HYDROGEN'S HIDDEN EMISSIONS

Shell's misleading climate claims for its Canadian fossil hydrogen project

January 2022

Shell's Scotford petrochemicals and tar sands oil complex in Alberta, Canada, where the company produces fossil hydrogen.
Robert McGouy/Alamy

> Shell says the carbon capture system at its 'Quest' fossil hydrogen plant in Canada stopped five million tonnes of carbon dioxide from entering the atmosphere in less than five years.

> This claim only tells one side of the story, as a Global Witness investigation found the hydrogen plant released a further 7.5 million tonnes of greenhouse gases into the atmosphere over the same period – emissions from the plant that Shell does not publicise.

> Per year, the plant has the same carbon footprint as 1.2 million petrol cars.

> Industry lobbyists claim that 90% or more of the carbon dioxide produced at fossil hydrogen plants will be captured. However, only 48% of the carbon emissions produced at Shell's plant are being captured – far less than promised by the industry in general.

> When the plant's overall greenhouse gas emissions are factored in, such as methane pollution from the fossil gas supply chain, only 39% of its total emissions are captured.

> Shell's hydrogen plant is part of the company's tar sands operations in Alberta, where Indigenous and First Nations people are resisting the industry's severe environmental damage.

> The hydrogen plant's low carbon capture rate comes despite its carbon capture system costing a reported US$1 billion, with US$654 million of this amount coming from government subsidies.

> Fossil hydrogen is part of the fossil gas industry's strategy to prolong its life, despite the urgent need for a rapid phaseout of fossil fuels in order to meet the Paris Agreement goals.

> Policymakers, including in Canada, the US and EU, should not support new fossil hydrogen projects, and instead work to phase out existing ones or replace them with renewables-based alternatives.

Introduction: fossil-fuelled hydrogen hype

A well-funded army of gas industry lobbyists is pushing governments around the world to subsidise and deploy fossil hydrogen on a huge scale.[1]

The gas lobby is heavily promoting hydrogen as a climate-friendly fuel that can replace fossil fuels across the economy, from transport to home heating to power generation.

Hydrogen's main selling point is that it emits no greenhouse gases at the point of consumption.[2] But this only tells part of the story, as at present hydrogen is commonly produced from fossil gas, which causes high climate heating emissions.

Fossil fuel companies say that to reduce these emissions, they will apply 'carbon capture and storage' (CCS) systems to plants that produce hydrogen from fossil gas. Industry lobbyists claim that CCS can reduce the carbon emissions from fossil hydrogen by 90% or more.[3]

The fossil fuel industry calls hydrogen made with fossil gas and CCS 'blue hydrogen', and says it is a 'clean' or 'low carbon' fuel.

Governments, which often have close ties to the gas industry, have taken up lobbyists' call and are starting to champion fossil hydrogen.

Thirty-nine countries now have hydrogen strategies,[4] from Australia to Chile to South Korea. Many of them pave the way to regulatory and financial support for fossil hydrogen,[5] including the EU and UK strategies, as well as the US 'Hydrogen Earthshot' plan which promises government funding for fossil hydrogen.[6]

At present, global production of fossil hydrogen with CCS comes to around 700,000 tonnes per year.[7] The International Energy Agency (IEA) contends that this should increase massively, going up to 200 million tonnes a year by 2050, with the agency saying this is needed to meet the Paris Agreement goals.[8]

To help assess industry's claims for fossil hydrogen's climate-friendliness, Global Witness investigated the greenhouse gas emissions from one of only a handful of existing fossil hydrogen plants that use CCS.[9] The plant is owned by the oil major Shell, and is part of the company's Scotford refinery in Alberta, Canada, where the hydrogen is used to convert tar sands bitumen into synthetic crude oil.[10]

Key terms

- **Carbon capture and storage** (CCS) is a technology that aims to prevent carbon dioxide from entering the atmosphere at the point of emission – for example in the smokestack of a power plant. The captured carbon is then stored underground, or sold for use in other industrial processes.
- **Fossil hydrogen** (or 'blue hydrogen') is a fuel that oil and gas companies are promoting, which can be used instead of fossil fuels. It's made by converting fossil gas into hydrogen, and using CCS to capture some of the emissions that occur during the production process. CCS systems can be retrofitted to existing plants that produce hydrogen from fossil gas, or by including CCS in new fossil hydrogen plants.
- **Renewable hydrogen** (or 'green hydrogen') can also be used instead of fossil fuels, and is made by passing a current of renewable electricity through water. If the electricity used is 100% renewable, the resulting hydrogen is virtually carbon free.

Shell's claims v climate impact

Shell has claimed that "blue [fossil] hydrogen produces little to no greenhouse gas emissions",[11] and is advocating for a large-scale expansion of fossil hydrogen.[12] The company is also a member of industry lobby groups that are pushing for a huge increase in fossil hydrogen production.[13]

So-called 'clean hydrogen' – a term used by Shell that covers both fossil and renewable hydrogen[14] – plays a prominent role in Shell's energy transition strategy, with the company aiming for "a double-digit market share of global clean hydrogen sales by 2030".[15]

The 'Quest' CCS system at Shell's Albertan hydrogen plant is one of the company's flagship climate projects, and is cited in Shell's 'Climate Target' briefing as an example of what it's doing to tackle global heating.[16]

The CCS system also featured in Shell's 'Energy Podcast' series, is mentioned in the company's 'Powering Progress' organisational strategy, and has been covered multiple times in its promotional videos on YouTube.[17]

The CCS system was added to Shell's Albertan plant in 2015, which had been producing hydrogen from fossil gas for several years by that time.[18]

Ben van Beurden, Shell's CEO, attended the launch of the CCS system. In his speech, he said that the project "represents a significant milestone in the successful design, construction and use of carbon capture and storage technology on a commercial scale",[19] and that CCS is "a key technology in the transition to a low-carbon future and in the fight against climate change."[20]

Shell CEO Ben van Beurden launching the company's carbon capture and storage facility in Alberta, Canada in November 2015. *Reuters/Alamy*

In its promotional materials for the Albertan CCS system, Shell says that it prevented five million tonnes of carbon dioxide from reaching the atmosphere in under five years.[21]

But this doesn't provide a full picture of the project's impact on the climate, as five million tonnes is less than half of the carbon dioxide produced at the hydrogen plant over this period, so it remains a major emitter.

In fact, Shell's CCS system captures just 48% of the carbon emissions produced at its fossil hydrogen plant.[22] This is far below the 90% or higher carbon capture rate promised by industry for fossil hydrogen production in general.[23]

When the project's overall greenhouse gas emissions are factored in, such as methane pollution from extracting and transporting fossil gas used to produce the hydrogen, only 39% of its emissions are prevented from reaching the atmosphere.[24]

This means that while Shell's CCS system captured 4.81 million tonnes of carbon dioxide from 2015 to 2019, the hydrogen plant emitted a further 7.66 million tonnes of greenhouse gases over the same period.[25] Per year, the plant has the same climate footprint as 1.2 million UK petrol-powered cars.[26]

Shell states that its Albertan project shows CCS is a "safe and effective measure to reduce CO2 emissions",[27] and that the project "continues to be a thriving example of how carbon capture and storage is working; showing it can make a significant contribution to lowering CO2 emissions."[28]

Global Witness believes these claims about the CCS facility are misleading, as they create the impression that the hydrogen plant is less damaging for the climate than is actually the case, while Shell's promotional materials give no sense of the proportion of carbon dioxide emitted from its hydrogen plant.

GREENHOUSE GASES (GHG) CAPTURED VS EMITTED

Millions of tonnes, 2015-2019

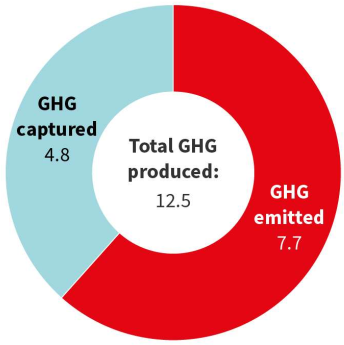


Chart: Global Witness
Source: Shell (2021), Pembina Institute (2021)

Why Shell's CCS system has a low carbon capture rate

Shell's Albertan plant produces hydrogen through a process known as 'steam methane reforming', or SMR. This is by far the most common way of producing hydrogen from fossil gas, and it will remain so for many years to come.[29]

The Albertan government requires Shell to publish technical reports on the performance of its CCS system. These show that it captures around 80% of the carbon emissions from the SMR process.[30]

However, the SMR process only accounts for around 60% of the carbon emissions produced at the hydrogen plant. Another 40% of the carbon emissions come from a waste stream known as ‘flue gas’, and are not captured by Shell’s CCS system.[31]

As the CCS system captures only 80% of 60% of the carbon emissions produced at Shell’s plant, this brings its carbon capture rate down to 48%.

Why only 39% of the project’s overall greenhouse gas emissions are captured

We know that 52% of the carbon emissions produced at Shell’s hydrogen plant – the ‘on-site’ emissions – are not captured. But even this only tells part of the story, as fossil hydrogen projects generate greenhouse gas emissions outside of the production plant, which are also not captured. These include:

- Methane emissions from the supply chain of fossil gas used to produce the hydrogen – from the gas fields where it’s extracted, through to gas processing plants and pipelines.
- Carbon emissions from the energy used to power the CCS system.[32]

Methane emissions from the supply chain for fossil gas are a particular concern. As a climate-heating pollutant, methane is more than 80 times more powerful than carbon dioxide over a 20-year period.[33]

Methane leaks or is deliberately released at every stage of the fossil gas supply chain.[34] These emissions occur outside of hydrogen production plants, and are not captured by CCS systems.

Methane emissions rates

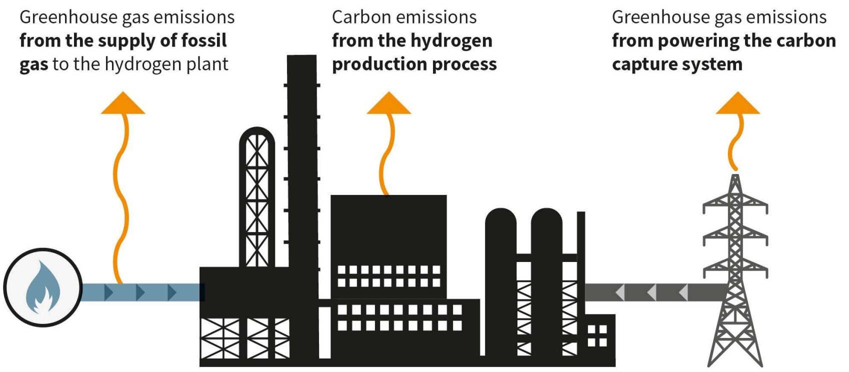
Along with the on-site carbon capture rate, the ‘methane emissions rate’ is a crucial factor in determining the climate impact of fossil hydrogen production. The methane emissions rate is the amount of methane emitted to the atmosphere from a supply chain of fossil gas as a percentage of the overall gas consumed.

Methane emissions rates vary depending on the methods used to identify them, and where the fossil gas is sourced from. Some reports show relatively low methane emissions rates. For example, the fossil gas used by Shell’s hydrogen plant in Alberta is estimated to have a methane emissions rate of 0.6%.[35]

This is substantially lower than the IEA’s estimate that the average methane emissions rate from fossil gas operations globally is 1.7%.[36] Other country-level studies have shown far higher methane emissions rates of up to 8%.[37]

When all of the greenhouse gas emissions from Shell’s fossil hydrogen project are factored in, only 39% of them end up being captured.[38] This means that from 2015 to 2019, the project released 7.66 million tonnes of greenhouse gases into the atmosphere.

Sources of greenhouse gas emissions from fossil hydrogen production



Greenhouse gas emissions from Shell's Albertan fossil hydrogen plant, 2015-19

	Source of GHGs					
	Supply chain for fossil gas	On-site CO2 produced at the hydrogen plant	Electricity to power the CCS system	Total GHGs produced	Total GHGs captured	Total GHGs released
Tonnes of GHGs	1,580,000	10,023,000	868,000	12,469,000	4,813,000	7,656,000
% of overall GHGs	12.7%	80.3%	7%	100%	38.6%	61.4%

Global Witness estimates, see Annex for the methodology and sources.

Shell's tentative plan to increase the Albertan plant's carbon capture rate

In July 2021, Shell announced that it may try to increase the carbon capture rate at its Albertan hydrogen plant to 90% or more, with a final investment decision expected in 2023.[39] However, even if Shell goes ahead with the proposed project expansion, a number of points need to be considered:

> The hydrogen produced would carry on being used to refine fossil fuels[40] that will be burnt and emit greenhouse gases, even though the vast majority of Canada's oil reserves need to stay in the ground to stand a 50% chance of limiting global heating to 1.5°C.[41]

Canada has ratified the Paris Agreement which aims to limit warming to this level, and Shell claims that it supports this goal.[42] As such, Shell should be actively working to phase out its high carbon businesses, rather than using hydrogen to claim its fossil fuel products can be greener.

> Success is not guaranteed. As shown below on page 10, almost 80% of government-backed, large-scale CCS projects initiated over the past three decades have been cancelled or suspended, and at least some of the CCS projects currently operating are capturing carbon at lower rates than intended.

> Even if Shell managed to increase the carbon capture rate at its hydrogen plant, this would not reduce greenhouse gas emissions from the supply chain for fossil gas or the energy used to power the CCS system.

Shell's response

Global Witness requested comments from Shell on the findings of this investigation, but the company did not respond.

First Nations' fightback

The damaging effects of fossil hydrogen don't stop at high greenhouse gas emissions. Hydrogen made from fossil gas is inextricably linked to fossil fuel industries that are having destructive impacts on people's health and livelihoods in Indigenous and other marginalised communities.

As an important element of Shell's tar sands operations, the Albertan hydrogen plant plays a role in supporting one of the most environmentally damaging extractive developments in the world,[43] which has encroached on Indigenous people's traditional lands for decades.[44]

Tar sands production in Alberta – essentially mining and processing bitumen to produce oil – covers an area the size of England, and is one of the largest extractive projects on Earth.[45] The industry is causing environmental damage on a huge scale, including high greenhouse gas emissions, large-scale deforestation, air and water pollution, contamination of wildlife and land disturbance.[46]

As Melina Laboucan-Massimo, a member of the Lubicon Cree First Nation said, "whether it be from toxic emissions and water contamination to the complete fragmenting and decimation of the boreal forest, tar sands development is completely altering our homelands and destroying the very foundation of who we are as Indigenous peoples."[47]

First Nations communities have been seeking justice for the damaging impacts of tar sands extraction on their health, livelihoods and land rights for many years. In 2008 for example, the Beaver Lake Cree Nation sued the federal and Albertan governments for failing to uphold its treaty rights.[48]

Activists say that Beaver Lake Cree territory has been adversely affected by a huge number of industrial projects and infrastructure. These include 35,000 oil and gas sites, 21,700 kilometres of seismic lines, 4,028 kilometres of pipeline and 948 kilometres of road.[49]

The lawsuit claims that the impacts of these developments are preventing the Beaver Lake Cree Nation from exercising their treaty rights, including to hunt and fish in their traditional territories.

The case could set a powerful precedent that would force regulators to evaluate industrial projects not on a one-by-one, piecemeal basis, but according to the cumulative impacts of industrial development on treaty rights.[50]

As Crystal Lameman, treaty coordinator for the Beaver Lake Cree Nation said: "Indigenous rights are the last stronghold we have to stop the unmitigated expansion of the tar sands at source. The Beaver Lake Cree are carrying a case on their backs that could set historical precedence: success would mean that it would become much harder if not impossible to expand tar sands projects and would greatly curtail the industry's expansion plans."[51]

The Albian tar sands project in Alberta, Canada, part-owned by Shell. *Larry MacDougal/Design Pics Inc/Alamy*

Thirteen years after it was filed, the case is ongoing and is not due to reach trial until 2024.[52] The protracted timeline highlights how difficult it can be for Indigenous communities to access environmental justice, with legal cases often taking a decade or more.

Currently, the Beaver Lake Cree Nation is fighting to obtain a court order that would see the Canadian and Albertan governments pay for some of the legal costs – a remedy that has historically been granted to some Indigenous Nations to ensure their access to justice.

Representatives for the Beaver Lake Cree Nation say that, while it has access to funds, these are needed for essential services and emergency support, such as repairing trucks that bring clean water to the community. According to one report, 85% of homes in the Beaver Lake reserve community are not connected to the main water line.[53]

In an interview with The Narwhal, Crystal Lameman said: "Had we put all that money towards the litigation, we would have no money to fix our school."[54]

Lameman sees a double standard in how her nation is being treated. "A court would not say, 'Alberta, you need to be completely broke.' The same application would not be applied to a municipality, to a provincial government, to the federal government," she added. "The systemic racism is so deeply embedded… The fact they feel they can do this to a First Nations government is the reason why we didn't just let this die."[55]

An economically unviable technology?

The low carbon capture rate at Shell's fossil hydrogen plant comes despite its CCS system receiving US$654 million in government subsidies, with the total cost of the CCS system being a reported US$1 billion.[56]

According to a 2019 study by the IEA Greenhouse Gas R&D Programme (IEAGHG), the high capital and operating costs of Shell's Albertan CCS system show that deploying CCS in heavy oil processing plants is "not yet economic without considerable support in the form of government or external funding."[57] As a means to address Canada's obligations under the Paris Agreement, this is a poor use of tax-payer dollars.

The US$1 billion outlay covered the cost of capturing only 48% of the on-site carbon emissions. More of the on-site emissions could be captured by applying CCS to the flue gas outlet, which Shell is considering as part of its tentative plans to expand the Albertan project.

However, this would incur even higher costs. Shell reports that capturing flue gas emissions would increase the cost of installing CCS at fossil hydrogen plants by 60%, partly because it requires larger carbon capture equipment.[58]

Applying CCS to flue gas emissions would therefore increase what already appear to be prohibitively high costs. According to Shell, a typically-sized hydrogen plant that sells the captured carbon dioxide could lose US$12 million a year in revenues if it applied CCS to the flue gas emissions, because of the high cost.[59]

Cleaner fossil hydrogen: more industry hype?

Some industry lobby groups have admitted that – when applied to SMR plants – CCS can result in low emissions capture rates.[60] As it traps only 48% of the on-site carbon emissions, Shell's Albertan CCS system is a case in point.

So instead of producing it with SMR technology, supporters of fossil hydrogen say that new production plants can be built that use different technologies to make hydrogen from fossil gas.

First Nation activists Melina Laboucan-Massimo (fifth from left) and Crystal Lameman (sixth from left) on the front row of a march in Washington DC. *Manuel Balce Ceneta/AP/Shutterstock*

These are 'autothermal reforming' (ATR), and 'partial oxidation' (POx).[61]

ATR and POx technologies still generate high on-site carbon emissions, so they would need CCS systems to capture these emissions.[62]

The on-site carbon emissions from ATR and POx plants are released at one point in the hydrogen production process, rather than two points as with SMR.[63] This means that, in theory, CCS systems would be able to capture a higher proportion of on-site emissions at ATR and POx plants than is the case with SMR plants.

ATR and POx technologies, so industry claims, can outperform SMR with carbon capture rates of 94%[64] to 98%.[65] However, promises of low emissions from these technologies should be treated with caution, for several reasons:

Emissions from ATR and POx plants can easily exceed the limit allowed by EU sustainability rules

The carbon capture rates cited for ATR and POx technologies don't account for the overall greenhouse gas emissions produced, such as from the fossil gas supply chain and from powering CCS systems. Once these are factored in, the proportion of emissions released into the atmosphere will be higher, and potentially much higher if the methane emissions rate is high.[66]

Even with low methane emissions and high carbon capture rates, greenhouse gas emissions from fossil hydrogen produced with ATR and POx technologies could easily exceed the limit allowed by new EU sustainability regulations, which include criteria that define which investments are environmentally sustainable.

Meeting these criteria is desirable for companies as it could bring significant commercial benefits, such as making them more attractive to investors, enhanced competitiveness and further policy support from governments.

The EU regulations exclude any hydrogen that emits three or more tonnes of greenhouse gasses for every tonne of hydrogen produced[67] (Shell's Albertan plant emits double the EU limit, largely as a consequence of its low carbon capture rate).[68]

Researchers have shown that even if an ATR plant had a high carbon capture rate of 98%, the methane emissions rate for its fossil gas supply would need to be below 0.6% for the hydrogen to comply with the EU's sustainability regulations.[69] This analysis uses a 100-year 'Global Warming Potential' value for methane (see box below).

If a 20-year methane Global Warming Potential value is used, the methane emissions rate for fossil gas supplied to an ATR plant would need to be even lower – under 0.2% – for the hydrogen to comply with the EU regulations, assuming a high carbon capture rate of 98%.[70]

Methane's Global Warming Potential

Methane's impact on the climate is commonly measured by its 'Global Warming Potential' (GWP) over time. Over a 20-year period, methane is estimated to be 83 times more powerful than carbon dioxide as a climate heating gas. Over a 100-year period, methane is 30 times more potent than carbon dioxide.[71]

Because methane emissions make up a substantial proportion of fossil hydrogen's climate footprint, estimates of fossil hydrogen's overall emissions can vary significantly depending on which GWP timeframe for methane is used.

If a 20-year GWP value is used, this results in methane emissions making a higher contribution to fossil hydrogen's overall emissions than a 100-year GWP value for methane.

The emissions figures for fossil hydrogen cited in this briefing, including for Shell's Albertan plant, use the more conservative 100-year GWP value for methane, unless otherwise stated.

Studies on countries that export fossil gas to the EU have found methane emissions rates that far exceed the levels needed to comply with the EU's sustainability regulations for hydrogen.

For example, a report by MIT researchers on fossil gas used in the US power sector estimates that methane emissions rates range from 1.5% to 4.9%.[72] Another study estimates that Russian fossil gas, which makes up around 40% of the EU's gas imports, has methane emissions rates of 5% to 7%.[73]

If ATR or POx plants used fossil gas with methane emissions at these rates, the resulting hydrogen would almost certainly overshoot the EU limit by a much wider margin, even if they achieved high carbon capture rates.

Emissions from ATR production v EU sustainability regulations

Methane Global Warming Potential	20 years	100 years
Carbon capture rate	98%	98%
Methane emissions rate	0.2%	0.6%
Greenhouse gasses emitted per tonne of hydrogen produced	3 tonnes (25 kgCO2e/GJ H2)	
EU sustainability regulations – greenhouse gas emissions threshold for hydrogen per tonne produced	Below 3 tonnes	

Source: Baur *et al*, 2021.

Carbon capture's dismal track record

Globally, CCS technology has received billions of dollars in public funding over the past three decades.[74] Despite this, promises made by industry that CCS will be an effective tool for reducing carbon emissions have consistently failed to materialise.

A study of 263 government-supported CCS projects shows that of the 127 large-scale projects in this dataset, 78% had been cancelled or suspended for three years or more.[75]

The high project failure rate means that globally, existing CCS systems have the capacity to capture only 17% of the carbon emissions that announced CCS systems aimed to capture.[76]

The actual volume of carbon being captured by existing CCS systems may be even lower than this 17% figure, as several of them are capturing less carbon than intended.[77]

As such, a concern is that CCS systems for ATR or POx plants could capture less carbon than promised, or fail completely.

The SMR problem doesn't go away

SMR will remain the dominant technology used to produce hydrogen from fossil gas for many years to come. SMR plants already produce large volumes of hydrogen – around 53 million tonnes per year globally.[78] According to the Energy Transitions Commission, currently there are no ATR or POx plants that use CCS to produce fossil hydrogen,[79] and CCS systems can take six to 10 years to build.[80]

So even if energy companies planned a large expansion of ATR or POx plants, it would be many years before they overtook production from SMR plants, if at all.

The vast majority of existing SMR plants have no CCS systems in place. Together, they emit around 600 million tonnes of greenhouse gases every year[81] – more than the UK's and Italy's combined annual emissions from burning fossil fuels.[82] Shell's Albertan plant highlights the risk that applying CCS to try and decarbonise more of the world's SMR plants could result in only a fraction of these emissions being captured, which would be disastrous for the climate.

Therefore, the problems inherent in using CCS to reduce emissions from SMR plants, as outlined in this briefing, remain critical.

Viable alternatives exist

Carbon-free alternatives to fossil hydrogen are available. These include direct electrification from renewables, energy efficiency, renewable hydrogen, and phasing out refineries.

In the EU, energy scenario modelling shows that genuinely sustainable options such as these would be able to meet the Paris Agreement goals by 2040 without the need for any fossil hydrogen,[83] and they can be ramped up within a similar timeframe to proposed new fossil hydrogen capacity.[84]

A wind and solar energy development near Shanghai, China. Boosting renewables is a viable alternative to fossil hydrogen. *Yaorusheng/Getty Images*

Hydrogen policy for a safe climate

Fossil fuel companies see fossil hydrogen as a way of continuing to make profits from extracting and burning fossil gas, whilst greenwashing it at the same time. This is despite all the evidence that fossil gas needs a rapid and managed phaseout to avoid catastrophic global heating.

As this briefing illustrates, any push to increase fossil hydrogen production would be dangerous. Far from being a low carbon fuel, hydrogen from fossil gas generates unacceptably high climate-heating emissions, and is inextricably linked to fossil fuel industries that are having devastating impacts on communities of colour.

Global Witness is calling for an accelerated transition away from fossil gas and with it, an end to the industry's destructive impacts on local communities. To help achieve this goal:

Policymakers, including in Canada, the US and EU should not provide regulatory or financial support for new fossil hydrogen projects. Instead they should work to phase out existing fossil hydrogen plants, and promote carbon-free alternatives to fossil hydrogen.

Shell should be fully transparent about the emissions from its fossil hydrogen plant, stop claiming fossil hydrogen is 'low carbon' and end its lobbying – directly and through industry associations – for governments' support for fossil hydrogen.

The Canadian government should ensure that communities affected by fossil fuel development have access to justice and are able to hold companies accountable for human rights and environmental harms.

Annex: methodology and sources

The emissions totals presented here for Shell's Albertan hydrogen plant are estimates based on data published by Shell and the Pembina Institute, a leading Canadian energy think tank.

Table 1: On-site CO2 captured as a percentage of overall CO2e produced by Shell's Albertan hydrogen project

Figure	Calculation	Source
On-site CO2 captured	**33.8 gCO2/MJ H2** = 36.6 / 52 x 48 = on-site CO2 emitted (gCO2/MJ H2) / % of on-site CO2 emitted x % of on-site CO2 captured	On-site CO2 emitted (gCO2/MJ H2) – Pembina Institute, table 2, 'Plant operation', page 12: https://www.pembina.org/reports/carbon-intensity-of-blue-hydrogen-revised.pdf On-site CO2 captured (%) – Pembina Institute, table 2, 'Carbon capture rate', page 12: https://www.pembina.org/reports/carbon-intensity-of-blue-hydrogen-revised.pdf
Overall CO2e produced	**87.6 gCO2e/MJ H2** = 53.8 + 33.8 = overall CO2e emitted + CO2 captured (gCO2/MJ H2)	Overall CO2e emitted – Pembina Institute, table 2, 'GHG intensity total', page 12: https://www.pembina.org/reports/carbon-intensity-of-blue-hydrogen-revised.pdf
On-site CO2 captured as % of overall CO2e produced	**38.6%** = 33.8 / 87.6 x 100	

Table 2: CO2e emissions from Shell's Albertan hydrogen project expressed in tonnes, 2015-19

Figure	Calculation	Source
Overall CO2e produced	**12.469 Mt** = 4.813 / 38.6 x 100 = on-site CO2 captured (Mt) / on-site CO2 captured as % of overall CO2e produced x 100	On-site CO2 captured (Mt) – Shell, table 4-1, page 4-2: https://open.alberta.ca/dataset/f74375f3-3c73-4b9c-af2b-ef44e59b7890/resource/ff260985-e616-4d2e-92e0-9b91f5590136/download/energy-quest-annual-summary-alberta-department-of-energy-2019.pdf % of overall CO2e produced – GW calculation shown in Annex, table 1

On-site CO2 emitted	**5.210 Mt** = 36.6 / 87.6 x 12.469 = on-site CO2 emitted (gCO2/MJ H2) / overall CO2e produced (gCO2e/MJ H2) x overall CO2e produced (Mt)	On-site CO2 emitted (gCO2/MJ H2) – Pembina Institute, table 2, 'Plant operation', page 12: https://www.pembina.org/reports/carbon-intensity-of-blue-hydrogen-revised.pdf Overall CO2e produced (gCO2e/MJ H2) – GW calculation shown in Annex, table 1
CO2e emitted from the fossil gas supply chain	**1.580 Mt** = 11.1 / 87.6 x 12.469 = CO2e emitted from gas supply (gCO2e/MJ H2) / overall CO2e produced (gCO2e/MJ H2) x overall CO2e produced (Mt)	CO2e emitted from gas supply (gCO2/MJ H2) – Pembina Institute, table 2, 'Natural gas production and transport', page 12: https://www.pembina.org/reports/carbon-intensity-of-blue-hydrogen-revised.pdf
CO2e emitted from powering the CCS system	**0.868 Mt** = 6.1 / 87.6 x 12.469 = CO2e emitted from CCS system (gCO2e/MJ H2) / overall CO2e produced (gCO2e/MJ H2) x overall CO2e (Mt)	CO2e from CCS system (gCO2e/MJ H2) – Pembina Institute, table 2, 'Electricity', page 12: https://www.pembina.org/reports/carbon-intensity-of-blue-hydrogen-revised.pdf
Overall CO2e emitted	**7.656 Mt** = 12.469 - 4.813 = overall CO2e produced - CO2 captured	

*Due to rounding and the use of two different data sources, the overall CO2e emissions figure total shown in row 2 does not match exactly the sum of the broken-down emissions figures.

Table 3: Average annual emissions from Shell's Albertan hydrogen project compared with average annual emissions from UK petrol cars

Average annual GHG emissions from one UK petrol-powered car		
Figure	**Calculation**	**Source**
Average fuel consumption per UK petrol car per year	**163.9 gallons** = 5,900 / 36	Average miles travelled per UK petrol car per year (2020) – UK Department for Transport, reported by Nimblefins:

	= average miles travelled per UK petrol car per year / average miles per gallon for UK petrol cars	https://www.nimblefins.co.uk/cheap-car-insurance/average-car-mileage-uk# Average miles per gallon for UK petrol cars – Spritmonitor data, reported by Nimblefins: https://www.nimblefins.co.uk/cheap-car-insurance/average-mpg
CO_2 emitted per UK petrol car per year	**1,456.58 kg** = 163.9 x 8.887 = average petrol consumption per UK petrol car per year x CO_2 emissions per gallon of petrol	CO_2 emissions per gallon of petrol – US Environmental Protection Agency: https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references#gasoline
Total CO_2e emissions per UK petrol car per year, after factoring in GHG emissions other than CO_2	**1,466.85 kg** = 1,456.58 / 0.993 = CO_2 emitted per UK petrol car per year / ratio of CO_2 emissions to total CO_2e emissions	Ratio of CO_2 emissions to total GHG emissions – US Environmental Protection Agency: https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references#gasoline
Average annual GHG emissions from Shell's Albertan hydrogen plant		
On-site CO_2 emissions captured by Shell's CCS system over 4 full years' operation, 2016-19	**4.442 Mt**	Shell, table 4-1, page 4-2: https://open.alberta.ca/dataset/f74375f3-3c73-4b9c-af2b-ef44e59b7890/resource/ff260985-e616-4d2e-92e0-9b91f5590136/download/energy-quest-annual-summary-alberta-department-of-energy-2019.pdf
Overall CO_2e emitted, 2016-19	**7.066 Mt** = 4.442 / 38.6 x 61.4 = on-site CO_2 emissions captured (Mt) / % of overall CO_2e emissions captured x % of overall CO_2e emitted	% of overall CO_2e emissions captured and emitted – GW calculation shown in Annex, table 1
Average annual CO_2e emissions from Shell's plant	**1.767 Mt** = 7.066 / 4	

	= Overall CO2e emitted / years of full operation	
Number of UK petrol cars whose average annual CO2e emissions equal the average annual CO2e emissions from Shell's hydrogen plant	**1,213,000 cars** = 1,767,000 / 1.45658 = annual CO2e emissions from Shell's plant (t) / CO2e emitted per UK petrol car per year (t)	

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