Future focus: CO_2 management and hydrogen decarbonisation

Five years ago, the trajectory of hydrogen decarbonisation and CO_2 management was uncertain. There is still some time to act and plenty of good reasons to refocus

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A fresh vision for fossil fuels

European and US debt is at an all-time high. Developing nations are struggling to feed their people and bring them basic healthcare provisions. The costs of war and plans for rising defence expenditure are eating into national budgets.

The notion that governments will be borrowing huge additional sums of money to pay for a net-zero future is unrealistic. We must accelerate progress with limited budgets, which means we should focus on achieving the best bang for our buck with hydrogen decarbonisation.

We must rethink the decarbonisation paradigm. 'Green' ideology and regulations suited for 2050, rather than 2025, have held back progress towards net zero for too long. It is not the 'greenest' projects that will proceed and receive infrastructure-scale investment; only the 'best' projects will be bankable. What does 'best' mean? To the bank, it means a clear business case with an acceptably low level of risk.

As we review carbon dioxide (CO_2) management and hydrogen decarbonisation mid-decade, it is abundantly clear that responsible use of fossil fuels is a reality that we must work with, not against, for many years to come. The use of fossil fuels with appropriate greenhouse gas (GHG) emissions mitigation is compatible with a net-zero vision. Fossil CO_2 and methane emissions to the atmosphere are the issue, not the use of fossil fuels per se. Let us attack the issues with razor-sharp precision, not get distracted by peripheral noise.

Sequester CO_2 that is already captured

When ammonia is made from steam methane reforming of natural gas, CO_2 leaving the

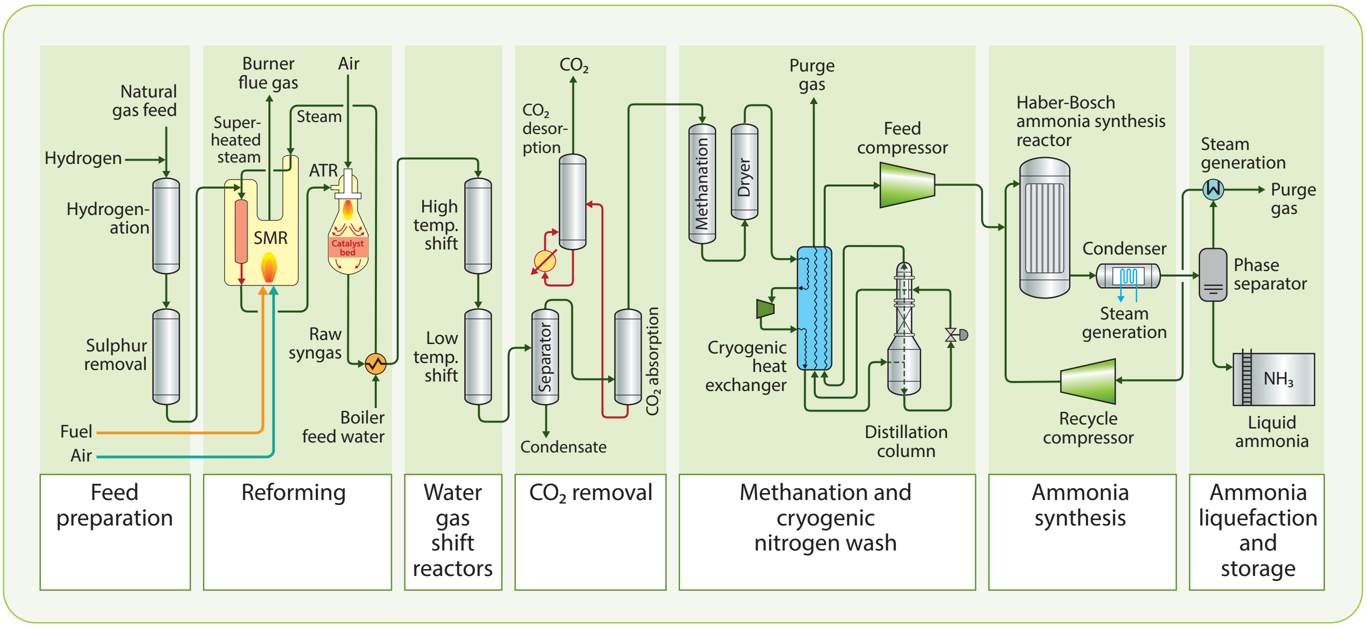
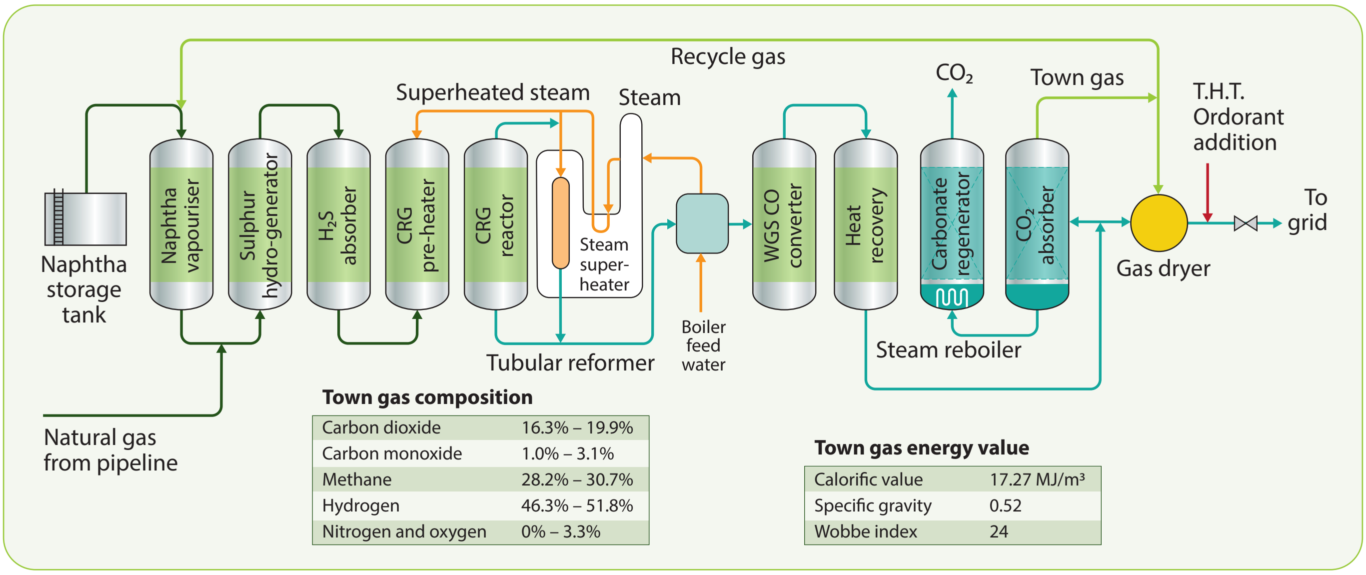


Figure 1 Air-fed ammonia production process



Town gas composition

Carbon dioxide	16.3% – 19.9%
Carbon monoxide	1.0% – 3.1%
Methane	28.2% – 30.7%
Hydrogen	46.3% – 51.8%
Nitrogen and oxygen	0% – 3.3%

Town gas energy value

Calorific value	17.27 MJ/m³
Specific gravity	0.52
Wobbe index	24

Figure 2 Hong Kong Town Gas – Tai Po catalytic rich gas naphtha/methane reformer and CO_2 capture process

reformer must be removed to enable the catalytic Haber-Bosch ammonia synthesis reaction to take place (see **Figure 1**). Every natural gas-fed ammonia plant already has a CO_2 capture facility. The Capex is spent, and the energy costs for CO_2 capture are committed. This CO_2 must be sequestered to reduce the CO_2 intensity of this ammonia. Large-scale projects for green hydrogen for ammonia production should not be prioritised until we have decarbonised existing natural gas-fed ammonia plants massively.

Coal-to-chemicals is another area of low-hanging fruit. Immediately after coal gasification, the raw syngas is fed to a Rectisol unit, where CO_2 and sulphurous gases are removed. At present, this CO_2 is blown to atmosphere, just like the CO_2 from ammonia production is vented on most ammonia plants today.

This captured CO_2 must be a priority for sequestration since the capital and operating costs of the Rectisol plant are absorbed into the overall costs of the coal-to-chemicals production. To reduce the CO_2 intensity of coal-to-chemicals, the only incremental costs are CO_2 transmission and sequestration.

In Hong Kong, Town Gas production already involves CO_2 capture to control the heating value of the product (see **Figure 2**). This CO_2 is vented to atmosphere. It should be sequestered.

Production of ethylene oxide on many petrochemical plants also requires CO_2 removal within the process to purge CO_2 (a byproduct of ethylene oxidation) from the process recycle. Also, natural gas processing removes CO_2 in midstream operations to ensure dry, acid-free gas enters the pipeline transmission infrastructure. These are tier 1 priorities for sequestration of captured CO_2.

Decarbonising refinery hydrogen

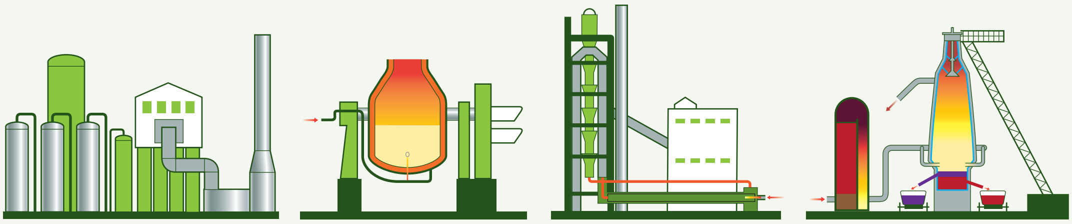
In many oil refineries, grey hydrogen produced from natural gas on steam methane reformers (SMRs) is used to produce marketable liquid fuels. The CO_2 from these SMRs is not captured at present. However, 60 to 70% of the CO_2 produced on the SMR is available at a very high partial pressure prior to the reformate gas mixture entering the hydrogen separation pressure swing adsorption (PSA) unit. The unit cost of CO_2 capture in this location is low.

New equipment and new energy would be required. But the incremental costs of capturing this CO_2 would be less than the incremental cost of implementing carbon capture and storage (CCS) to processes with more dilute CO_2 streams, such as power generation, cement, or steel making (see **Figure 3**)

Despite the ideal process conditions, there is not an overwhelming wave of SMR CO_2 capture projects being implemented because the business case is not strong enough. The costs of CO_2 emissions do not cover the costs of new equipment and the energy penalty.

CCS of CO_2 from SMRs would be 'good value for money' and help with the rapid decarbonisation of hydrogen production

Notes:
– CO_2 emissions are also associated with the energy and power requirements for this industry sector
– These can potentially be decarbonised with renewable power and electrical heating or microwaves
– CCS to capture CO_2 from the process and/or the associated energy production is possible



	Oil refining	Aluminium smelting	Cement making	Iron making
Application that releases CO_2	Hydrogen production from methane reforming for fuels desulphurisation	Reduction of alumina to aluminium using graphite electrodes	Reduction of limestone to calcium oxide	Reduction of iron ore to iron using coke
Chemical reaction producing CO_2	$CH_4 + H_2O \rightarrow CO + 3H_2$ $CO + H_2O \rightarrow CO_2 + H_2$	$2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2$	$CaCO_3 \rightarrow CaO + CO_2$	$2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$ $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$
Decarbonisation approach for CO_2 generated by the process	Use turquoise hydrogen or green hydrogen to avoid the reforming reaction; or feed the reformer with biomethane instead of natural gas	Use carbon from turquoise hydrogen production instead of carbon from fossil fuels to make the electrodes	Replace a portion of the limestone with alternative materials such as calcined clay to make clinker for cement	Use hydrogen instead of coke; or substitute coke with carbon from turquoise hydrogen production
Reactions for the decarbonised process	As above using renewable methane	As above using renewable graphite electrodes	Above reaction can only partially be avoided	As above using renewable carbon, or use hydrogen: $Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$
Other industries with similar applications	Ammonia, urea, methanol, gas-to-liquids	Gold and silver refining, electric arc furnace to melt scrap steel	– Lime making, as above – Refractory materials; $MgCO_3 \rightarrow MgO + CO_2$ – Glass making Na_2CO_3, $CaCO_3$, $MgCO_3$	None

Figure 3 Difficult-to-decarbonise industries – CO_2 is released from within the process

and refinery operations. Policymakers must recognise the benefits of hydrogen with any degree of reduced CO_2 intensity. The current criteria for 'blue' hydrogen are tight, and if a decarbonisation initiative does not get the 'blue' badge, the case is weak.

CO_2 intensity must be a sliding scale

The 'blue' hydrogen benchmark is relevant for new-build projects based on autothermal reformers (ATRs) or gas heated reformers (GHRs) with built-in CCS, but 2,000 SMRs operating today can be decarbonised with CO_2 capture equipment retrofits. This is 2025, and in many parts of the world, there has been significantly less progress towards declared net-zero targets than has been promised. 'More of the same' will not help us achieve 1.5°C and is unlikely to cap climate change at 2 or 3°C. We need high-impact action now – ideas that can rapidly and cost-effectively be deployed.

The costs and scalability of green, blue, or hydrogen of any degree of CO_2 intensity must be seen in the context of alternative industrial decarbonisation measures. The idea of a hydrogen project going for 'green, blue, or broke' has resulted in failed business cases and inhibited meaningful progress. CO_2 intensity is what matters. Every reduction in GHG emissions is beneficial.

Making a rapid impact means there is no room for the perfect to be the enemy of the good. We must accept that the next 30 years will be about rapid decarbonisation of existing infrastructure in addition to progressive development and deployment of ultra-clean technology. There must be support for GHG emissions reduction in all forms rather than CO_2 intensity thresholds, which indirectly promote some technologies above others.

Policy priorities for hydrogen and CO_2 management in the second half of this decade
Use the 'polluter pays' principle for GHG gas emissions with meaningful minimum costs (such as CO_2 €150 to €200 per tonne and others based on CO_2 equivalence). This will: ❶ Incentivise sequestration of CO_2 that is already captured from natural gas processing, ammonia and ethylene oxide production, and coal-to-chemicals. ❷ Incentivise capture of CO_2 from high partial-pressure process streams on SMRs. ❸ Eliminate the need for a threshold approach to CO_2 intensity with an arbitrary cut-off point for 'blue' hydrogen. The 'polluter pays' principle would, in effect, implement a sliding scale of embedded CO_2 and tax or incentivise based on that.
Broaden policy acceptance and viability of EOR and EGR as valid mechanisms for CO_2 sequestration.
Commit to building common CO_2 pipeline infrastructure to link fossil, geogenic, and biogenic CO_2 emitters with CO_2 storage/utilisation/removals locations.
Commit to building a colour-agnostic, common hydrogen pipeline infrastructure with underground hydrogen storage in salt or rock caverns.
Support projects that build the bankability of green hydrogen to allow a progressive ramp-up of green hydrogen as renewable power ramps up to support it.

Table 1

A fair assessment of CCS, EOR, and EGR

Despite some failures, disappointments, and poor reporting in certain carbon capture and geological storage (CCS) projects, there have also been many successes. The way to get better is to do more and learn faster. Enhanced oil recovery (EOR) and enhanced gas recovery (EGR) should also be seen as meaningful ways to store CO_2 in suitable geological formations.

Dismissal of EOR and EGR as valid CCS mechanisms due to concerns that they may increase fossil fuel production is not valid on a global scale. There is an abundance of crude oil and natural gas reserves in the Middle East and Russia; these nations will produce according to demand.

To say that EOR or EGR stimulate demand for fossil fuels is a flawed argument. Local production avoids the cost and environmental impact of fuels distribution. Extending the life of wells can increase economic efficiency. Policymakers must take a more supportive view of EOR and EGR as valid means of CO_2 sequestration. Also, when we consider the number of successful EOR schemes, underground geological storage of CO_2 has an overwhelmingly positive history.

Greenhouse gas emissions are the problem

Excessive CO_2 in the atmosphere is the problem now and will remain a risk for eternity. We must address the problem rather than favour one solution ahead of others. To do that is a risky guessing game that no policymaker can afford to make. In many areas, policy is no longer technology agnostic – it should return more closely to that principle.

Now more than ever, a focus on CO_2 emissions reduction and carbon dioxide removals (CDR), by whatever means, must be priorities. The costs of GHG emissions, whether they be CO_2, methane, F-gases, or others, must be paid by the polluter. Taxation of the polluter pays principle has driven the reduction of NOx and SOx emissions in several countries in northern Europe.

At present, CO_2 emissions are too cheap. The tax penalties or incentives for GHG emissions reduction are too weak. The cost of CO_2 emissions should be in the order of €150 to €200 per tonne (see **Table 1**). Methane, F-gases and nitrous oxide must be scaled in line with their CO_2 equivalence. Any concerns about unfair competition due to policies moving at different speeds around the world can be met with embedded CO_2 cross-border tax adjustments.

The EU ETS, US 45Q, and other 'carrot or stick' schemes around the world must set a cost to CO_2 emissions, ensuring there is a business case for decarbonisation investments. Even if there is a degree of GHG emissions cost fluctuation, there must be a meaningful minimum to de-risk the business case. Higher avoided CO_2 emissions costs should be an upside rather than a risk multiplier and business case killer.

Common infrastructure for biogenic, geogenic, and fossil CO_2

The most important area for governmental focus in the second half of this decade must be a comprehensive pipeline network to link CO_2 emitters with CO_2 storage, utilisation, and removals projects (see Table 1**)**. Liquid CO_2 storage terminals will be required to allow aggregation and transportation modality transitions within the CO_2 logistics chain.

Western Europe is an ideal place to implement this concept. There is a dense industrial cluster and CO_2 storage potential in the North Sea. The Gulf Coast of the USA would have similarly high potential. In both locations, repurposing oil and gas pipelines could help offset some of the cost.

CO_2 entering and leaving the pipeline should be treated in the same way as biogas entering and leaving the gas transmission grid. Biogenic, geogenic, and fossil CO_2 must be allowed to mix and share the infrastructure. Metering and monitoring for mass balancing will be required as a key enabler. If this is not done, we will stimulate long-distance transportation of biogenic CO_2 for utilisation or CDR in parallel to fossil and geogenic CO_2 for geological storage. Allowing this parallel system to develop would be the most absurd waste of capital and resources.

Mass balancing and hydrogen purchase agreements

If we accept that hydrogen, produced by any means, will play a central role in future energy systems, pipeline infrastructure to move hydrogen around will also be an essential investment. Pipelines are, by far, the most economical way to move hydrogen short and medium distances over land. However, due to the long investment cycle and high capital requirement, there is no business case for this today, so a huge amount of belief and supporting capital from governmental bodies is required to get this underway (see **Figure 4**).

Low-cost, high-capacity underground hydrogen storage in salt and rock caverns must complement the pipeline network. It will enable seasonal supply and demand balances to be smoothed. It will also allow intermittent hydrogen production renewable power that would otherwise be curtailed, at exceptionally low cost.

As with the CO_2 pipeline, the hydrogen pipeline must operate in the same way the electricity grid carries green, grey, and pink electrons: the hydrogen pipeline must be colour agnostic. Hydrogen purchase agreements (HPAs), like renewable power purchase agreements, can be used to link green hydrogen

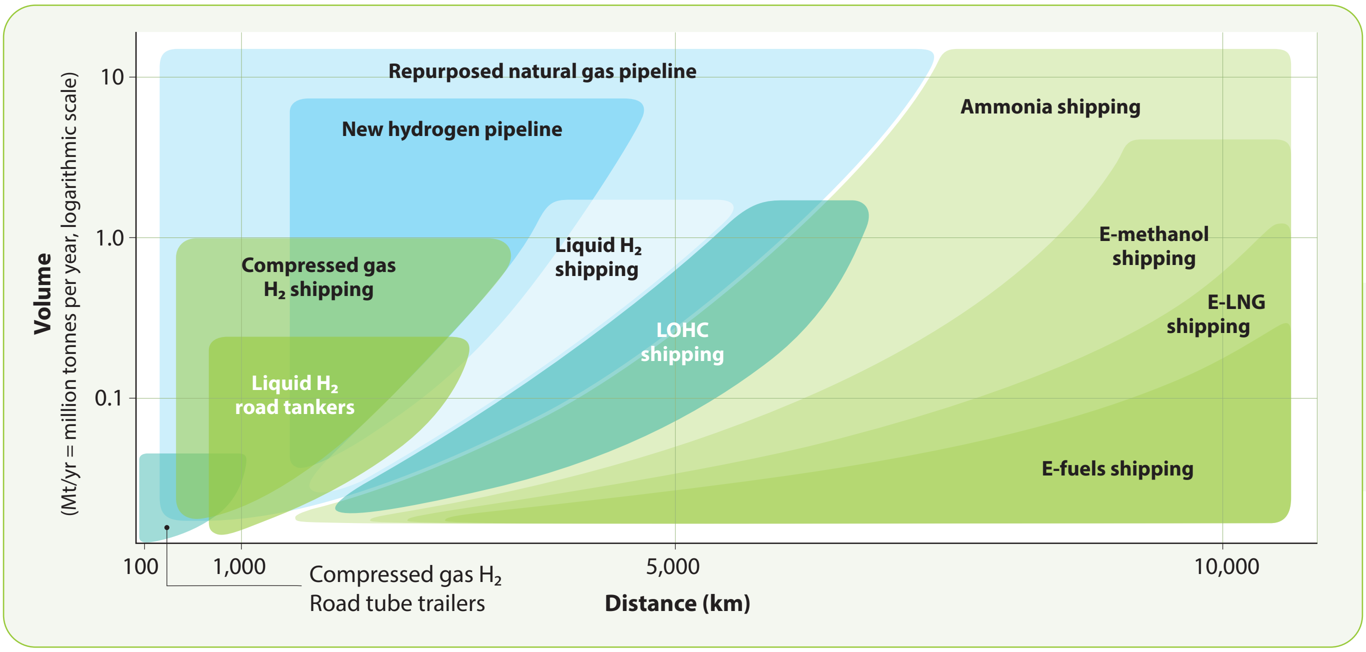


Figure 4 Hydrogen and hydrogen derivatives transport options when considering volume and distance

producers with green hydrogen off-takers through a mass balance.

Development of common infrastructure is one of the most important roles that any government can play. The principles applied to build road networks, railway tracks, and electricity grids must be used to build pipelines. Planning CO_2 and hydrogen pipelines together will create synergies. Coordination is the key.

What it means to the private and public sectors

Pipeline and transmission infrastructure requires cross-border collaboration, rapid development of international pipeline and CO_2 purity standards, and massive investment in common infrastructure. It will also require regional peace and international security. There is ultra-important work to be done in many domains.

The role of governments must be to focus on effective and coherent policy development and common infrastructure enablement. The private sector, not governments, has the expertise and resources to excel in technology innovation, project finance, and project development.

Policy must focus on GHG gas emissions reductions as the problem. It must allow the solutions, such as renewable power generation, long-duration energy storage, hydrogen (of any colour), direct air capture, geological CO_2 storage, batteries, electrification of industrial processes, heat pumps, and energy efficiency, to evolve. Regulators must enable these solutions with permitting and must simultaneously remain broadly technology agnostic and avoid incentivising one solution ahead of another.

Nobody knew what trajectory hydrogen decarbonisation and CO_2 management would take five years ago. If we had, then policies and incentives would have been written differently. However, there is still some time to act and plenty of good reason to adjust and refocus in the second half of this decade. Policymakers must review this dynamic situation to set a clear direction in line with the latest facts, the best research, and likely technology deployment trajectories.

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