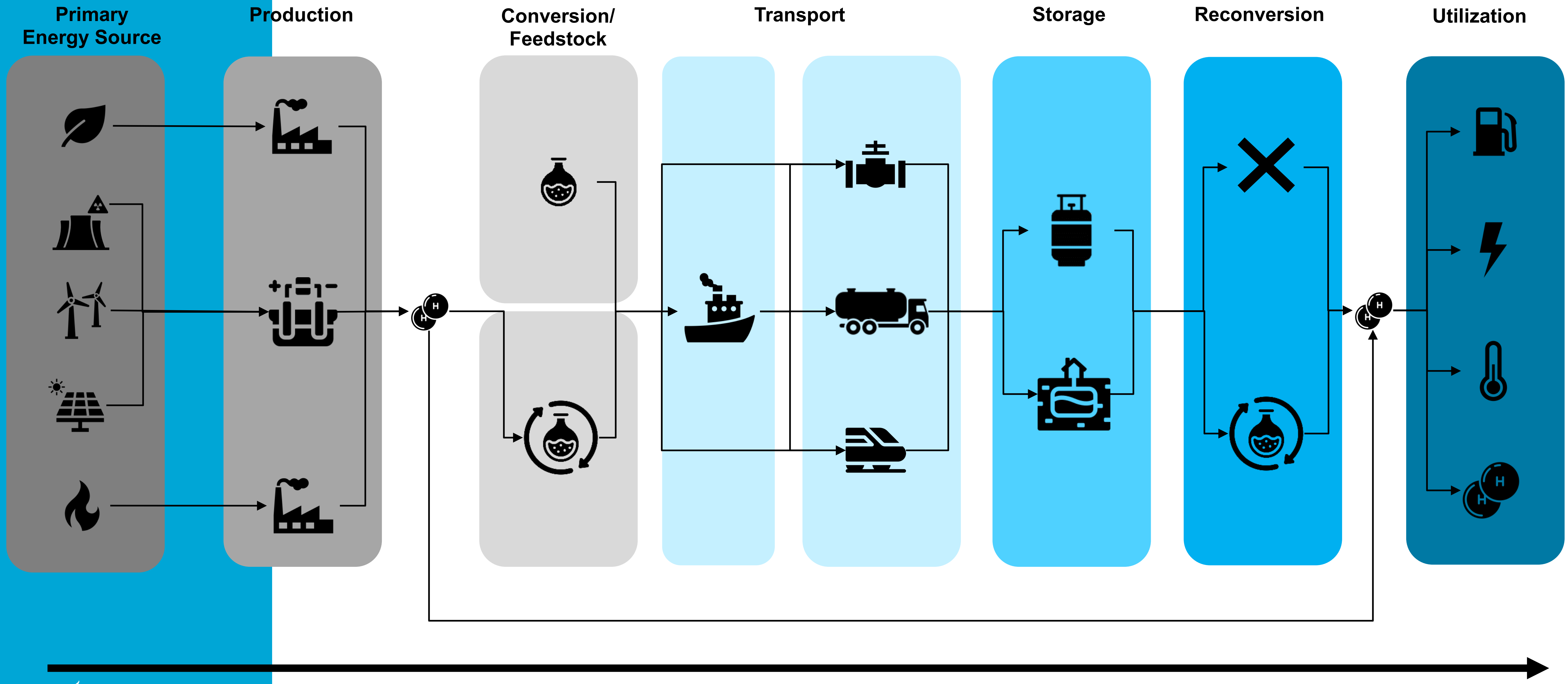


Delft University of Technology, Hydrogen Europe, 40GW Electrolyser Initiative

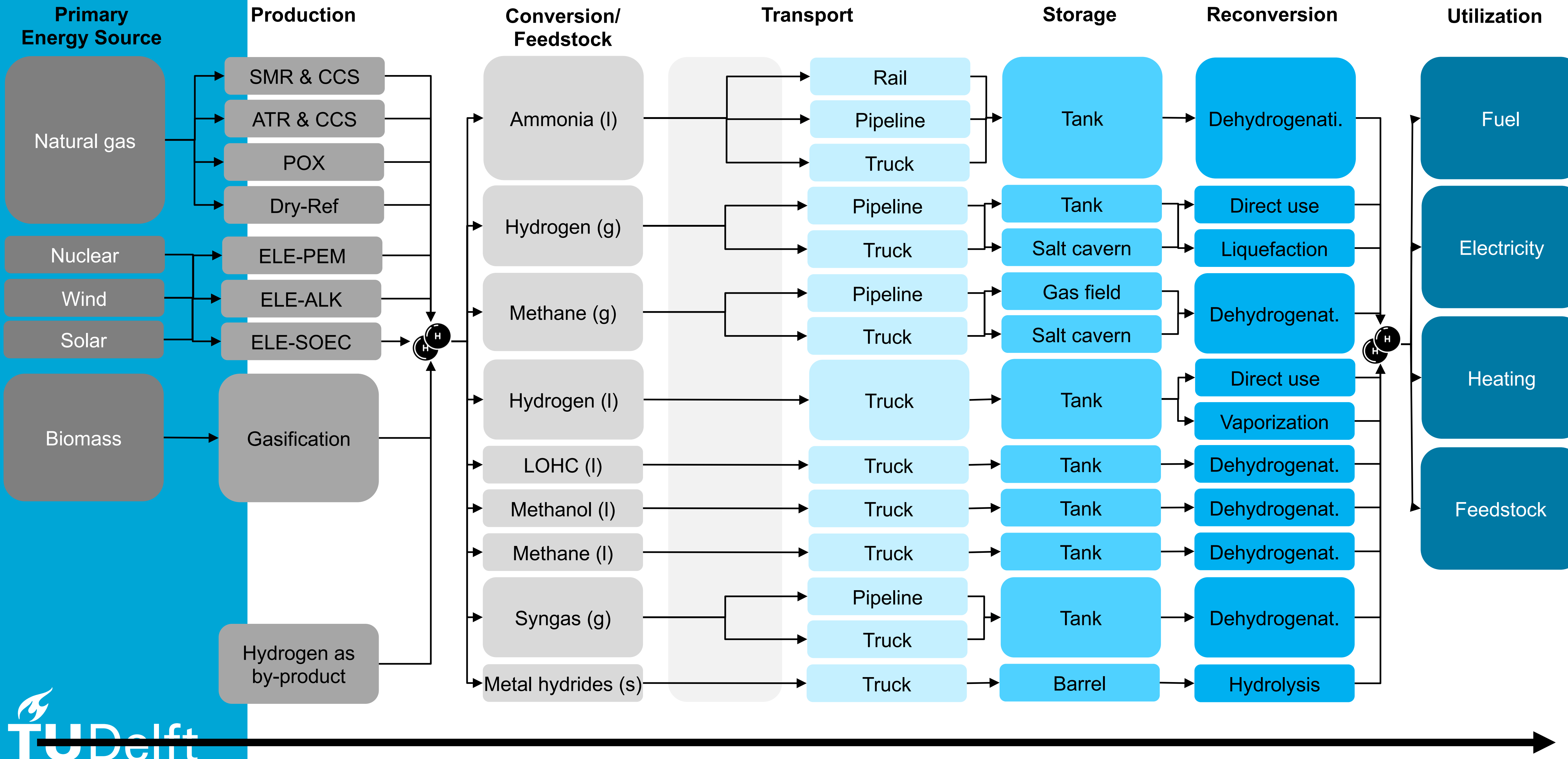
- How will current infrastructure be used?
- Who decides?
- What is the new infrastructure that needs to be in place? When? where? Who pays?



H_2 value chain



Source: Hiestermann M., (2022).



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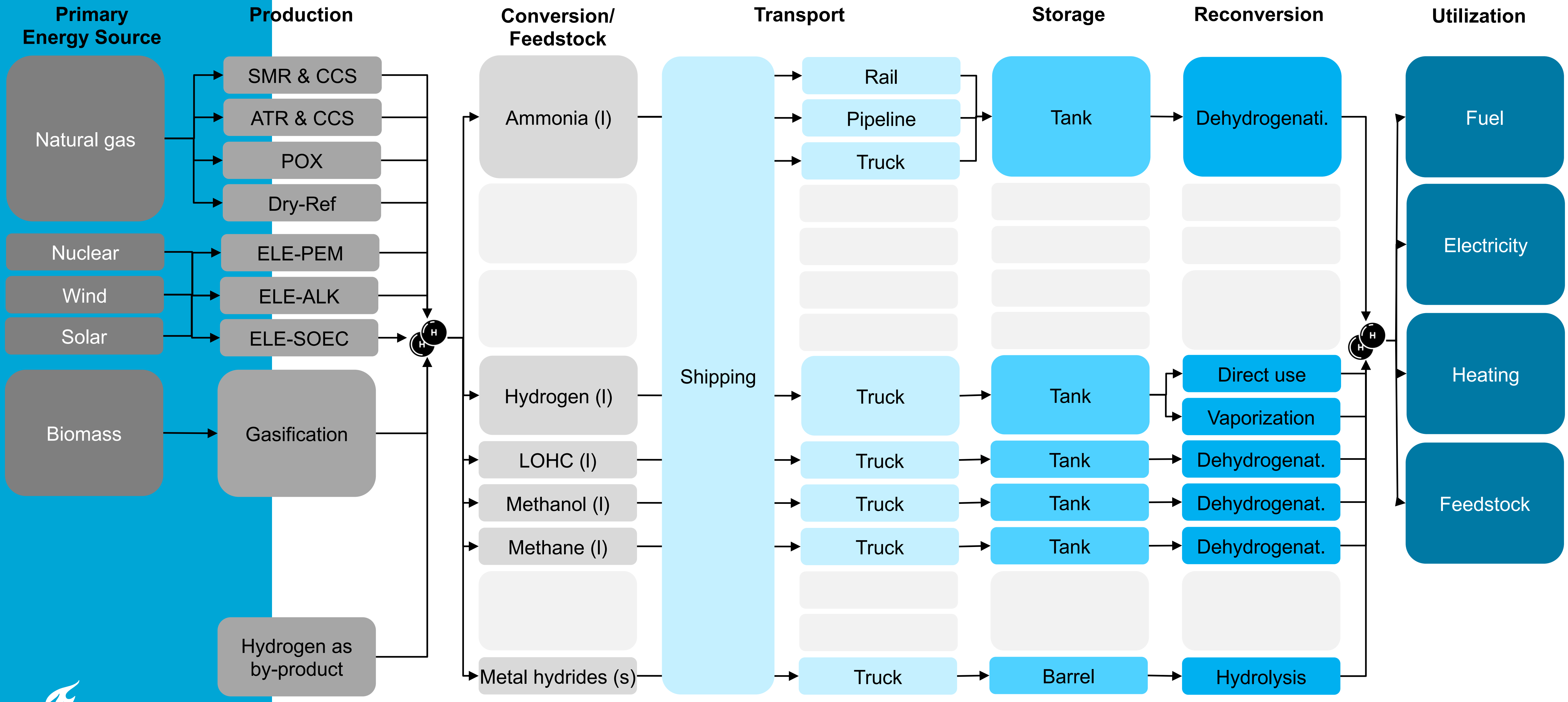

Source: Hiestermann M., (2022).

CO_2 as feedstock….how does it influence infrastructure design?

Contribution of CO2 fuels to net zero targets

- **Direct:** when the CO_2 is inherently sequestred in the product and will not be re-released to the atmosphere ⇢ CCU takes credit for the CO_2 that is embedded in the product minus CO_2 emitted in the CCU chain
- **Indirect:** CO_2 is re-emitted back at the end of the life-cycle but the product replaces current fossil-based products ⇢CCU takes credit for the CO_2 that will not be emitted minus the CO_2 that is emitted in the utilization chain
  - If carbon is biogenic/atmospheric in theory the chain could be neutral to negative
  - If carbon is of fossil origin- the process will add net fossil CO2 to the atmosphere, but in theory this is less than if "fresh" fossil fuel is used
  - This indirect benefit decreases as fewer fossil fuels are used in the economy
  - Fossil origin carbon is therefore not considered a sustainable alternative over time
  - *Where do we place "unavoidable" emissions?*

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Source: CO2next 2017

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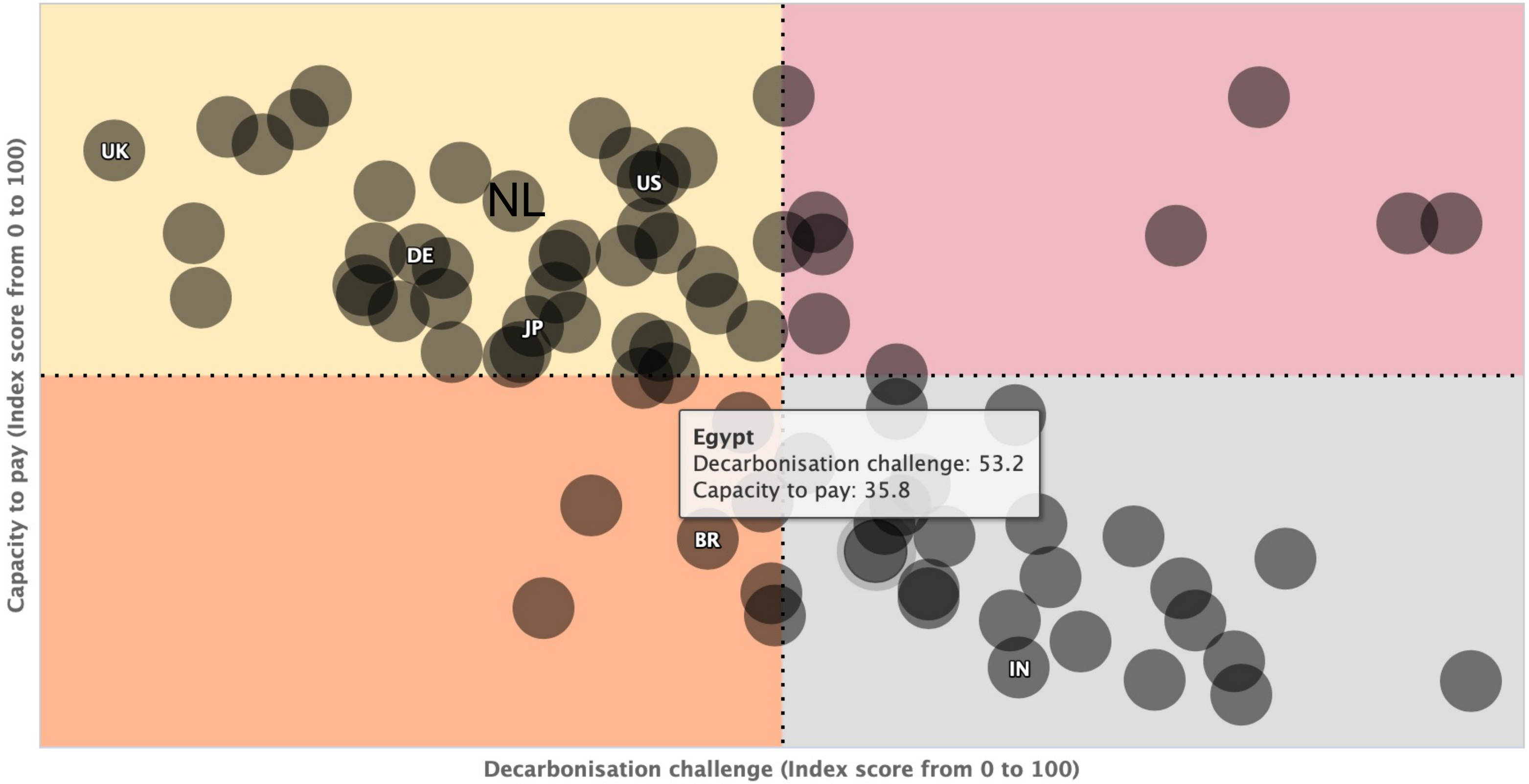
Major CO_2 emmitting industries and their current use of bioenergy and CO_2 capture

Industry	Direct CO_2 emissions (2019, global)	Status of biomass use	Status of CO_2 capture
Cement	2300 Mt fossil 30–80 Mt biogenic[1]	Commercial, with individual kilns firing up to 35–40% biomass, typically wastes [11]	Demonstration, up to 75 kt/year
Steel	2100 Mt fossil	Commercial partial replacement of coal with charcoal. Primarily used in small-scale production in Brazil	Demonstration for blast furnace steelmaking. Commercial for direct reduced iron steelmaking
Petro-chemical refining	1400 Mt fossil	Early commercialisation for methanol (1 facility) and biomass-to-liquids from biowastes (multiple facilities under construction)	Commercial for methanol and coal-to-liquids, up to 100 kt/year
Paper	200 Mt fossil 700–800 Mt biogenic[2]	Commercial. Process is inherently biobased. Residues used for cogeneration of heat and electricity	Demonstration, 11 kt/year [16]
Ethanol	82 Mt biogenic[3]	Commercial. Process is inherently biobased, with maize and sugarcane as primary feedstocks. Sugarcane bagasse is used for cogeneration of heat and electricity. Early commercialisation of fermentation of cellulosic biomass	Commercial for capture of high-purity fermentation CO_2, including 1 Mt/year to dedicated storage

Source: Tanzer S., et al. , (2021). Current sustainable/renewable energy reports 8: 253-262

Green infrastructure transition: Decarbonisation challenge and capacity to pay



Top left	Higher (but falling) CO_2 emissions to abate Higher levels of existing infrastructure to transition to green Greater ability to afford
Top right	Higher (but stabilising) CO_2 emissions to abate Lower levels of existing infrastructure to transition to green Greater ability to afford
Bottom left	Lower (but rising) CO_2 emissions to abate Higher levels of existing infrastructure to transition to green Lower ability to afford
Bottom right	Lower (but rising) CO_2 emissions to abate Lower levels of existing infrastructure to transition to green Lower ability to afford

Source: PwC/Oxford economics

Challenges to develop enabling infrastructure are multiple….

Lack of understanding on how the system will develop	• lock-in situations • danger of stranded assets
Inadequate policy guidance	• unclear role in achieving climate targets • limited existing policy design • new policies needed to speed scaling -up
Challenging permitting environment	• numerous jurisdictions involved • variability in conditions for transport and storage regulations
Uncertain costs	• challenges aligning players, permitting and financing • long-term liability
Lack of public awareness and varying support	• low public awareness and varied opinions about infrastructure • historic inequities in infrastructure sitting • concern of continued fossil fuel use

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Thanks for your attention!

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Investments costs will be significant

CO_2 Infrastructure Hub Projects Around the World

Transport/ Storage Project	Alberta Carbon Trunk Line	Longship/Northern Lights	Net Zero Teesside
Location	Canada	Norway	United Kingdom
Status	Operational; CO_2 used for EOR; 1 million metric tons of CO_2 delivered as of March 2021	Implementation Phase; engineering and design studies completed; verification well drilled; plans for transport, development, installation, and operations are developed	Study Phase; partnerships formed; engineering and design studies underway
Transport Capacity	1.6 $MtCO_2$/year (used today) 14.6 $MtCO_2$/year (total potential)	1.5 $MtCO_2$/y (Phase 1) 5.0 $MtCO_2$/y (Phase 2)	0.8 $MtCO_2$/y (Phase 1) 10 $MtCO_2$/y (at scale)
Storage Capacity	TBD	100 $MtCO_2$	>1 $GtCO_2$
Storage Type	Mature gas field, onshore	Sandstone reservoir, offshore	Saline reservoir, offshore
Funding	• US$520 million (2020$) from the Government of Alberta in 2009 • US$73 million (2020$) from the Government of Canada in 2011 • US$240 million (2020$) from Canadian Pension Investment Board in 2018	• US$1.2 billion for transport and storage in Phase 1 • US$1.6 billion for two capture projects • State covers 80% of transport and storage investment costs • State covers 95% of transport and storage operation costs in year 1, declines to 80% for years 4-10 • State covers 50% of costs for additional ships/wells	• US$68 million awarded via UK Innovation fund with about 2:1 matching funds from industry • US$1 billion pledged by UK government to establish two capture projects • Additional US$260 million investment pledged by UK government
Liability	Liability assumed by owner/operator; can be transferred to the government after closure; operator required to contribute to stewardship fund	State assumes 80% of costs of "extraordinary events" without a sunset date; Northern Lights DA will share liability among partners	TBD
Transport and Storage Ownership Structure	Wolf Midstream owns and operates pipeline and compression site; Enhance Energy owns and operates the utilization and storage of CO_2 for EOR and permanent storage	Equinor will be licensee and operator until Northern Lights DA (a new general partnership between Equinor, Shell, and Total) is established; Northern Lights DA will share liability, development, and operation of the project; profits will be based on future additions to the project	Operated by BP; OGCI members BP, Eni, Equinor, Shell, and Total form consortium that support project; 3 MOUs signed between Net Zero Teesside and potential capture sites
Scaling Strategy/ Potential	Unspecified	7 MOUs signed with other emissions sources, 11 projects in EU expecting to rely on Northern Lights for storage	Additional industrial emissions sources in Teesside; connecting Humber industrial cluster (2027-2030)