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S3) Methods

S3.1) Goal and scope definition

As alluded to in the text, a table is provided outlining each of the technologies assessed as part of this study. Each technology plays a role in at least one assessed supply chain.

Table S3.1 – technologies within scope of the study.

Label	Technology name	Input	Output
T1	2nd generation fermentation	End-of-life biomass	Ethanol
T2	Biomass gasification	End-of-life biomass	Syngas
T3	Biomass pyrolysis	End-of-life biomass	Pyrolytic oil (long linear alkanes)
T4	Plastics pyrolysis	End-of-life plastics	Pyrolytic oil (long linear alkanes)
T5	Plastics gasification	End-of-life plastics	Syngas
T6	CO_2 electrochemical reduction to syngas	CO_2 (DAC)	Syngas
T7	CO_2 electrochemical reduction to syngas	CO_2 (PS)	Syngas
T8	Gas fermentation of CO_2/CO	CO_2 (DAC)	Ethanol
T9	Gas fermentation of CO_2/CO	CO_2 (PS)	Ethanol
T10	Methanol synthesis (WGS)	Syngas	Methanol
T11	Fischer-Tropsch synthesis	Syngas	Long linear alkanes
T12	Ethanol dehydration	Ethanol	Ethylene
T13	Methanol to olefins (MTO) process	Methanol	Ethylene
T14	Direct CO_2 ECR to ethylene	CO_2 (DAC)	Ethylene
T15	Direct CO_2 ECR to ethylene	CO_2 (PS)	Ethylene
T16	Dehydrogenation	Long linear alkanes	LAS-appropriate olefins
T17	Shell Higher Olefin Process (SHOP)	Ethylene	LAS-appropriate olefins
T18	Single pass conversion of syngas to ethanol	Syngas	Ethanol

S3.3) Indicator weighting values

Within the development of the screening tool, the opportunity for stakeholders to scale the sustainability scores for each individual indicator allows for more stakeholder-specific results. Through different companies, or even projects within the same company, the idea of specific priorities and trade-offs is ubiquitous. However, these are often difficult to quantify, especially when the scenarios presented are several years in the future. Nonetheless the quantification of these priorities is vital and common within the sustainability assessment sector.

Weighting method approaches considered

When looking to generate and apply weightings, several classifications of methods have been outlined in the literature. The selection of the most appropriate method is made on a case-by-case basis, but all options should be considered before a decision is made. These have been reviewed in the literature by Pizzol *et al.,*[1] with each method and appropriate commentary for the context of this application given below.

Approach 1: distance to target

Within this approach, the impacts are weighted based on their distance to their own specific targets, with impacts furthest from their respective targets holding the greatest weighting. Within this context, the distance to target approach is very difficult to understand, given that these weightings are with a 2030 timeframe in mind.

The best example of the distance to target approach is the Planetary Boundary approach,[2] where specific targets have been calculated for nine different environmental sustainability indicators. This approach is appropriate as it comments on the importance of each indicator in the *here-and-now* and highlights which anthropogenic pressures are causing the greatest strain on the planet at present.

To operate within the context of the sustainability screening tool, the predicted performance of each option will have to be estimated and then compared to the final performance targets for each indicator. Whilst this could be *more* (but still not entirely) straightforward for certain indicators, such as the economic-centric indicators, other indicators such as Arable Land Use do not necessarily hold explicit targets, meaning any weightings will be open to interpretation by the screening operator and not a broader influence.

Approach 2: panel weighting

The panel weighting approach allows for the quantification of the opinions of a selected group or groups of people. This is one of the most widely used approaches due to its effectiveness and simplicity. Panels are selected based on the application of the weightings, ranging from the general public to selected experts, with the final output a set of dimensionless weightings based on "sustainability importance".

A key example for illustration is the development of a single sustainability score within environmental life cycle assessments, undertaken and presented by the European Commission.[3] In this study, Sala looked to take the impact categories of an ISO 14044[4] conforming life cycle assessment and through two opinion surveys aimed at the general public and LCA experts. Through these surveys, the opinions of both groups were normalised and scaled into percentages, with the application of a Simple Additive Weighting in mind. For this application, Sala was looking to provide single sustainability scores with respect to overall environmental impact, allowing for straightforward communication of the overall impact of a process to a wider audience.

Within the context of the sustainability screening tool, the use of a panel weighting method allows for greater flexibility than that shown in approach 1 in terms of the scenarios it is applied to. With an appropriately defined future scenario (or set of scenarios) provided, the opinions of those selected are more easily obtainable than a difficult-to-predict target for parameters without quantifiable impacts, improving overall assessment coverage.

Approach 3: monetary-based weighting

This is where impacts are given an estimated economic value and scaled accordingly, based on which impact holds the greatest potential monetary detriment. This takes a similar approach to that of approach 2 but looks to provide a monetary value to each impact as opposed to the dimensionless sustainability importance.

Overall, the monetary-based system does not allow for easy coverage, with finding the potential for a monetary value for many indicators is very difficult, either through data or through panel opinion. Given the temporal variability of economic value, it is clear to see how a panel could find it hard to predict the intrinsic value of a qualitative impact, especially when considering scenarios years in the future. This is backed by Sala *et al.*[3] who commented that monetary-based methods are not recommended in general and should only be considered as an option in “endpoint scenarios”. This is where impacts are grouped based on specific categories and weighted together, an approach which is not suited to the sustainability screening tool given that several indicators provide insight beyond what can be categorised. ReCiPe structures the endpoint scenarios based on what each impact is directly damaging, either human health, ecosystem or resource availability.[5] To apply a similar approach for the sustainability screening tool would be difficult given that indicators stem from economic, environmental, and social concerns.

Approach 4: binary weighting

By far the most straightforward of the approaches, here the assessment practitioner selects the impacts of importance and gives an equal weight to each, with all other indicators disregarded and given a weight of zero. Whilst unpublished, according to Sala *et al.,*[3] it is applied in practice but is criticised by Sala for its lack of robustness and documentation.

For use within the sustainability screening, a binary weighting method would provide very little insight into the values of the stakeholder, especially given that all other methods still essentially provide a *score 0* option.

Final decision

Through the above review and commentary with respect to the sustainability screening, a panel weighting approach (approach 2) is the clear and obvious decision, given its flexibility and coverage with future scenarios in mind. It then duly follows that a final method within this category be developed as a means of obtaining appropriate weighting values.

Weighting methodology considerations

Analytical Hierarchy Process (AHP)

One of the most common methods with respect to sustainability assessment is the Analytical Hierarchy Process (AHP), where each individual indicator is pitted against one another, with a direct score of priority given for each pairing, with a total priority score for each indicator calculated once all pairings have been completed.[6] A long-standing and generally well-regarded method of generating priority values,[7] the main issue with AHP is the time it requires when applied to an assessment with many indicators, which increases exponentially with every indicator added. With ten indicators, 55 individual comparisons must be made. Given the fact that the sustainability screening tool being developed is to allow for flexibility in terms of indicator choice and quantity, a methodology more accommodating to more expansive assessments should be considered.

Simple Multi-Attribute Ranking Technique with Swings (SMARTS/SWING)

Developed significantly after AHP is the Simple Multi-Attribute Ranking Technique, another technique which employs a panel approach.[8] Here, practitioners are asked to highlight the indicator of lowest importance, which is then given a score (for example 10). The practitioners are then asked to identify the next-least important indicator, scoring it relative to the previous score given, until all importance scores are given. This method applies well to scenarios with more indicators, with only as many comparisons as there are indicators present, unlike with AHP. SMARTS was later drafted by Edwards & Barron[8] which looked to solve an issue found with SMART. With the original methodology starting at the least important and scaling upwards with no cap, the replicability between practitioners was seen as a serious issue, given that any magnitude of scores could be given to the indicators of higher importance. Given that, the idea of working in reverse, with a score of 100 being initially given to the indicator of highest importance, was drafted. This method ultimately provides a set of normalised indicator weights through a reasonable number of judgements for this application.

Weighting survey outline

Method

Alluding to the SMARTS/SWING methodology outlined above, the final weighting survey which was utilised as part of the study presented the panel with a hypothetical scenario in which they were developing a new, defossilised supply chain for the production of LAS-appropriate olefins in the scenario described within the text. This supply chain initially, with respect to each of the eleven indicators, performs at levels which could be seen as “as poor as reasonably practicable”. Naturally, this supply chain would not be considered for utilisation. The panel are then prompted to put “full research investment” into just one of the eleven indicator performances. This initial indicator is given an importance score of 100, as alluded to before. This indicator is then struck from the list, with the panel then tasked with selecting which indicator to put “full research investment” into, of the remaining ten indicators, assuming the first selected one is now fully optimised. Once selected, this is given an importance score less than or equal to 100. The process then continues until all indicators are assigned scores and struck from the list, with each importance score less than or equal to the previously assigned score. These importance scores are then represented as percentages of the total of all importance scores, which are then to be used as the weighting coefficients (a_{ij}).

Whilst there are obvious levels of uncertainty associated with this method, it is important to remember the application of these values. The goal of the screening tool is to get an early understanding of supply chain viabilities and screen-out any underperforming technologies or supply chains from further sustainability assessment. This methodology provides the insight necessary to tailor these results to best represent the stakeholder’s sustainability priorities, and compute potential trade-offs when making decisions. The simplicity of this method also then allows for updates and repeats of the survey as the likely future scenario changes. Any further complications or convolutions to this method could prove cumbersome and take away from the broad-yet-insightful nature intended of the methodology.

Panel selection

On the topic of panel selection, the literature provides a set of four guidelines to ensure a suitable panel is chosen:[9]

- The intended representativeness – who is the panel representing?

- Understanding the models and terms used – ensure the panel understand what is being asked of them.
- The expected return rate.
- Selective return. The shares of people who do not reply may not be equally distributed, leading to an unrepresentative panel of respondents.

Following the first bullet point outlined by Brunner,[9] the intended representativeness of this specific study is that of Unilever Home Care's decision-makers and advisors when it comes to new supply chain investment decisions. The ultimate goal of the screening is as a decision-making aid, meaning the results should tailor to the opinions of those who make these decisions. As a result, a panel of twelve individuals, each with a degree of influence over decision-making with respect to process sustainability and procurement, was selected. With an expert panel familiar to the field of sustainability assessment, the understanding of the model and terms was largely understood, with an opportunity to ask the assessment operator any questions about specific terms clearing up any issues surrounding the second bullet point.

With a return rate of 75% (9 from 12), significant, consistent, and insightful trends into where the wider company's sustainability values lie were drawn. As mentioned in the main text, exact values fall outside of what is deemed suitable for publication, however it can be said that material operating costs, overhead operating costs and feedstock renewability stood out as the most important, with the rest of the indicators sharing the rest relatively equally.

S3.4) Baseline definition

Here, the review of the literature surrounding the baseline performances of each indicator is developed further for clarity. This includes further discussion of the information presented in Table 1 of the main text, as well as key factors that are considered when assessing the performance of defossilised technologies against the baseline.

S3.4.2) Indicator baseline performances

Adding to the information given in the main text, further comments and sources have been reviewed below for the baseline performances of each indicator.

Indicator 1 - Capital expenditure

Within this study and in industry, the capital expenditure is defined as "The fixed, one-time expense which covers the land acquisition and complete plant purchasing or construction. The total cost needed to bring a process or supply chain to commercially operable status." Within the literature, UOP have themselves published a total erected cost at 30 million USD2016.[10] This covers the cost of land for a process of the Pacol process' footprint as well as the cost of all relevant plant shown in Figure 2 of the main text. Throughout history, the capital cost of the Pacol process has steadily fallen, given advancements in engineering design and catalyst improvements.[10] This is for a plant similar to the size of the CFW plant in Germany and can be taken as an appropriate figure for the baseline. As a means of comparison with other processes, this estimate covers the land, charge heater, Pacol reactor, separator and stripping process which follows the formation of the LAS-appropriate olefins. Bhasin *et al.*[11] provides further detail on the reactor, stating it to be an adiabatic, fixed-bed reactor, and takes place under "relatively mild temperature conditions of 400-500°C" and lack of necessity of catalyst regeneration plant due to the naturally long-life of the catalyst. Further information on the plant used is provided by Zahedi *et al.*,[12] who states the Pacol reactor internal dimensions are 0.75m in height and 0.4m in radius, with corresponding pressure and temperature data to that presented by Bhasin *et al.*[11] and Meyers.[10]

When assessing new technologies, the plant size and mass of material processed are both considered, due to the assumption that plant scale and capital expenditure are directly related to one another. The nature of the plant is also to be considered, with plant that processes toxic materials, operates under extreme conditions[13] or utilises other specialised reaction conditions, such as electrochemical processing, all being tied to greater capital expenditure. The total number of processing units for the process, including pre- and post-reaction cleaning/conditioning/processing and the land required by these extra units are also considered.

Indicator 2 – Material operating costs

In terms of materials, the only key materials required by the Pacol process are the paraffin feed and the resupplying of catalytic material once it has been spent. The alumina-supported platinum catalyst used today is a result of years of research and development, with a minute amount consumed per unit mass of product produced. UOP published cost estimates of the Pacol catalyst at 32.2 USD2004 (around 62 USD2021 according to the Chemical Engineering Plant Cost Indices (CEPCI)) per ton of olefin produced.[14] For the price of the n-paraffin feed, more recent data suggests a price of 480 USD2021 per ton, equating to 504 USD2021 per ton of olefin produced when accounting for losses.[10,15] Besides these materials, which total an estimated 566 USD2021 per ton of product, no other material costs are to be considered.

When assessing new defossilised technologies, the mass and relative market values are to be considered, as well as any known, outlying conditions which could cause price fluctuations/changes until the year of process deployment, 2030. The presence and reliance on expensive consumables are also considered, as well as the recovery rate of expensive catalyst recycling (if published), with top-up catalyst being considered a material operating cost.

Indicator 3 – Added sustainability value through process symbiosis

Deviating slightly from the *conventional* indicators listed previously, Indicator 3 looks to credit process sustainability due to a utilisation of a parallel process' by-products. This practice looks to lower the risk of feedstock/reactant supply risk, especially if the parallel process can be defined as integral to society (such as the cement, steel, and agricultural industries). This provides both the economic benefit of a low-risk supply chain and generally cheaper-to-produce materials, and the environmental benefit of by-product utilisation and greater supply chain circularity and the overall benefits of such practices.[16] This indicator was drafted following extensive communications between industrial and academic researchers involved within the project and provides vital information on a technology's adherence to the Clean Future targets.[17]

With regards to baseline performance, the current means of production through petrochemicals unlocks no sustainability value through symbiosis and therefore would not be a suitable success baseline value. Whilst difficult to quantify, it can be described within good reason that a success baseline description of a process being *largely* symbiotic with another process can be seen as successful, as an opportunity for consequential benefit is achieved. This therefore classes the indicator as a *green-flag* indicator in which these added sustainability benefits are rewarded.

When assessing new technologies, the scope of assessment is expanded to consider any symbiotic processes associated and their relative risk of supply. The sustainability benefit of selling defossilised by-products is also considered on a wider basis, with the sustainability benefits of introducing new defossilised materials into the broader technosphere providing added weighting to the scoring.

Indicator 4 – TRL

With the Clean Future initiative targets holding temporal limits, it is integral that assessed technologies are operational at a commercial scale and operating within their respective markets within said timeframe. With a supply chain defossilisation target timeframe of 2030, understanding the current TRL and forecast rate of development of the prospective technologies is paramount, as well as the consequential likelihood that said technologies will be market-ready by that year. Ultimately the process in question must be of TRL 9 for the market readiness level to also be of an appropriate order, and therefore the baseline score is 9. TRL 4 is renowned for being where most technologies either *sink or swim*, with most developmental failures occurring at this stage.[18] Technologies after this stage hold a much larger probability of commercialisation by the target year of 2030.

When assigning performance scores for this indicator, the current TRL is considered, as well as any evidence of technological maturity or commercial deployment of the technology, for example the pre-production announcement of the Sierra end-of-life material gasification plant by Fulcrum Bioenergy.[19]

Indicator 5 – Use of renewables in feedstocks

An environmental-centric indicator, the use of renewables in feedstocks, especially with regards to the net zero by 2039 target within the Clean Future initiative, is of high importance and paramount to the assessment. Under current carbon accounting rules, as previously outlined, the accounting of avoided emissions cannot be undertaken.[20] This therefore means that only "renewable" materials (based on biogenic carbon sources, such as DAC-sourced CCU and end-of-life biomass) can be counted as a "negative in-flow" of carbon dioxide (or avoided accountancy of the final degraded product).[21] As a result, the final global warming potential (GWP), and overall environmental performance of a given technology or feedstock could well be largely influenced by the renewability of the feedstock. As a means of baseline performance, for GWP levels to fall within the appropriate targets for the Clean Future initiative, the process must be at least *largely* dependent on renewable carbon. This regards a majority (50%<) stake in the input carbon for the direct use in the product LAS molecule stemming from renewable sources.

Here, the use of biogenic carbon within feedstocks is considered, due to the fact that under current carbon accounting rules, avoided emissions cannot be accounted for when reporting life cycle carbon emissions of products.[20]

Indicator 6 – Arable land use

When considering arable land use, the Pacol process holds very little threat to arable land. The process takes place with a relatively small footprint,[22] which holds a degree of flexibility as feedstocks are fed through pipelines, meaning the use of arable land can be avoided to a degree. However, a counterfactual assessment is still to be considered here, due to the arable land threat associated with the mining of platinum for catalysts. Mining of all metals, including platinum, has been long linked to arable land threats, with evidence published that platinum mining holds the potential to compromise up to 12% of arable land in platinum mining countries, such as South Africa.[23] A counterfactual basis can therefore be used, given that processes can fall either side of this baseline, despite the small quantity of catalyst used per ton of olefin produced.

Whilst there is no quantitative data published on the arable land use per unit mass of platinum, the threat described above can be used as a reliable baseline, using catalyst type and quantity used as a basis for assessment, as well as any other arable land use threats such as feedstock production.

When assigning scores, the reliance on arable land for feedstocks is considered, with economic allocation applied for biogenic, agricultural wastes within the examples which utilise end-of-life biomass. As previously mentioned, plant footprint is also considered for extreme scenarios, as well as the flexibility of plant location. Mining reliance is also considered, due to issues previously addressed by Baskaran.[23]

Indicator 7 – Ecosystem depletion

Concerning the supply chain's overall material balance with the local ecosystem, there is a considerable reliance again with respect to the mining of catalytic materials. These will be considered with respect to global ecosystem depletion due to the finite resource which is under relative threat according to the British Geological Survey Risk List.[24] Detailed designs of plant also list wastes produced as acidic waters, which must be neutralised before deposited into the ecosystem.[22] The use of fossil-based feedstocks also has a large part to play in ecosystem depletion, being cited as the largest contributor to the lifetime abiotic depletion potential (ADP) behind the construction of the plant and catalyst.[25] Whilst at a considerable level, the potential for defossilised routes to have greater reliance on abiotic catalysts and other materials justifies the counterfactual approach to the ecosystem depletion indicator.

Indicator 8 – Overhead operating costs

Both the Daaboul report[22] and the Meyers book chapter[14] can both be used to firstly understand what factors contribute to the overhead costs and secondly an estimated magnitude of overhead costs per tonne of olefins produced. With regards to overheads, both waste management techniques and specialist health and safety measures are taken as the primary factors defining overhead operating cost performance, with the need for extra labour specific to certain processes also considered. With regards to waste treatment, Daaboul[22] outlines (for the Pacol process) the need for spent alumina catalyst management, which whilst carried out off-site, does come with an added cost. Despite this, the previously mentioned diminutive consumption of catalyst implies that this cost is very low. With regards to specialist safety measures, the only listed measures concerning the Pacol process and subsequent stripping processes are those associated with fire extinguishing. This is to be expected given the nature of the components being handled, though beyond this no further specialist safety equipment is listed. With respect to labour, no such figures are defined by Daaboul,[22] instead Meyers quotes a figure from UOP directly, stating that "labor, maintenance, direct overhead and supervision" equates to 25.2 USD2004, or around 48 USD2021 per ton of olefin formed.[14] These figures imply no significant overhead costs are required labour-wise and such the overhead operating costs associated with the Pacol process can be taken as common within the industry with no major flags to consider.

Indicator 9 – Energy demand

With respect to energy demand, a full study, citing UOP sources, can be used due to its use within the wider literature and longstanding use within the ecoinvent database. Franke *et al.*[26] publishes a full life-cycle inventory for LAS-appropriate olefins, publishing both material and energy requirements for the production and processing of crude oil feedstocks to the final product. Summarised in the ecoinvent 3.8 submission for olefins, the energy requirement for 1 ton of olefins stands at 215 kWh of medium voltage electricity and 9.32 GJ of heat energy, in this case predominantly from natural gas sources. Overall, 57% of the total energy consumption is used for the production of olefins from paraffins, with the rest associated with the production and processing of feedstocks.[25,26] These figures are to be considered when comparing to defossilised processes, including both the production and processing of feedstocks.

Indicator 10 – Social impacts

With regards to social impacts, the lack of standardisation of social impact assessments means there is little information on social impacts specific to the Pacol process. As a result, a wider study on the social impacts of oil and gas extraction and processing was used, given the conventional nature of the Pacol process it can be assumed that these social impacts are relevant.

As mentioned in Section 3.2.10 of the main body of text, Unilever currently operate under a Responsible Partner Policy.[27] This ensures a standard of social, environmental, and ethical practices is met, and any process deemed to fall below these standards will not be considered. As a result, the social impacts indicator will only concern impacts which fall outside of this policy, allowing for relevant and decisive influence based on social impacts which the company would still commit to.

Even with the abundance of social impacts within the oil industry, very limited works within the literature provide a concise reporting of social impacts within the oil production and refining industry. Despite publication over two decades ago, *Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption*, published by O'Rourke and Connolly,[28] still maintains regular citation. As a result, it can be taken that many of the social impacts outlined can be taken as relevant in present day. With respect to exploration drilling and extraction, O'Rourke and Connolly[28] report the "range of acute and chronic health impacts" associated, due to exposure to harmful chemicals, as well as noise and vibration at the drilling sites. This extends to heightened asthma and other respiratory disease risks for those operating on site and nearby communities. Worldwide, communities are also reported to have been displaced by oil exploration and drilling, elevating the social impacts associated with the industry. When discussing the refinery of crude oil, it is apparent that poorer communities are largely those being affected by oil refining, with severe social impacts both "inside and outside the walls of refineries", particularly concerning the health of workers and communities in proximity.[28] However, the paper does not fully extend into control measures for these risks. This information can be taken from more recent sustainable sourcing reports from UK-based bank Barclays. As part of their public investment strategy in 2015, Barclays published a report series titled Environmental and Social Risk, which provides environmental and social sustainability risks and mitigation factors for a variety of industries. With regards to the Pacol process, both the "Oil & Gas" and "Mining & Metals" entries are of relevance, for the procurement of feedstocks and catalysts respectively.[29,30] The report shows serious social risk for the exploration, production drilling, separation, compression and dehydration of crude oils, as well as the refining and use phases. With regards to the exploration phase, Barclays[29] report very similar points to O'Rourke and Connolly[28] touching on the effects of "noise, vibration, dust creation, vehicular movement, emissions and air quality", particularly concerning nearby communities. The report also mentions issues surrounding cultural archaeological heritage and the spread of diseases to local and foreign populations as a result of oil exploration. It does however report on existing controls to these risks, with buffer zones around land clearing options, though this still leads to community displacement. Further risks and control measures, of an equivalent nature, are described for oil refinery processes.[30] There are also a wide and extensive array of impacts surrounding disasters within the oil industry. These will not however be used within the assessment baseline as the aim of the study is to assess processes under normal operating conditions. This would also skew the study further, given that the processes being assessed against the baseline are largely not commercial, and so a lack of research into the impacts of defossilised process failure would negatively affect the performance of the fossil routes.

Overall, the social impacts are objectively difficult to quantify due to lack of reporting. Within this study, the social impacts indicator is primarily used as an opportunity to red flag any social issues associated with defossilised processes, justifying its selection within the assessment. By comparing to the social impacts of the oil industry, the assessment of defossilised processes and supply chains is simplified as the processes can be assessed based on what is currently seen as acceptable.

Indicator 11 – Supply chain risk

With regards to the supply chain risk of the Pacol process, two factors which hold the greatest risk to the supply chain have been highlighted, being the availability of catalyst metals and the non-renewable and fossil nature of the carbon feedstock. With respect to the availability of catalytic materials, the platinum used in the Pacol process catalysts holds a “high risk” to supply, according to the British Geological Survey of 2015.[24] For reference, platinum holds a risk score of 7.6 out of a possible 10.[24] This list provides a “simple indication of the relative risk” of valuable Earth metals compared to one another, based on a variety of external supply factors. This study is a useful resource when comparing to defossilised processes which use metals, especially within catalysts, and illustrates the challenges facing the Pacol process operative maintenance.

When looking into the non-renewable nature of the Pacol process using fossil-sourced paraffins, many practical supply chain risks are present due to the general shift away from fossil sources within the chemical industry and beyond. These factors however are somewhat usurped by Unilever’s climate promises within the Clean Future and Carbon Rainbow initiatives.[17] Within the context of this assessment, the main risk to the operation of the Pacol process with fossil-based paraffins is Unilever’s commitment to the removal of all fossil feedstocks from their supply chains by 2030. However, even out of context of these initiatives, the financial threat of carbon taxation and pricing of product lifecycles provides extra potential supply chain threat, on top of the recently illustrated volatility of fossil carbon prices based on the global geopolitical climate. As a result, a clear baseline can be defined, showcasing a wide array of external threats against the supply chain, all of which are to be considered when performing comparative assessments.

S4) Results

S4.1) Technology assessment results

As mentioned in the text, full scoring tables, with individual justifications, are included.

Table S1 – technology assessment sheet for end-of-life biomass fermentation (T1).

Indicator	Scoring	Score	Result	Justification
Capital cost	Highly likely to exceed baseline	4	3	Expensive plant would be required for high pressure steam pretreatment. Need for yeast culture rearing plant. Many stages to production and pretreatment also result in expensive plant. Primary reaction at low temperature and pressure. Wastewater treatment plant also required for solids in wastewater effluent.[31]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Material operating costs	Highly likely to exceed baseline	4	4	Not currently economically viable and not forecast to change. Expensive enzymatic hydrolysis providing serious economic barriers. [31]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Added sustainability value through process symbiosis	Highly likely to exceed baseline	4	0	Fully symbiotic alongside primary biomass production. Potential for process to provide for other supply chains, with electricity production through lignin combustion driving turbine.
	Likely to be exceed baseline	3		
	Neither nor unlikely to	2		

	exceed baseline			
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
TRL	Highly unlikely to exceed baseline	4	2	Generally, TRL 6-8. Not enough to warrant score of 0. Lack of commercial potential means needed TRL progression is hampered but yet still possible.[32,33]
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Use of renewables in feedstocks	Highly unlikely to exceed baseline	4	0	End-of-life biomass fully renewable, no degradation CO_2 to be accounted for.[34,35] Overall carbon balance provided by Humbird *et al.*,[34] essentially all outputs utilise biogenic carbon input. Significant lifetime reductions to GWP certain. Burning of lignin provides electricity to process, also biogenic.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Arable land use	Highly likely to exceed baseline	4	4	Land use factored for production of end-of-life biomass to a degree, as predominant use of land is for primary biomass. Land use still to be factored however as no matter the means of allocation, land use increased drastically when compared to fossil means. Deforestation listed as issue. Plant difference negligible. Despite (through allocation) large amount of land use credited to primary biomass, secondary biomass share still significant when compared to fossil baseline. [36,37]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed	1		

	baseline			
	Highly unlikely to exceed baseline	0		
Ecosystem depletion	Highly likely to exceed baseline	4	3	End-of-life biomass used, meaning no food vs fuel debate. However gross deforested area worse for 2nd generation biomass when compared to first generation. Strain on forests and farmland essential, even for 2nd generation by-products. Potential for ecosystem depletion likely as utilisation of end-of-life biomass generally high within farming (animal beds/feed) and sourcing replacements without compromising ethanol supply chains is likely to cause depletion when compared to fossil means. [36,37]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Overhead operating costs	Highly likely to exceed baseline	4	2	Wastewater management required and is factored within scope of system. No major hazardous materials handled or processed. Trace furan-derived products handled by internal wastewater treatment acts as inhibitor for process and is a possible human carcinogen.[38] No plant operation outside of industry convention. High pressure steam also at higher temperatures than those handled by fossil means.[31] Though no handling of combustible atmospheres or materials when compared to fossil production of olefins (ethylene and natural gas in particular). Advantages and disadvantages, therefore 2 given.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Energy demand	Highly likely to exceed baseline	4	2	Again, main issue revolves around high pressure steam generation, though internally produced. Otherwise generally mild reaction conditions which do not require energy due to internal electricity generation from lignin cake consumption.[35] Process of harvesting holds energy use, though little allocated to end-of-life biomass due to relatively low value.[39]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to	0		

	exceed baseline			
Social impacts	Highly likely to exceed baseline	4	1	Biomass collection jobs and factory created, local pollutants of no detriment to local communities. Demand for biomass may cause shortage of end-of-life biomass for those who use it for fertilisers/soil enrichment. One issue could be the deviance for smallholders, with the high quantities of biomass required potentially favouring larger farming businesses, withdrawing potential business from smaller farm sites.[36] Overall likely beneficial to supply chain compared to baseline, hence score 1 given.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Supply chain risk	Highly likely to exceed baseline	4	1	Biomass ubiquitous, can be of a wide variety of sources, such as farming or sawmill wastes. Germany produces 70m tonnes lignocellulosic end of life biomass each year by 2030.[40] Germany has the best reported logistics of supply in Europe.[40] Fermentation cultures are maintained on site eliminating outside risk to supply chain. DAP also necessary for culture growth, though is one of the worlds most produced fertilisers, again can be assumed that supply chain risk is low as a result.[41,42] As previously mentioned, directly linked to farming/food production, a paramount system.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Table S2 – technology assessment sheet for the gasification of end-of-life biomass (T2).

Indicator	Scoring	Score	Result	Justification
Capital cost	Highly likely to exceed baseline	4	2	Relatively simple plant, no specialist equipment. 65kt/year scale around 6.8m USD2017.[43] Zeolite catalyst required if fluidised bed gasification undertaken[25] though included in given price. Biomass collection infrastructure required which is not present in most locations. Plant/storage required for biomass drying, to moisture levels of max 25%, which drives capital cost.[44]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed	1		

	baseline			
	Highly unlikely to exceed baseline	0		
Material operating costs	Highly likely to exceed baseline	4	3	Operation of collection infrastructure poses questions to operation affordability. Plant does not usually utilise specialist equipment/catalysts, though a zeolite catalyst can be used within fluidised bed gasification which will therefore need recycling though very little consumed if utilised.[25,45] One considerable issue is the separation plant materials (chemical and physical solvents) required for clean syngas which could lead to expensive production. The processing of dry biomass should lower the need for this substantially though this cannot necessarily be guaranteed.[44]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Added sustainability value through process symbiosis	Highly likely to exceed baseline	4	0	All by-products burned to supply energy for gasification. Excess heat provided (5MWth) though difficult to harness as in the form of heat. CHP not considered in scope though could be utilised at a high capital and operating expenditure.[45] All of which could provide to external supply chains. Production of 2nd generation biomass fully symbiotic with production of primary biomass.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
TRL	Highly unlikely to exceed baseline	4	1	6-7 for all end-of-life biomass. Proven at pilot scale and in 100kg/h demonstration plant, 10% of intended industrial scale. Almost at 8 but scale not at required demonstration scale to reach 8. TRL 9 expected by dates of targets. Biomass dependent, woody biomass TRL 9.[46,47]
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed	0		

	baseline			
Use of renewables in feedstocks	Highly unlikely to exceed baseline	4	0	All contributions from feedstock use, heat energy source etc from biogenic carbon.[25] Process energy fully fuelled by End-of-life biomass combustion.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Arable land use	Highly likely to exceed baseline	4	4	Land use factored for production of end-of-life biomass to a degree, as predominant use of land is for primary biomass. Land use still to be factored however as no matter the means of allocation, land use increased drastically when compared to fossil means. Deforestation listed as issue. Plant difference negligible. Despite (through allocation) large amount of land use credited to primary biomass, secondary biomass share still significant when compared to fossil baseline.[36,37]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Ecosystem depletion	Highly likely to exceed baseline	4	3	Gross deforested area worse for 2nd generation biomass when compared to first generation. Strain on forests and farmland essential, even for 2nd generation by-products. Potential for ecosystem depletion likely as utilisation of end-of-life biomass generally high within farming (animal beds/feed) and sourcing replacements without compromising ethanol supply chains is likely to cause depletion when compared to fossil means.[36,37]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Overhead	Highly likely to exceed	4	2	Tar to be processed. Not specialist. No listed toxic chemicals.[48] High temperature plant. Far

operating costs	baseline			higher than temperatures associated with fossil olefin production, but not at levels pushing industrial capacity/limits. Explosion potential of plant similar to that of natural gas handling plant due to similarity of products. Extra costs due to safety and waste management both not of major note, hence, score of 2 given.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Energy demand	Highly likely to exceed baseline	4	1	Overall, much lower due to self-sustaining heat. Potential for issues surrounding transport and storage of biological matter to add to energy demand. Gate-to-gate process almost entirely self-sustaining [25,43]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Social impacts	Highly likely to exceed baseline	4	1	Biomass collection jobs and factory created, some local pollutants (from char burning) but of no considerable detriment to local communities. Demand for biomass may cause shortage of end-of-life biomass for those who use it for fertilisers/soil enrichment.[44]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Supply chain risk	Highly likely to exceed baseline	4	0	Biomass ubiquitous, can be of a wide variety of sources, such as farming or sawmill wastes. Germany produces 70m tonnes lignocellulosic end of life biomass each year by 2030 [40] Germany has the best reported logistics of supply in Europe. [40] Little else in the way of feed
	Likely to be exceed	3		

	baseline			input means highly likely benefits to supply chain when compared to fossil alternate supply chains. As previously mentioned, directly linked to farming/food production, a paramount system. Zeolite catalyst of lower supply risk compared to platinum baseline.[24]
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Table S3 – technology assessment sheet for the pyrolysis of end-of-life biomass (T3).

Indicator	Scoring	Score	Result	Justification
Capital cost	Highly likely to exceed baseline	4	3	Modelled values vary a lot, but generally expensive due to expensive and specialist plant. Many process sections with wide variety of extreme conditions. 9 total key process stages. Upgrading plant also required to ensure quality product. Many stages of post-pyrolysis upgrading required, each to be done in different vessels/environments as well as catalyst separation plant.[49,50]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Material operating costs	Highly likely to exceed baseline	4	3	Mixed ruthenium and platinum catalysts necessary for upgrading of bio-oil, both with greater listed consumption than fossil supply chains.[50] 2nd generation biomass prices mixed reports but average around 42 2021€/t,[51] very few other materials required.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Added	Highly likely to exceed	4	0	Any heat produced is fully reintegrated into process. Pyrolysis section working at a heat

sustainability value through process symbiosis	baseline		0	deficit. Bio char combusted on site. No by-products of use.[49,50] Fully symbiotic alongside primary biomass production.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
TRL	Highly unlikely to exceed baseline	4	2	TRL 6+[52] for fast pyrolysis, the most common type. Generally moving towards commercial scale demonstrated in US and western Europe. Lower for catalytic pyrolysis.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Use of renewables in feedstocks	Highly unlikely to exceed baseline	4	0	End-of-life biomass fully renewable, no degradation CO_2 to be accounted for.[50] Heat produced from feedstock processing reintegrated into other processes in supply chain, meaning renewable heat generated too.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Arable land use	Highly likely to exceed baseline	4	4	Land use factored for production of end-of-life biomass to a degree, as predominant use of land is for primary biomass. Land use still to be factored however as no matter the means of allocation, land use increased drastically when compared to fossil means. Deforestation
	Likely to be exceed	3		

	baseline			listed as issue. Plant difference negligible. Despite (through allocation) large amount of land use credited to primary biomass, secondary biomass share still significant when compared to fossil baseline.[36,37]
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Ecosystem depletion	Highly likely to exceed baseline	4	3	Gross deforested area worse for 2nd generation biomass when compared to first generation. Strain on forests and farmland essential, even for 2nd generation by-products. Potential for ecosystem depletion likely as utilisation of end-of-life biomass generally high within farming (animal beds/feed) and sourcing replacements without compromising ethanol supply chains is likely to cause depletion when compared to fossil means.[36,37]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Overhead operating costs	Highly likely to exceed baseline	4	1	Tar to be processed. Not specialist. High temperature plant. Far higher than temperatures associated with fossil olefin production, but not at levels pushing industrial capacity/limits. No toxic material handling.[49,50,52] Lower required handling of explosive materials due to longer-chain hydrocarbons produced having generally lower volatility than natural gas and light alkane handling when processing fossil oil.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Energy demand	Highly likely to exceed baseline	4	3	High energy demand likely due to post-pyrolysis upgrading conditions. High temperatures required from external sources. High electrical demand too.[50] Pyrolysis alone pushes to limits of total cradle-to-gate energy demand for fossil carbon to n-paraffins according to Vienescu *et al.* [50] and Franke *et al.*.[26] Therefore, pyrolysis likely to be detrimental to the total supply chain energy demand for pyrolysis-based supply chain olefins manufacturing.
	Likely to be exceed baseline	3		
	Neither nor unlikely to	2		

	exceed baseline			
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Social impacts	Highly likely to exceed baseline	4	1	Biomass collection jobs and factory created, some local pollutants (from char burning) but of no considerable detriment to local communities. Demand for biomass may cause shortage of end-of-life biomass for those who use it for fertilisers/soil enrichment. Overall beneficial compared to fossil ethanol or primary biomass fermentation (food vs fuel).[53]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Supply chain risk	Highly likely to exceed baseline	4	1	End of life biomass ubiquitous. Germany produces 70m tonnes lignocellulosic end of life biomass each year by 2030.[40] Germany has the best reported logistics of supply in Europe.[40] Similar to gasification in a sense where input materials are minimal besides biomass. Shared issue with baseline regarding catalyst sourcing - ruthenium and platinum grouped as part of BGS study.[24] Overall supply chain risk still likely to outperform baseline due to feedstock sourcing, hence score of 1 given.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Table S4 – technology assessment sheet for the pyrolysis of end-of-life plastics (T4).

Indicator	Scoring	Score	Result	Justification
Capital cost	Highly likely to exceed baseline	4	2	Very mixed literature estimates, though generally lower than biomass pyrolysis plants which received a score of 3. Potentially due to post-production upgrading of pyrolysis oil required. Plant of similar nature and size to Pacol process, though higher temperatures required as
	Likely to be exceed	3		

	baseline			well as much larger plant for volume of material processed. [54–56]
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Material operating costs	Highly likely to exceed baseline	4	1	No expensive catalysts required in most cases. No need for hydrogen or other expensive reactants. [54–56] Material costs "very cheap".[54]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Added sustainability value through process symbiosis	Highly likely to exceed baseline	4	4	Char burned on site for heat and only produced in small quantities (1-1.3g/kg plastic).[57] Syngas also formed as a by-product (wt% ~2.2%) though relatively insignificant.[56,58] Overall by-products not likely to provide to external supply chains. Process symbiosis alongside production of non-recyclable plastics not of benefit due to unknown future of end-of-life plastics, therefore unsustainable and of no company sustainability benefit.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
TRL	Highly unlikely to exceed baseline	4	0	TRL 9 as of recently. One of the most viable new plastics recycling methods.[59] TRL 4+ for new augmented processes (plasma, microwave assisted, w/ in-line reforming).[60]
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to	2		

	exceed baseline			
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Use of renewables in feedstocks	Highly unlikely to exceed baseline	4	4	By-product char burning non-biogenic and therefore counted from a cradle-to-grave basis. Carbon emitted due to decomposition of product LAS also non-biogenic and to be accounted for.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Arable land use	Highly likely to exceed baseline	4	2	Plant land use negligible. No other land use to be associated other than plastic storage. Short plastic supply turnaround (4 weeks max) reduces storage size requirements.[61] Plant location relatively flexible, though advantageous to be close to existing plastic waste facilities.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Ecosystem depletion	Highly likely to exceed baseline	4	0	Removal of end-of-life plastics from ecosystem of great value. Plastic waste one of the greatest ecosystem threats (especially to marine life) - goal 14.1.1b of UNSDGs specifically aimed at reduction in plastics waste.[62] Credit to be due in finding alternate use for end-of-life plastics and essentially achieving a second use for the hydrocarbon molecules.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed	1		

	baseline			
	Highly unlikely to exceed baseline	0		
Overhead operating costs	Highly likely to exceed baseline	4	1	Very little in the way of waste produced, entire plastic feedstock is used in some way, with by-products collects as VACs or used to drive process (char burning).[57] High temperature plant. Far higher than temperatures associated with fossil olefin production, but not at levels pushing industrial capacity/limits. No toxic material handling.[49,50,52] Processing safeguards lower than fossil baseline due to lower presence of explosive environments.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Energy demand	Highly likely to exceed baseline	4	4	Higher energy (heat) requirement compared to fossil-based resource. Less char produced than biomass pyrolysis and therefore more heat required from other sources (1089MJ heat produced from char burning per ton pyrolysis oil, whereas 3260MJ required for pyrolysis process.[55] Crude oil production 1090MJ per ton, half that of plastics pyrolysis. Highest costs associated with energy demand,[54] therefore high overall energy demand assumed.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Social impacts	Highly likely to exceed baseline	4	0	Plastics collection and factory jobs created. Strong means for job retention too. Social improvements of end-of-life plastics disposal also of huge proportions worldwide. [62,63]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to	0		

	exceed baseline			
Supply chain risk	Highly likely to exceed baseline	4	1	Utilises non-recyclable plastic feedstocks which are currently collected and processed at landfills/waste incineration sites all over Western Europe. Supply chain risk still overall likely to be of benefit relative to baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Table S5 – technology assessment sheet for the gasification of end-of-life plastics (T5).

Indicator	Scoring	Score	Result	Justification
Capital cost	Highly likely to exceed baseline	4	2	Relatively simple plant, no specialist equipment. Typically, more expensive plant than biomass gasification but comparable to fossil processing baseline. Zeolite catalyst required if fluidised bed gasification undertaken.[25] To achieve a plant of "profitable" processing volumes[64] estimated prices of plant likely to increase to comparable levels to fossil-sourced syngas.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Material operating costs	Highly likely to exceed baseline	4	2	No expensive catalysts required in most cases. No need for hydrogen or other expensive reactants.[54–56] Material costs "very cheap".[54] One considerable issue is the separation of waste materials (chemical and physical solvents) required for clean syngas which could lead to expensive production.[44]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed	1		

	baseline			
	Highly unlikely to exceed baseline	0		
Added sustainability value through process symbiosis	Highly likely to exceed baseline	4	4	Nearly all by-products burned for process energy. No mention in the literature of excess heat in the same vein as biomass gasification, likely due to fewer by-products. Only by-product seemingly tar as methane is turned to syngas through WGS reaction and low-value condensates.[65] Process symbiosis alongside production of non-recyclable plastics not of benefit due to unknown future of end-of-life plastics, therefore unsustainable and of no company sustainability benefit.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
TRL	Highly unlikely to exceed baseline	4	0	TRL 9 for conventional gasification. Potential variance in form of plasma-aided gasification lower TRL but still has strong potential for future applications of hazardous end-of-life plastics.[66] First full-scale plant commissioned in December 2022.[19]
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Use of renewables in feedstocks	Highly unlikely to exceed baseline	4	4	By-product char burning non-biogenic and therefore counted from a cradle-to-grave basis. Carbon emitted due to decomposition of product LAS also non-biogenic and to be accounted for.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed	0		

	baseline			
Arable land use	Highly likely to exceed baseline	4	2	Plant land use negligible compared to fossil-based plant. No other land use to be associated other than plastic storage. Short plastic supply turnaround (4 weeks max) reduces storage size requirements.[61] Plant location relatively flexible, though advantageous to be close to existing plastic waste collection facilities.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Ecosystem depletion	Highly likely to exceed baseline	4	0	Removal of end-of-life plastics from ecosystem of great value. Plastic waste one of the greatest ecosystem threats (especially to marine life) - goal 14.1.1b of UNSDGs specifically aimed at reduction in plastics waste [62] Credit to be due in finding alternate use for end-of-life plastics and essentially achieving a second use for the hydrocarbon molecules.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Overhead operating costs	Highly likely to exceed baseline	4	2	Very little in the way of waste produced, entire plastic feedstock is used in some way, with by-products collects as VACs or used to drive process (char burning).[57] High temperature plant. Far higher than temperatures associated with fossil olefin production, but not at levels pushing industrial capacity/limits. No toxic material handling.[49,50,52,67]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Energy demand	Highly likely to exceed	4	1	Overall, much lower due to self-sustaining heat (autothermal).[68] Post-gasification plant

	baseline			simple cooling process to collect condensates and then storage.[65] Energy demand likely to of benefit compared to fossil baseline, though gas cleaning processes withhold score of 0.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Social impacts	Highly likely to exceed baseline	4	0	Plastics collection and factory jobs created. Strong means for job retention too. Social improvements of end-of-life plastics disposal also of huge proportions worldwide [62,63]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Supply chain risk	Highly likely to exceed baseline	4	1	Utilises non-recyclable plastic feedstocks which are currently collected and processed at landfills/waste incineration sites all over Western Europe. Supply risk in the form of future banning of single-use plastics possible, in turn curtailing supply chain. Supply chain risk still overall likely to be of benefit relative to baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Table S6 – technology assessment sheet for the electrochemical reduction of CO_2 to syngas, captured via direct air capture (DAC) (T6).

Indicator	Scoring	Score	Result	Justification

Capital cost	Highly likely to exceed baseline	4	4	EC cells very expensive, as well as CO/CO_2 separation plant. DAC plant also specialist. Poor economic performance, especially compared to fossil olefin production steps.[69] Capital costs provide majority of final expenses with regards to DAC.[70] Further expenses associated with ECR, with capital expenses associated with electrodes for a full CO_2 to diesel plant a "notable element".[71]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Material operating costs	Highly likely to exceed baseline	4	4	Highly dependent on H_2 to work - price of H_2 must decrease dramatically to achieve profitable process.[72] Not likely by 2030, despite large reductions predicted, unclear if such a reduction will occur. Material costs associated with electrode replacement large. This does not factor the operating costs associated with DAC which further pushes from affordable, currently operating at $500-600/tonne.[69,73]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Added sustainability value through process symbiosis	Highly likely to exceed baseline	4	4	No by-products formed - all unreacted materials put back into process. Carbon biogenic therefore no affiliation with source, no credit of parallel/by- products. [69,72,74]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
TRL	Highly unlikely to exceed baseline	4	3	TRL 4-6 [75]. DAC TRL 6.[76] Overall unlikely to reach baseline by 2030.

	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Use of renewables in feedstocks	Highly unlikely to exceed baseline	4	0	Feedstock fully renewable, though processing provides no benefit to other components of process.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Arable land use	Highly likely to exceed baseline	4	2	No threat to arable land as DAC location versatile.[70,77] ECR plant insignificant with respect to land use.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Ecosystem depletion	Highly likely to exceed baseline	4	3	Copper mining for electrodes holds large concerns for acidic outflows which hold a great threat to the local ecosystem, with terrestrial, freshwater, and marine ecotoxicity highlighted as issues that "could not be ignored".[25,78]
	Likely to be exceed baseline	3		

	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Overhead operating costs	Highly likely to exceed baseline	4	3	Spent electrodes to be handled and disposed of in specialist manner, lifespan of electrodes difficult to quantify in commercialised setting. Currently pointed out as a point for improvement by the literature.[79] Handling of acid electrolytes in ECR. Lower pressures and temperatures than coal gasification. Handling of syngas more explosive than atmospheres and gaseous mixtures within fossil routes. Early safety screens imply mixed results yet no major red flags.[80]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Energy demand	Highly likely to exceed baseline	4	4	Vast quantities of electrical energy required for production of hydrogen from water, as well as reduction of CO_2. Very poor performance.[74] Far greater energy requirements than baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Social impacts	Highly likely to exceed baseline	4	3	Key social issue will be upscaling of electricity networks in areas which cannot support "nontrivial" electrical demands. [81] Rest of social impacts easy to negate or beneficial (i.e., job creation). Electrical energy strain also for electrochemical reduction.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		

	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Supply chain risk	Highly likely to exceed baseline	4	4	Materials at no risk as DAC allows for CO_2 capture at any site. Risks arise in the form of the immense power requirement. If such demands aren't met, the production of syngas from CO_2/H_2O reduction is impossible and given the "nontrivial" electrical demand,[81] such demands would cause a huge strain on current power infrastructure in almost all countries, resulting in huge supply chain risks. Risks associated with planar metals for electrodes also negatively affecting supply chain risk[24,71]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Table S7 – technology assessment sheet for the electrochemical reduction of CO_2 to syngas, captured via point source capture (PS) (T7).

Indicator	Scoring	Score	Result	Justification
Capital cost	Highly likely to exceed baseline	4	4	EC cells very expensive, as well as CO/CO_2 separation plant. Capital cost of PS capture also poor, but not as poor as DAC, though still economic performance compared to fossil syngas.[69]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Material operating costs	Highly likely to exceed baseline	4	4	Highly dependent on H_2 to work - price of H_2 must decrease dramatically to achieve profitable process.[72] Not likely by 2030, despite large reductions predicted, unclear if such a reduction will occur. Material costs associated with electrode replacement large. This does not factor the operating costs associated with DAC which further pushes from affordable,
	Likely to be exceed baseline	3		

	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Added sustainability value through process symbiosis	Highly likely to exceed baseline	4	0	Process fully symbiotic with point source, providing steady stream of flue gas.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
TRL	Highly unlikely to exceed baseline	4	3	TRL 4-6.[75] Overall unlikely to reach baseline by 2030. PS TRL 9.[82]
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Use of renewables in feedstocks	Highly unlikely to exceed baseline	4	4	Non-renewable feedstock as CO_2 source is from non-renewable means. Eventual degradation of product not cancelled out due to non-biogenic carbon source.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		

	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Arable land use	Highly likely to exceed baseline	4	2	No threat to arable land. ECR plant not of a considerable footprint. Land use of PS capture again not a major threat. Only limitation is plant should ideally be located close to existing point source as transport infrastructure expensive or insufficient.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Ecosystem depletion	Highly likely to exceed baseline	4	3	Copper mining for electrodes holds large concerns for acidic outflows which hold a great threat to the local ecosystem, with terrestrial, freshwater, and marine ecotoxicity highlighted as issues that "cannot be ignored". [25,78]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Overhead operating costs	Highly likely to exceed baseline	4	3	Spent electrodes to be handled and disposed of in specialist manner, lifespan of electrodes difficult to quantify in commercialised setting. Currently pointed out as a point for improvement by the literature.[79] Safety factors have been included within designs yet not in detail.[83] Handling of combustible gases of equal safety concern compared to cracking of naphtha (ethylene present in both product streams). Presence of acidic electrolytes a cause for concern. Takes place at far lower temperatures and pressures compared to naphtha cracking. [83] Early safety screens imply mixed results yet no major red flags. [80]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		

	Highly unlikely to exceed baseline	0		
Energy demand	Highly likely to exceed baseline	4	4	Vast quantities of electrical energy required for production of hydrogen from water, as well as reduction of CO_2. Very poor performance.[74] Far greater energy requirements than baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Social impacts	Highly likely to exceed baseline	4	2	Electrical energy strain for electrochemical reduction. No other obvious negative impacts. Good potential for job creation and retention due to continuous operation of plant.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Supply chain risk	Highly likely to exceed baseline	4	4	Largely dependent on site connected to. Steel production broad in Western Europe[84] Risks arise in the form of the immense power requirement. If such demands aren't met, reaction is impossible and given the "nontrivial" electrical demands, [81] such demands would cause a huge strain on current power infrastructure in almost all countries, resulting in huge supply chain risks. Risks associated with planar metals for electrodes also negatively affecting supply chain risk.[24,71]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Table S8 – technology assessment sheet for the fermentation of CO_2 to ethanol via gas fermentation, captured via DAC (T8).

Indicator	Scoring	Score	Result	Justification
Capital cost	Highly likely to exceed baseline	4	4	EC cells very expensive and necessary for CO_2 to CO reduction. CO required for fermentation to ethanol. Poor economic performance compared to fossil equivalent.[69] Then specialist plant required for CO fermentation to ethanol though not under high temperature and pressures due to biological nature of process.[85] Initial growth of bacterial cell culture also included in capital cost as required before production also holds large potential for capital cost contributions.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Material operating costs	Highly likely to exceed baseline	4	4	Highly dependent on H_2 to work - price of H_2 must decrease dramatically to achieve profitable process.[72] Not likely by 2030, despite large reductions predicted, unclear if such a reduction will occur. IF H_2 is not in feed stream, formed by bacteria through WGS, but high concentrations of CO needed (greater stress on CO_2 reduction aspect). This does not factor the operating costs associated with DAC which further pushes from affordable, currently operating at $500-600/tonne.[69,73] Maintenance of bacterial cell culture also needed. Low temperature but consistent reaction conditions necessary.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Added sustainability value through process symbiosis	Highly likely to exceed baseline	4	4	No by-products formed - all unreacted materials put back into process. Carbon biogenic therefore no affiliation with source, no credit of parallel/by- products.[83]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		

	Highly unlikely to exceed baseline	0		
TRL	Highly unlikely to exceed baseline	4	3	ECR TRL 4-6.[75] Overall unlikely to reach baseline by 2030. DAC TRL 6[76]. CO to chemicals through CO fermentation TRL 8.[86]
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Use of renewables in feedstocks	Highly unlikely to exceed baseline	4	1	Fully renewable feedstocks. No extra sustainability benefit to process due to lack of renewable energy generation when processing feedstocks. GWP based on eventual degradation cancelled out by biogenic carbon source. [83]
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Arable land use	Highly likely to exceed baseline	4	2	No threat to arable land as DAC location versatile. [70,77] ECR and CO fermentation plant insignificant with respect to land use.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Ecosystem depletion	Highly likely to exceed baseline	4	3	Copper mining for electrodes holds large concerns for acidic outflows which hold a great threat to the local ecosystem, with terrestrial, freshwater, and marine ecotoxicity highlighted as issues that "cannot be ignored". [25,78]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Overhead operating costs	Highly likely to exceed baseline	4	3	Spent electrodes to be handled and disposed of in specialist manner, lifespan of electrodes difficult to quantify in commercialised setting. Currently pointed out as a point for improvement by the literature. [79] Little reported for lack of full-scale plant. Safety factors have been included within designs yet not in detail. [83] Handling of combustible gases of equal safety concern compared to cracking of naphtha (ethylene present in both product streams). Presence of acidic electrolytes a cause for concern. Takes place at far lower temperatures and pressures compared to naphtha cracking. [83] Early safety screens imply mixed results yet no major red flags.[80] Production of ethanol from reduced CO_2 and H_2 fermentation holds no unique reported safety risks.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Energy demand	Highly likely to exceed baseline	4	4	Vast quantities of electrical energy required for reduction of CO_2 and/or production of hydrogen.[85,87]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Social impacts	Highly likely to exceed baseline	4	3	Key social issue will be upscaling of electricity networks in areas which cannot support "nontrivial" electrical demands.[81] Rest of social impacts easy to negate or beneficial (i.e.,

	Likely to be exceed baseline	3		job creation). Electrical energy strain also for electrochemical reduction.
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Supply chain risk	Highly likely to exceed baseline	4	4	Materials at no risk as DAC allows for CO_2 capture at any site. Risks arise in the form of the immense power requirement. If such demands aren't met, the production of syngas from CO_2/H_2O reduction is impossible and given the "nontrivial" electrical demands,[81] such demands would cause a huge strain on current power infrastructure in almost all countries, resulting in huge supply chain risks. Risks associated with planar metals for electrodes also negatively affecting supply chain risk. [24,71] CO fermentation largely risk-free with cultures maintained on site. Risks associated with CO_2 reduction overarching.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Table S9 – technology assessment sheet for the fermentation of CO_2 to ethanol via gas fermentation, captured via PS (T9).

Indicator	Scoring	Score	Result	Justification
Capital cost	Highly likely to exceed baseline	4	4	EC cells very expensive, as well as CO/CO_2 separation plant. Capital cost of PS capture also poor, but not as poor as DAC, though still economic performance compared to fossil syngas.[69] Fermentation of CO_2 capital cost to ethanol furthers capital expenditure. Almost certain to exceed baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Material operating costs	Highly likely to exceed baseline	4	4	Highly dependent on H_2 to work - price of H_2 must decrease dramatically to achieve profitable process.[72] Not likely by 2030, despite large reductions predicted, unclear if such a reduction will occur. This does not factor the operating costs associated with PS capture which further pushes from affordable, currently operating at around $80-90/tonne.[88] If H_2 not fed in, CO required for WGS of H_2O and CO to H_2 and CO_2, requiring reduction of CO, an expensive to run energy intensive process. Maintenance of bacterial cell culture also needed. Low temperature but consistent reaction conditions necessary.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Added sustainability value through process symbiosis	Highly likely to exceed baseline	4	0	Process fully symbiotic with point source, providing steady stream of flue gas.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
TRL	Highly unlikely to exceed baseline	4	3	ECR TRL 4-6.[75] Overall unlikely to reach baseline by 2030. PS TRL 9.[82] CO to chemicals through CO fermentation TRL 8.[86]
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Use of renewables in	Highly unlikely to exceed baseline	4	4	Non-renewable feedstock as CO_2 source is from non-renewable means. Eventual degradation of product not cancelled out due to non-biogenic carbon source.

feedstocks	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Arable land use	Highly likely to exceed baseline	4	2	No threat to arable land. ECR plant not of a considerable footprint. Land use of PS capture again not a major threat. Only limitation is plant should ideally be located close to existing point source as transport infrastructure expensive or insufficient.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Ecosystem depletion	Highly likely to exceed baseline	4	3	Copper mining for electrodes holds large concerns for acidic outflows which hold a great threat to the local ecosystem, with terrestrial, freshwater, and marine ecotoxicity highlighted as issues that "cannot be ignored". [25,78]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Overhead operating costs	Highly likely to exceed baseline	4	3	Spent electrodes to be handled and disposed of in specialist manner, lifespan of electrodes difficult to quantify in commercialised setting. Currently pointed out as a point for improvement by the literature. [79] Little reported for lack of full-scale plant. Safety factors have been included within designs yet not in detail. [83] Handling of combustible gases of
	Likely to be exceed baseline	3		

	Neither nor unlikely to exceed baseline	2		equal safety concern compared to cracking of naphtha (ethylene present in both product streams). Presence of acidic electrolytes a cause for concern. Takes place at far lower temperatures and pressures compared to naphtha cracking.[83] Early safety screens imply mixed results yet no major red flags.[80] Production of ethanol from reduced CO_2 and H_2 fermentation holds no unique reported safety risks.
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Energy demand	Highly likely to exceed baseline	4	3	Vast quantities of electrical energy required for production of hydrogen from water, either through electrolysis of water or ECR of CO_2 to CO and WGS.[87] Energy associated with reduction of CO_2 to CO within stream also very high.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Social impacts	Highly likely to exceed baseline	4	2	Electrical energy strain for electrochemical reduction. No other obvious negative impacts. Good potential for job creation and retention due to continuous operation of plant.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Supply chain risk	Highly likely to exceed baseline	4	4	Largely dependent on site connected to. Steel production broad in Western Europe.[84] Risks arise in the form of the immense power requirement. If such demands aren't met, reaction is impossible and given the "nontrivial" electrical demands,[81] such demands would cause a huge strain on current power infrastructure in almost all countries, resulting in huge supply chain risks. Risks associated with planar metals for electrodes also negatively affecting supply chain risk.[24,71] CO fermentation largely risk-free with cultures maintained on site.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		

	Unlikely to exceed baseline	1		Risks associated with CO_2 reduction overarching.
	Highly unlikely to exceed baseline	0		

Table S10 – technology assessment sheet for the water-gas conversion of syngas to methanol (T10).

Indicator	Scoring	Score	Result	Justification
Capital cost	Highly likely to exceed baseline	4	2	Plant not of any major concern, industrially standard pumps, compressors, WGS reactors and ABS column.[89] Hence score of 2.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Material operating costs	Highly likely to exceed baseline	4	1	Cost associated with reactor conditions when using defossilised syngas slightly milder than when methane/steam used. Catalysts of long regeneration period (4 years) which diminishes detriment likelihood.[89]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Added sustainability value through process	Highly likely to exceed baseline	4	4	No by-products produced, any hydrogen remaining burned.[89] No symbiosis potential.
	Likely to be exceed baseline	3		

	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
TRL	Highly unlikely to exceed baseline	4	0	Methanol from syngas largest production process of methanol globally.[90]
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Use of renewables in feedstocks	Highly unlikely to exceed baseline	4	2	GWP overall comparable to fossil method when excluding reactant/product impacts (gate-to-gate). Largest potential for GWP reduction in form of feedstock decision. Reaction conditions mentioned before do however hold potential for GWP change too. Ecoinvent gate-to-gate backs this up.[25] No detriment to degradation as a result hence score of 2 given.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Arable land use	Highly likely to exceed baseline	4	2	No direct disruption to arable land use when compared to fossil olefins plant.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		

	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Ecosystem depletion	Highly likely to exceed baseline	4	2	Ecotoxicity low.[25] Very little cause for concern when considering inventories of defossilised and fossilised equivalents, hence 2 given. No notable difference to fossil olefins production.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Overhead operating costs	Highly likely to exceed baseline	4	2	As above, ecosystem depletion. Regeneration/disposal of spent catalysts the largest cause for concern but both processes comparable. Considerably lower temperatures, but higher pressures when handling defossilised syngas [25,89] but neither in both cases at levels of great concern within wider industry in terms of safeguarding expenses.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Energy demand	Highly likely to exceed baseline	4	1	Considerably lower temperature (~265C compared to 800C[25,89]) but pressure slightly higher (60 bar compared to 40 bar [25,89]). Lower overall energy demand with respect to defossilised process due to lack of need for heating in defossilised scenario.[25]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		

	Highly unlikely to exceed baseline	0		
Social impacts	Highly likely to exceed baseline	4	2	Social impacts equal with regards to both processes with respect to social employment benefits (based on plant scale and plant configurations). Electrical requirements greater for defossilised process not considered an issue due to the fact the process would not likely impact local electricity grids.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Supply chain risk	Highly likely to exceed baseline	4	2	Little-to-no supply chain risk associated with power or material requirements. Much like that of a non-feedstock handling petroleum-based olefins process, hence, score of 2 given.[25]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Table S11 – technology assessment sheet for the Fischer-Tropsch synthesis reaction (T11).

Indicator	Scoring	Score	Result	Justification
Capital cost	Highly likely to exceed baseline	4	1	Bubble column reactor for FT vessel, then phase separation to give long chain hydrocarbons[91] No distinct issues with regards to plant cost. FT Reactor capital cost and compressor/HEX share both small share of total defossilised supply chains.[92]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		

	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Material operating costs	Highly likely to exceed baseline	4	1	FT associated operating inventory very minimal, with only cobalt catalyst losses required. Exothermic reaction means activation energy self-sufficient,[92] as well as cobalt recycling rate high, lowering costs further. Lower energy requirements to fossil n-paraffins[26] largely means lower operating costs.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Added sustainability value through process symbiosis	Highly likely to exceed baseline	4	2	Excess/unconverted syngas burned for electricity generation, though CO_2 formed as a result. Excess heat also produced which is usually integrated within other adjacent processes.[91] Therefore, potential for sustainability improvements to other external processes through symbiosis.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
TRL	Highly unlikely to exceed baseline	4	0	TRL of FT production (gate-to-gate) 9.[75] TRL variances present upstream in supply chain in variances between syngas production. Not considered within this assessment sheet.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		

	Highly likely to exceed baseline	0		
Use of renewables in feedstocks	Highly unlikely to exceed baseline	4	2	Dependent on feedstock for syngas. FT has no impact on degradation of final product, hence score of 2 given.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Arable land use	Highly likely to exceed baseline	4	2	Plant land use negligible compared to fossil-based plant. No other land use to be associated. Standard plant of equal (no) threat to fossil counterpart, therefore, score 2 given.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Ecosystem depletion	Highly likely to exceed baseline	4	1	Very little threat for any form of ecotoxicity. Catalysts highly stable and very little lost through regeneration. Lower ecotoxicity compared to fossil naphtha production based on process emissions output. [25,91]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Overhead operating costs	Highly likely to exceed baseline	4	3	Cobalt catalyst stable but still within waste. Higher waste potential than fossil naphtha fractioning or formation through ethylene[26,91] though not of great detriment. Relatively high temperatures and pressures, but again not of any level which pushes beyond industrial "norms". Flammable atmospheres present but in equal vein to petroleum fraction forming, though syngas more volatile than crude oil, light ends of crude oil fractions also present on site of equal concern. Toxic risk of syngas also a concern.[93] Rapid heat removal required to avoid runaway.[94]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Energy demand	Highly likely to exceed baseline	4	0	Energy demand much lower due to exothermic nature of process providing activation energy and perpetual operation.[91] Energy required for start-up but not listed in the literature as a point of interest within the plant lifetime energy analysis.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Social impacts	Highly likely to exceed baseline	4	2	Social impacts equal with regards to both processes with respect to social employment benefits (based on plant scale and plant configurations).
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Supply chain risk	Highly likely to exceed baseline	4	2	Little-to-no supply chain risk associated with power or material requirements. Much like that of a non-feedstock handling petroleum-based olefins process, hence, score of 2 given.

	Likely to be exceed baseline	3		[25,26,91]
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Table S12 – technology assessment sheet for the dehydration of ethanol to ethylene (T12).

Indicator	Scoring	Score	Result	Justification
Capital cost	Highly likely to exceed baseline	4	3	Multiple reactors required compared to naphtha cracking, resulting in increased capital costs, with 4 reactor stages. Ethylene purification required for industry-standard purity. Fully listed in Mohsenzadeh *et al.*,[95] summarised in Reznichenko & Harlin.[96] ETE predicted to be 30-50% higher cost when compared to naphtha cracking.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Material operating costs	Highly likely to exceed baseline	4	2	Acid required for catalyst.[95,96] Main bottleneck is cost of feedstock[95], for entire supply chains, therefore gate-to-gate with respect to screening black box scope might well mean supply chain operation expenditure contributions of lower detriment. Hence 2 given.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Added sustainability value through process symbiosis	Highly likely to exceed baseline	4	4	Only direct by-product is H_2O which is vented. No other products or potential for symbiosis.[96]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
TRL	Highly unlikely to exceed baseline	4	1	TRL 8 - few instances in China and Brazil. Almost available in Europe, dependent on ethanol prices falling[95]
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Use of renewables in feedstocks	Highly unlikely to exceed baseline	4	2	Large amount of reported GWP reduction down to ethanol feedstock, therefore, score 2 given.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Arable land use	Highly likely to exceed baseline	4	2	Plant land use negligible compared to fossil-based plant. No other land use to be associated. Standard plant of equal (no) threat to fossil counterpart, therefore, score 2 given.

	Likely to be exceed baseline	3	2	
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Ecosystem depletion	Highly likely to exceed baseline	4	2	Ecotoxicity generally lower across the board. Gate-to-gate data difficult to source but understanding of overall lower ecotoxicity understood. Cradle-to-gate ecotoxicity with biomass feedstock is lower in almost all ecotoxicity/ecosystem depletion categories so can be inferred that ethanol dehydration better than naphtha cracking.[97] The threat of ecosystem depletion due to use of natural resource of no difference
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Overhead operating costs	Highly likely to exceed baseline	4	4	WWT demand much higher than naphtha cracking alternative, with acetic acid removal key part of WWT[98,99], then also disposal of solid, spent catalyst also necessary with 4.2kg of spent catalyst being disposed of per tonne of ethylene produced, 1.2kg of which is deemed to be hazardous.[99] Safety required in handling ethylene and ethanol, though both are always below spontaneous combustion temperatures.[98] Both within standard bounds of industry and of equivalent safety risk to naphtha cracking which also produces ethylene. Considering overall ethylene demand this is of major concern, hence score of 4 given.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Energy demand	Highly likely to exceed baseline	4	0	Considerably lower energy demand processes than cracking, as mentioned above in GWP section. Burning of coked catalyst exothermic and therefore can be used for heat energy integration. Overall a highly beneficial system with respect to input energy.[95,99]
	Likely to be exceed baseline	3		

	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Social impacts	Highly likely to exceed baseline	4	2	Social impacts generally the same as fossil with plant size, job opportunities of equal scale. Electrical requirements not of any issue, yet equal to fossil alternative. Overall, largely equal to fossil alternative.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Supply chain risk	Highly likely to exceed baseline	4	3	Supply chain risk associated with activated alumina catalyst, which provides a key part of the process.[95] Aluminium mining key in Australia with largest market share of activated alumina in China. Long distance supply chains across multiple nations also leads to increased risk.[24] All likely to be subjected to greater supply chain risks than the fossil alternative.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Table S13 – technology assessment sheet for the conversion of methanol to olefins (T13).

Indicator	Scoring	Score	Result	Justification
Capital cost	Highly likely to exceed	4	2	Extensive separation needed remove ethylene from unreacted methanol, ethane,

	baseline			propylene, and propane by-products. In total fossil supply chain from natural gas to ethanol via methanol, capital costs hold a low share of around 17% of total plant across lifetime. Much of plant shared with cracking in terms of reactor/separation configuration.[100,101]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Material operating costs	Highly likely to exceed baseline	4	3	Spent zeolite catalyst regenerated effectively so little lost during operation, however still some losses. Formation of catalyst energy intensive over a variety of stages which must be considered - implying expensive.[102] No reliance on H_2. Overall, 3 given due to catalyst affordability issues, with upscaling issues outlined in detail by Tian *et al.*[102]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Added sustainability value through process symbiosis	Highly likely to exceed baseline	4	3	Several high-value by-products formed alongside ethylene, including ethane, propylene, and propane, all in fairly high quantity. Ethylene qualifies for 26% of chemical production from MTO process (by mass) and therefore the other by-products are of exceeding value with little compromise on process efficiency[103] resulting in some symbiosis potential but overall, not of any substantial benefit to the company.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
TRL	Highly unlikely to exceed baseline	4	1	7 total commercial-scale MTO processes. 6 in China, one in Belgium, though all utilise coal-derived methanol.[104] TRL 8 in Europe for gate-to-gate process.[105]
	Unlikely to be exceed	3		

	baseline			
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Use of renewables in feedstocks	Highly unlikely to exceed baseline	4	2	Feedstock dependent, therefore, MTO has no effect on renewables or degradation of product.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Arable land use	Highly likely to exceed baseline	4	2	Plant land use negligible compared to fossil-based plant. No other land use to be associated. Standard plant of equal (no) threat to fossil counterpart, therefore, score 2 given.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Ecosystem depletion	Highly likely to exceed baseline	4	1	Ecotoxicity lower than fossil counterpart due to lower air, soil, and water emissions. Lower fossil-carbon reliance results in lower ecotoxicity.[97,106] MTO provides lower end of ecotoxicity contributions for fossil MTO, with only indirect contributions for acidification and eutrophication.[106] Depletion of natural resources of no difference to fossil alternative.
	Likely to be exceed baseline	3		
	Neither nor unlikely to	2		

	exceed baseline			
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Overhead operating costs	Highly likely to exceed baseline	4	3	Catalyst disposal when spent and produced in greater quantity than fossil alternative. Reforming processes almost always require specialist waste management methods, requiring strong acid leaching.[107] Little else but catalyst treating enough to warrant detrimental overall score when compared to cracking. Temperature and pressure lower than fossil alternative.[104] Key area of process safety comes in form of reactor/regenerator as leak of either can cause venting of explosive gas mixture,[108] though again an issue within fossil alternative. Strong acids required in catalyst reforming requires specialist handling.[107]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Energy demand	Highly likely to exceed baseline	4	2	Deemed similar to fossil baseline due to greater catalyst reforming need, but milder conditions. Hence score of 2 given.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Social impacts	Highly likely to exceed baseline	4	2	Social impacts generally the same as fossil with plant size, job opportunities of equal scale. Electrical requirements not of any issue, yet equal to fossil alternative. Overall, largely equal to fossil alternative.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed	1		

	baseline			
	Highly unlikely to exceed baseline	0		
Supply chain risk	Highly likely to exceed baseline	4	3	Main supply chain risk to SAPO-34 catalyst, composed of aluminium, tin and phosphorus oxides. Listed by the British Geological Survey[24] as low risk, though all of higher risk compared to baseline, hence score of 3 given.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Table S14 – technology assessment sheet for the direct reduction of CO_2 to ethylene, captured via DAC (T14).

Indicator	Scoring	Score	Result	Justification
Capital cost	Highly likely to exceed baseline	4	4	EC cells very expensive, as well as CO/CO_2 separation plant. DAC plant also specialist. Poor economic performance [69] reference to syngas though comparable plant used for ethylene production with extra plant required for separation of products/by-products, comparable plant showed by Khoo *et al.*[109]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Material operating costs	Highly likely to exceed baseline	4	4	Highly dependent on H_2 to work - price of H_2 must decrease dramatically to achieve profitable process.[72] Not likely by 2030, despite large reductions predicted, unclear if such a reduction will occur. This does not factor the operating costs associated with DAC which further pushes from affordable, currently operating at $500-600/tonne. [69,73] Low catalyst
	Likely to be exceed baseline	3		

	Neither nor unlikely to exceed baseline	2		stability listed as a "major drawback" implying regular requirement for expensive catalyst replacement. [83]
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Added sustainability value through process symbiosis	Highly likely to exceed baseline	4	3	Key by-products of CO (0.377kg/kg of ethylene), ethanol (0.241 kg/kg of ethylene), O2 gas (5.220kg/kg of ethylene) all produced as well as trace methane, acetic acid, formic acid, and 1-propanol.[109] These could be utilised in external supply chains as sustainable materials. Carbon biogenic therefore no affiliation with source, no credit of parallel/by- products or symbiosis.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
TRL	Highly unlikely to exceed baseline	4	4	TRL 2-4. Very new and a long way from true pilot scale. All data based on modelling.[110] TRL 2 reported by Somoza-Tornos *et al*. [79]
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Use of renewables in feedstocks	Highly unlikely to exceed baseline	4	0	CO_2 input biogenic carbon, therefore, degradation of final product negated. No further sustainability benefit to process as a result.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		

	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Arable land use	Highly likely to exceed baseline	4	2	No threat to arable land as DAC location versatile. [70,77] ECR plant insignificant with respect to land use. Very little difference when compared to naphtha cracking.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Ecosystem depletion	Highly likely to exceed baseline	4	3	Copper mining for electrodes holds large concerns for acidic outflows which hold a great threat to the local ecosystem, with terrestrial, freshwater, and marine ecotoxicity highlighted as issues that "cannot be ignored".[25,78]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Overhead operating costs	Highly likely to exceed baseline	4	4	Recycling/repurposing/disposal of spent copper electrodes relies on electrochemical or acidic processing. Neither of which are required during steam cracking of naphtha.[111] Little reported for lack of full-scale plant. Safety factors have been included within designs yet not in detail. [83] Handling of combustible gases of equal safety concern compared to cracking of naphtha (ethylene present in both product streams). Presence of acidic electrolytes a cause for concern. Takes place at far lower temperatures and pressures compared to naphtha cracking. [83] On top of this, overhead OPEX of DAC holds high percentage of overall cost due to management of energy intensive process.[112]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		

	Highly unlikely to exceed baseline	0		
Energy demand	Highly likely to exceed baseline	4	4	DAC predicted to fall over time but predicted energy demand still likely to be detrimental to total supply chain. Huge electricity requirement for reduction (138.8GJ/t ethylene produced)[109] which is bound by kinetics of reaction. Plus 7.2GJ/t CO_2 for DAC.[76] Such high energy demands likely to cause huge spike in GWP simply due to fossil-nature of most grids in Western Europe, hence 4 given.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Social impacts	Highly likely to exceed baseline	4	4	Key social issue will be upscaling of electricity networks in areas which cannot support "nontrivial" electrical demands [81] for syngas production, even greater for ethylene production. Rest of social impacts easy to negate or beneficial (i.e., job creation). Electrical energy strain also for electrochemical reduction.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Supply chain risk	Highly likely to exceed baseline	4	4	Materials at no risk as DAC allows for CO_2 capture at any site. Risks arise in the form of the immense power requirement. If such demands aren't met, the production of ethylene from CO_2 reduction is impossible, and given the "nontrivial" electrical demands, [81] such demands would cause a huge strain on current power infrastructure in almost all countries, resulting in huge supply chain risks. Risks associated with planar metals for electrodes also negatively affecting supply chain risk.[24,71]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Table S15 – technology assessment sheet for the direct reduction of CO_2 to ethylene, captured via PS (T15).

Indicator	Scoring	Score	Result	Justification
Capital cost	Highly likely to exceed baseline	4	4	EC cells very expensive, as well as CO/CO_2 separation plant. DAC plant also specialist. Poor economic performance [69] reference to syngas though comparable plant used for ethylene production with extra plant required for separation of products/by-products, comparable plant showed by Khoo *et al*.[109]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Material operating costs	Highly likely to exceed baseline	4	4	Highly dependent on H_2 to work - price of H_2 must decrease dramatically to achieve profitable process.[72] Not likely by 2030, despite large reductions predicted, unclear if such a reduction will occur. Low catalyst stability listed as a "major drawback" implying regular requirement for catalyst replacement. [83] This does not factor the operating costs associated with PS capture which further pushes from affordable, currently operating at around $80-90/tonne. [88]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Added sustainability value through process symbiosis	Highly likely to exceed baseline	4	0	Process fully symbiotic with point source, providing steady stream of flue gas. Some direct by-products also listed: CO (0.377kg/kg of ethylene), ethanol (0.241 kg/kg of ethylene), O2 gas (5.220kg/kg of ethylene) all produced as well as trace methane, acetic acid, formic acid, and 1-propanol[109] and all hold potential for symbiosis with other processes.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		

	Highly unlikely to exceed baseline	0		
TRL	Highly unlikely to exceed baseline	4	4	TRL 2-4. Very new and a long way from true pilot scale. All data based on modelling.[113] TRL 2 reported by Somoza-Tornos *et al.* [79]
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Use of renewables in feedstocks	Highly unlikely to exceed baseline	4	4	Non-renewable feedstock as CO_2 source is from non-renewable means. Eventual degradation of product not cancelled out due to non-biogenic carbon source.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Arable land use	Highly likely to exceed baseline	4	2	No threat to arable land. ECR plant not of a considerable footprint. Land use of PS capture again not a major threat. Only limitation is plant should ideally be located close to existing point source as transport infrastructure expensive or insufficient.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Ecosystem depletion	Highly likely to exceed baseline	4	3	Copper mining for electrodes holds large concerns for acidic outflows which hold a great threat to the local ecosystem, with terrestrial, freshwater, and marine ecotoxicity highlighted as issues that "cannot be ignored".[25,78]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Overhead operating costs	Highly likely to exceed baseline	4	3	Recycling/repurposing/disposal of spent copper electrodes relies on electrochemical or acidic processing. Neither of which are required during steam cracking of naphtha.[111] Little reported for lack of full-scale plant. Safety factors have been included within designs yet not in detail.[83] Handling of combustible gases of equal safety concern compared to cracking of naphtha (ethylene present in both product streams). Presence of acidic electrolytes a cause for concern. Takes place at far lower temperatures and pressures compared to naphtha cracking.[83]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Energy demand	Highly likely to exceed baseline	4	4	Huge electricity requirement for reduction (138.8GJ/t ethylene produced)[109] which is bound by kinetics of reaction. Plus 8.65GJ/t CO_2 for PS capture.[109] Such high energy demands likely to cause huge spike in GWP simply due to fossil-nature of most grids in Western Europe, hence 4 given, even with predicted renewable nature of future grid.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Social impacts	Highly likely to exceed baseline	4	4	Key social issue will be upscaling of electricity networks in areas which cannot support "nontrivial" electrical demands[81] for syngas production, even greater for ethylene

	Likely to be exceed baseline	3		production. Rest of social impacts easy to negate or beneficial (i.e., job creation). Electrical energy strain also for electrochemical reduction.
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Supply chain risk	Highly likely to exceed baseline	4	4	Largely dependent on site connected to. Steel production broad in Western Europe.[84] Risks arise in the form of the immense power requirement. If such demands aren't met, the production of syngas from CO_2/H_2O reduction is impossible and given the "nontrivial" electrical demands,[81] such demands would cause a huge strain on current power infrastructure in almost all countries, resulting in huge supply chain risks. Risks associated with planar metals for electrodes also negatively affecting supply chain risk.[24,71]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Table S16 – technology assessment sheet for dehydrogenation of alkanes (T16).

Indicator	Scoring	Score	Result	Justification
Capital cost	Highly likely to exceed baseline	4	2	Baseline
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Material operating costs	Highly likely to exceed baseline	4	2	Baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Added sustainability value through process symbiosis	Highly likely to exceed baseline	4	4	Few by-products produced[92] None of which adding sustainability value to supply chain.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
TRL	Highly unlikely to exceed baseline	4	0	TRL 9+ already, as commercially practiced.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Use of renewables in	Highly unlikely to exceed baseline	4	2	Processing of platform chemicals - process not impacting of renewability of supply chain, hence score of 2 given.

feedstocks	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Arable land use	Highly likely to exceed baseline	4	2	Baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Ecosystem depletion	Highly likely to exceed baseline	4	2	Baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Overhead operating costs	Highly likely to exceed baseline	4	2	Baseline.
	Likely to be exceed baseline	3		

	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Energy demand	Highly likely to exceed baseline	4	2	Baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Social impacts	Highly likely to exceed baseline	4	2	Baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Supply chain risk	Highly likely to exceed baseline	4	2	Baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		

	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Table S17 – technology assessment sheet for the Shell Higher Olefin Process (SHOP) (T17).

Indicator	Scoring	Score	Result	Justification
Capital cost	Highly likely to exceed baseline	4	2	Baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Material operating costs	Highly likely to exceed baseline	4	2	Baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Added sustainability value through process	Highly likely to exceed baseline	4	4	Few by-products produced.[26] None of which adding sustainability value to supply chain.
	Likely to be exceed baseline	3		

	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
TRL	Highly unlikely to exceed baseline	4	0	TRL 9+ already, as commercially practiced.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Use of renewables in feedstocks	Highly unlikely to exceed baseline	4	2	Processing of platform chemicals - process not impacting of renewability of supply chain, hence score of 2 given.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Arable land use	Highly likely to exceed baseline	4	2	Baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		

	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Ecosystem depletion	Highly likely to exceed baseline	4	2	Baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Overhead operating costs	Highly likely to exceed baseline	4	2	Baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Energy demand	Highly likely to exceed baseline	4	2	Baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		

	Highly unlikely to exceed baseline	0		
Social impacts	Highly likely to exceed baseline	4	2	Baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Supply chain risk	Highly likely to exceed baseline	4	2	Baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Table S18 – technology assessment sheet for the single-pass conversion of syngas to ethanol (T18).

Indicator	Scoring	Score	Result	Justification
Capital cost	Highly likely to exceed baseline	4	4	Main capital costs arise through mining and processing of rare and modified metals to initial catalyst required for process start up. Reactor and separation equipment simpler than multi-stage alternative.[114] Higher-than-baseline capital costs still likely however due to catalyst specialty and therefore regeneration plant.[114]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		

	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Material operating costs	Highly likely to exceed baseline	4	4	Little information on catalytic losses though some inevitable - specialised nature of catalyst metals mean material operating costs inevitably higher than baseline.[114]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Added sustainability value through process symbiosis	Highly likely to exceed baseline	4	2	Some by-products produced, such as methane, methanol, and other hydrocarbons. Selectivity largely in favour of ethanol however.[114] Separation and utilisation/selling of by-products possible, in turn providing other defossilised platform chemicals to other processes, boosting symbiosis.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
TRL	Highly unlikely to exceed baseline	4	4	TRL currently 4 as achieved at laboratory scale. Almost certainly not meeting baseline by 2030.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		

	Highly likely to exceed baseline	0		
Use of renewables in feedstocks	Highly unlikely to exceed baseline	4	2	Maintains renewability of input syngas - no overall effect on renewability, hence score of 2 given.
	Unlikely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Likely to exceed baseline	1		
	Highly likely to exceed baseline	0		
Arable land use	Highly likely to exceed baseline	4	2	Plant land use negligible - potential threat with respect to catalyst mining, though currently difficult to report without catalytic regeneration rate.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Ecosystem depletion	Highly likely to exceed baseline	4	3	Ecosystem depletion likely worse than baseline due to catalyst mining requirements - previously mentioned ecosystem issues with catalytic mining likely to cause detriment to local ecosystem. Updates likely required as process progresses through development stages, though currently likely to exceed baseline.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

Overhead operating costs	Highly likely to exceed baseline	4	2	No significant differences compared to baseline in terms of type of materials handled with respect to process safety. Reaction conditions and wastes also not reported as significant - again potential for detriment dependent on catalyst regeneration - worth reviewing in future.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Energy demand	Highly likely to exceed baseline	4	2	Little comment in initial stages on energy requirements, other than process is designed to address issues of "high energy consumption" for the current syngas to ethanol process.[114]
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Social impacts	Highly likely to exceed baseline	4	2	None to report, except mining issues, in line with previous assessments.
	Likely to be exceed baseline	3		
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		
Supply chain risk	Highly likely to exceed baseline	4	4	Catalytic materials of most detriment here. Platinum (7.6/10), zirconium (6.4/10) zinc (4.8/10) and aluminium all needed, ranging from high to low supply risk on BGS index.[24]

	Likely to be exceed baseline	3		Likely to be worse than baseline as a result, in line with other processes requiring similar metals.
	Neither nor unlikely to exceed baseline	2		
	Unlikely to exceed baseline	1		
	Highly unlikely to exceed baseline	0		

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