Life Cycle Assessment of DWR treatments on waterproof, windproof and breathable jacket.

Summary report

Study according to DIN EN ISO 14040.

W. L. Gore & Associates' Fabrics division is committed to using sound science and continuously improving the environmental impact of our products. As a global leader in innovation, our research and development efforts are continuous. As such, we continue to make significant investments to explore alternative solutions that may have an even better environmental profile while still providing durable comfort at or above the performance level of today's best Durable Water Repellent (DWR) treatments. To support this commitment the division carried out a cradle-to-grave LCA (Life Cycle Assessment) of different DWR technologies used in consumer functional outerwear.

A Life Cycle Assessment is a standardised technique used to evaluate all the environmental impacts linked to the different steps of the product life cycle, from raw material extraction, processing and production right through to the use phase and disposal.

This report is an update and complement to the previous LCA work on functional outerwear carried out by Gore Fabrics since 1992. More specifically the series of LCA's published by Gore Fabrics in 2013 and 2014; where Gore's sustainability team measured the environmental impact of a typical GORE-TEX® outdoor jacket; and of a typical pair of GORE-TEX® lined hiking boots.

The goal of the third LCA in this series was to create data to guide future choices of DWR technologies. For this, Gore assessed the environmental impacts and toxicity potential of three different DWR technologies that are currently available to Gore for its functional textiles; and then compared their environmental impacts and toxicity potential.

The report passed a third party critical review, which was provided by Rita Schenk, Ph.D. LCACP, head of the Institute for Environmental Research. The Institute for Environmental Research is an independent not for profit organisation based in Vashon Island, Washington, USA.

1 GOAL & SCOPE

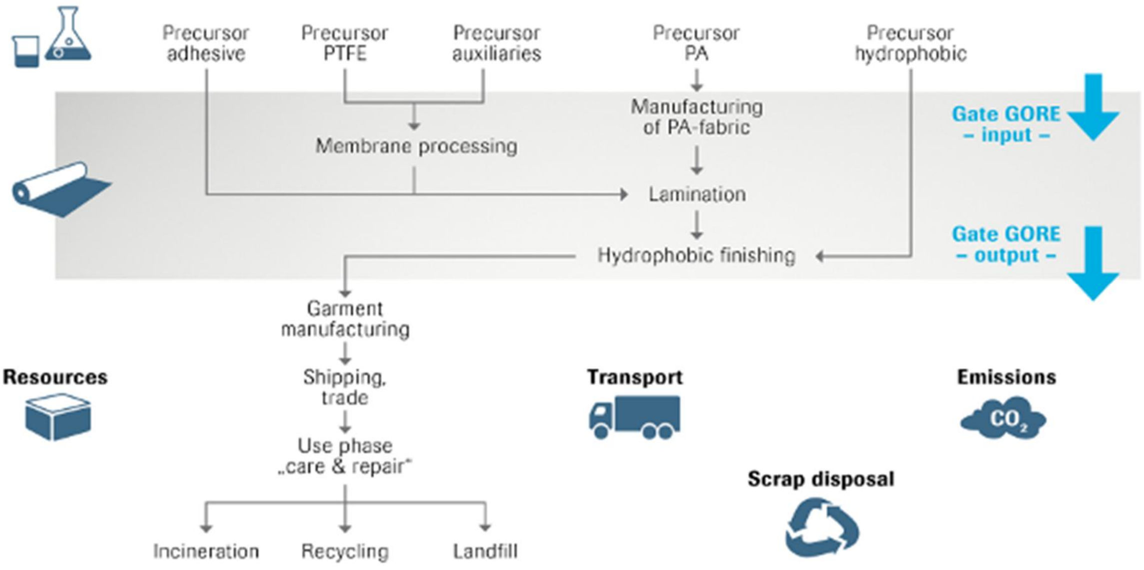
1.1 Goal

The LCA's goals were:

- Assess the environmental impacts and toxicity potential of different DWR technologies for GORE-TEX® branded apparel
- Compare the environmental impacts and toxicity potential of different DWR technologies that are used on outdoor garment. This includes the use phase (wash & care) necessary to maintain the minimum performance criteria

1.2 Scope

The study was conducted in full compliance with the DIN EN ISO 14040:2006 and DIN EN ISO 14044:2006 standards. This means that the evaluation was not limited to the functional fabric produced by Gore. Instead, the scope included the assessment of the finished product over the whole life cycle, from "cradle to grave." This includes the upstream processes, such as making adhesive, PTFE, auxiliaries, polyamide and the hydrophobic treatment. These materials enter the Gore manufacturing plants, where the ePTFE-membrane processing takes place. In the next step, hydrophobic treatment known as DWR is applied and textiles are laminated to Gore membranes, before they leave the Gore factory. After the garment has been manufactured in Indonesia, it is packed and distributed via a European distribution hub to European consumers. Transport of the finished garment is assumed to take place by overland or ship transport (90%) and air transport (10%). After a 5 year use phase the garment is assumed to end up in a landfill in the EU.



Unless otherwise stated, Gore's own processes and its fluoropolymer precursor chains were calculated using primary data. Whilst for downstream processes, the LCA had to rely on commercially available databases, e.g. the Ecoinvent database, despite the support of suppliers and customers. Bluesign technologies ag also provided an aggregated dataset on textile manufacturing relevant to the Gore supply chains. For the non-fluorinated DWR treatments in this study, for which only limited information on their chemical composition was available, Gore used proxy materials with a similar composition and characteristics.

Gore is aware of the incompleteness of the characterization factors for these substances in currently available LCA tools. To counterbalance this, Gore decided to use not only a standard LCA methodology (ReCiPe) but also the leading comparative model supported by UNEP for evaluating toxicity: the USEtox™ model. Using this model enabled Gore to derive results with a similar level of uncertainty making the comparison and analysis for decision-making meaningful.

2 PRODUCT SYSTEM

Gore chose to model a waterproof and breathable jacket that would represent a large volume of products.

Features:

- seam sealed
- Zip-in compatible
- Fully adjustable, removable drop hood with lower face protection
- Collar lining
- Centre-front zip and Velcro® closure
- Pit-zips
- Biceps pocket; internal chest zip pocket
- Average weight: 900g
- Length from centre back: 30 in.
- Fabric: 94 g/m² and 134 g/m² nylon
- GORE-TEX® Performance Shell two layer fabric

The jacket is assumed to last five years.

3 FUNCTIONAL UNIT

A functional unit is a measure of the service delivered by the product. The interest of the functional unit approach is to have a reference unit that enables the comparison between two products that provide an equivalent service, in the case of this field trial and study: outdoor backpacking.

For this study, the functional unit was defined as “The use of a single windproof, waterproof and breathable outdoor garment during five years with the DWR meeting a minimum performance requirement”; where DWR performance is described by the following parameters and measured using Gore’s lab test methods:

- Lab test beading rating (see Appendix 1)
- Normalized % water weight gain
- Lab test oil rating

The garment is assumed to be washed & tumble-dried (home laundry) and re-impregnated (with a water repellency treatment) to prevent wet-out of the outer textile layer, twice a year for the baseline scenario.

4 CHOICE OF DWR TECHNOLOGIES

For this study Gore evaluated the influence of three different DWR technologies on a windproof, waterproof and breathable "all-rounder" mountain sports jacket in terms of performance, and also in terms of environmental impact. These three technologies were:

- A long-chain fluorinated polymer treatment, known as "C8 based" DWR and referred to in this study as "C8". This fluorotelomer treatment is characterized by functional side chains that contain eight fully fluorinated carbon atoms. Gore phased out this specific technology from all its raw materials for its entire range of fabrics products at the end of 2013.
- The current Gore short-chain polymer DWR, referred to here as "Gore" or "Gore short-chain"
- A Non-Fluorinated DWR (hydrocarbon based), referred to here as "Non-F"

The choice of these three DWR technologies was based on several needs:

- To have a "baseline" with which to compare, in terms of performance & durability and in terms of environmental impact.
- To compare technologies currently used in the market, by competitors and customers.
- To avoid the bias in the findings that could occur from focusing only on the technology currently used by Gore, namely fluorinated short-chain polymer DWR.

The choice of which non-fluorinated DWR technology to use, for comparison with Fluorinated DWR technologies, was guided by Gore's lab test methods. First Gore screened non-fluorinated DWRs that were commercially available to Gore, in 2013/14, using lab tests (water weight gain, water beading [initial, after simulated use and after thermal regeneration], and oil rating). Gore short chain polymer DWR and historical C8 were added for comparison. The highest performing non-fluorinated material was then selected and included in an evaluation that consisted in a series of "split-jacket" blind backpacking field trials. The jackets were treated with Gore's current short-chain polymer DWR and the non-fluorinated DWR identified above. Jackets used the same laminate lot to minimize variability.

5 ASSUMPTIONS

Data on the actual product lifetime and the consumer care of outerwear is not readily available. An analysis of complaints received by the GORE consumer hotline indicates an average, across the product range of GORE-TEX® branded apparel products, of five and a half years up to the time of the first complaint. The five years lifetime assumed for this study is therefore a conservative assumption for GORE-TEX® consumer garments.

This is also true for the washing frequency and the fact that the jacket is assumed to be washed separately. A conservative approach was also taken by assuming that the consumer applies a DWR retreatment after every wash. A field trial comparing the current Gore short-chain polymer DWR with the best available[1] non-fluorinated DWR, under real life conditions - including highly aerobic activities as well as hiking - identified the need for the consumer to wash and apply re-impregnation more frequently than for Gore's fluorinated treatment, to maintain the water repellency level specified in the functional unit. This implied that the actual usage scenarios used in the model should differ between the fluorinated and non-fluorinated DWR treatments to represent these findings. For fluorinated DWR treatments the usage scenario would be two wash & care cycles, including reimpregnation per year of use. Whereas, based on the results of the field trial (see appendix), the usage scenario (in an attempt to maintain functional performance) for non-fluorinated treatments would be 26 wash & care cycles, including reimpregnation, per year of use.

However, Gore is very aware that in a "real life" situation that scenario is unlikely to be accepted by outdoor sports enthusiasts and general consumers, and will more likely lead to continued customer disappointment and/or early garment replacement. This would eventually lead to even higher environmental impacts, as supported by a previous LCA study that highlighted the strong negative influence of a shortened jacket lifetime on the overall impact of the functional unit.

[1] Based on screening of available to Gore commercial non-Fluorinated water repellent coatings and utilizing internal performance metrics (See Appendix)

6 RESULTS

ReCiPe Midpoint Results	Acronym	Unit	C8 based	Short - chain	Non-F
Climate change	GWP100	kg CO_2-eq	57.14	55.1	153.64
Ozone depletion	ODPinf	kg CFC-11-eq	9.27 e-5	4.02e-5	4.38e-5
Terrestrial ecotoxicity	TETPinf	kg 1,4-DCB	0.0039	0.0037	0.0124
Terrestrial acidification	TAP100	kg SO_2-eq	0.21	0.21	0.40
Freshwater ecotoxicity	FETPinf	kg 1,4-DCB	0.37	0.36	2.01
Freshwater eutrophication	FEP	kg P-eq	0.020	0.020	0.135
Marine eutrophication	MEP	kg N-eq	0.09	0.09	0.23
Marine ecotoxicity	METPinf	kg 1,4-DCB	0.35	0.34	1.95
Human toxicity	HTPinf	kg 1,4-DCB-eq	15.64	15.5	94.49
Photochemical oxidant formation	POFP	kg NMVOC	0.13	0.13	0.27
Particular matter formation	PMFP	kg PM10-eq	0.067	0.067	0.140
Ionising radiation	IRP_HE	kg U235-eq	7.68	7.63	50.19
Metal depletion	MDP	kg Fe-eq	0.83	0.82	5.06
Water depletion	WDP	m^3	1.02	1.02	9.86
Fossil depletion	FDP	kg oil-eq	14.78	14.5	43.61
Agricultural land occupation	ALOP	m^2a	0.669	0.667	2.383
Urban land occupation	ULOP	m^2a	0.34	0.32	0.80
Natural land transformation	NLTP	m^2	0.006	0.006	0.015
USEtox results					
Ecotoxicity, total		CTU	21.0	20.8	105.5
Human toxicity, total		CTU	4.66e-6	4.62e-6	2.30e-5
Human toxicity, carcinogenic		CTU	2.42e-6	2.4e-6	1.37e-5
Human toxicity, non-carcinogenic		CTU	2.24e-6	2.22e-6	9.29e-6

7 CONCLUSIONS

Based on these results, the main findings of this study can be summarised as follows:

- All DWR treatments available today come with some toxicity potential. However, in a cradle to grave perspective, the actual impact of the DWR ingredients are not the main drivers for the toxicity potential indicators.
- The results overwhelmingly point to the use phase as the most significant contributor to the jacket's toxicity potential: Using a non-fluorinated DWR treatment is the single biggest driver for the toxicity potential impact indicators. Confirming that durability of the jacket in general and of the DWR in this case are key factors to reduce the environmental footprint of outdoor apparel products.
- The conclusions of this study do not support the assumption that currently available alternative DWR treatments offer a better environmental and health profile when compared to Gore's fluorocarbon based DWR. Namely due to their inability to meet current performance expectations. Indeed, the field study data used for

this LCA indicates that among the tested and currently available DWR treatments, Gore's DWR formula is more durable. Requiring fewer wash & care cycles and therefore having a better environmental profile for the assessed end-uses.

- Conversely, the conclusions of this study do suggest that substituting a short-chain fluorinated treatment with a non-fluorinated DWR treatment, whose performance does not provide sufficiently long lasting water repellency in field use conditions, will result in increased adverse environmental and health effects
- The jacket’s production (Gore processes including PTFE, Textile supply chain, Accessories and manufacturing) represent together more than 53% of the jacket’s Global Warming Potential

7.1 Global warming potential (GWP) & Water depletion (WDP)

In the initial LCA published in 2013, the LCIA values for the indicators that Gore chose to focus on after normalisation: Climate change (GWP100) and Water Depletion (WDP), were 72.7 kg CO2-eq. and 2.08 m³ of water. The updated model provided Gore - aside of the inclusion of short chain DWR treatments - with new figures where GWP was 55.1 kg CO2-eq. and WDP was 1.02 m³ of water. These changes, relative to the initial LCA published in 2013 do not represent a technology change in the jacket’s manufacturing; but are representative of the different composition of the EU energy mix. They also take into account the fact that EU washing machines and tumble dryers tend to be more resource efficient.

The updated model also provided Gore with figures for a non-fluorinated DWR treatment; GWP was 153.64 kg CO_2-eq. and WDP was 9.86 m³ of water. The major factor influencing these results was the difference in the durability of the water repellency treatments. A field trial comparing the current Gore short-chain polymer DWR with the best available[2] non-fluorinated DWR, under real life conditions - including highly aerobic activities as well as hiking - identified the need for the consumer to wash and apply re-impregnation more frequently than for Gore’s fluorinated treatment, in an attempt to maintain the water repellency level specified in the functional unit. Confirming that durability is a key influencer in reducing the environmental footprint of outdoor apparel products.

[2] Based on screening of available to Gore commercial non-F water repellent coatings and utilizing internal performance metrics (See Appendix)

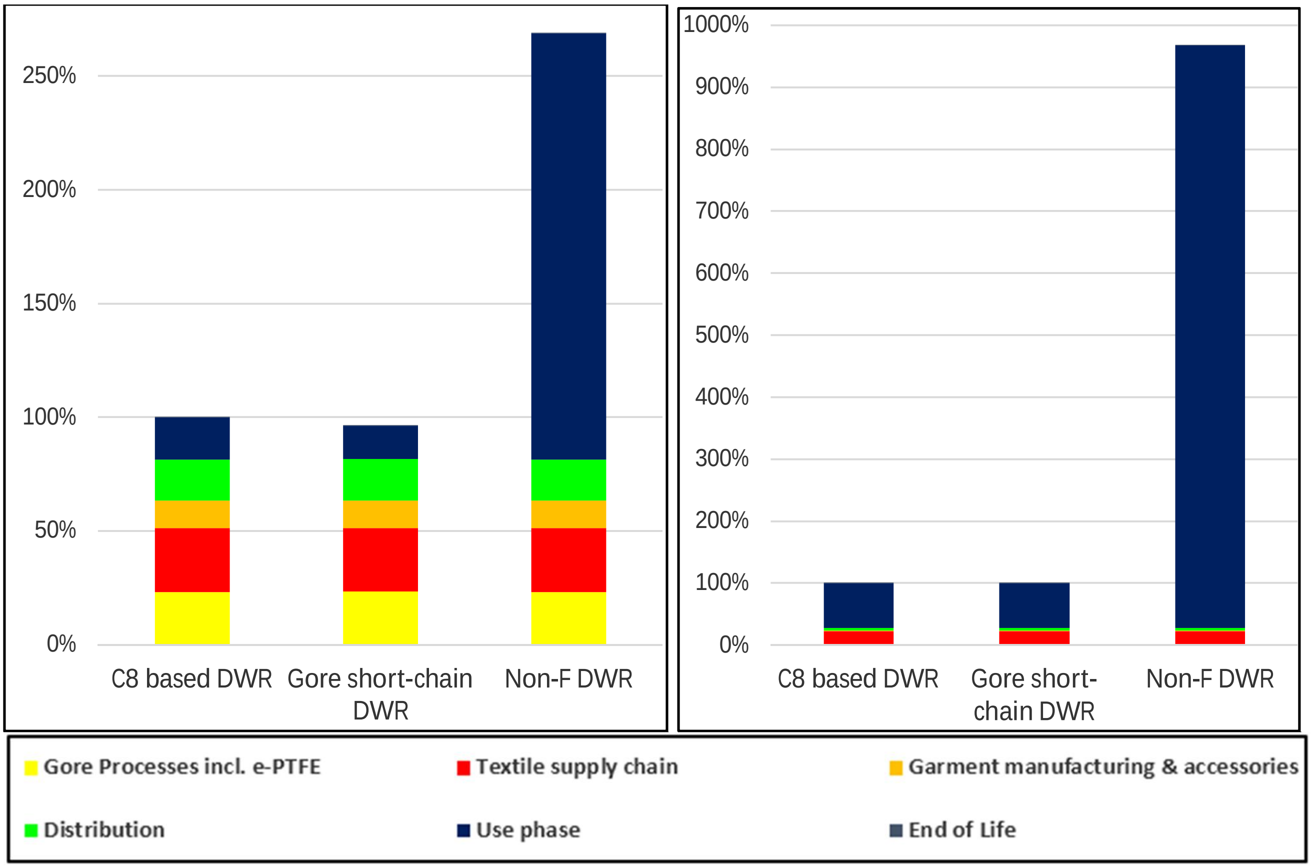


Figure 1: GWP LCIA results for all three modelled DWR treatments (left)
Figure 2: WDP LCIA results for all three modelled DWR treatments (right)

7.2 Toxicity potential

Considering that the goal of this study was to focus specifically on the potential toxicity linked to each one of the different DWR technologies; Gore decided to concentrate on four ReCiPe impact indicators looking specifically with toxicity as well as the USEtox^{TM} impact indicators.

The ReCiPe indicators used were:

- HTP - Human toxicity potential
- TETP - Terrestrial ecotoxicity potential
- FETP - Freshwater ecotoxicity potential
- METP- Marine ecotoxicity potential

The USEtox^{TM} indicators used were:

- Ecotoxicity
- Human toxicity carcinogenic
- Human toxicity non-carcinogenic

7.2.1 Cradle to gate toxicity potential of 1kg of DWR formula

Taking into account the fact that, at the level of the jacket the effect of the actual DWR mix on the toxicity impact indicators is so small that it does not even show on the graphs; Gore decided to take a look at the actual DWR solutions from a cradle to gate perspective. Cradle-to-gate is an assessment of a *partial* product life cycle from resource extraction (*cradle*) to the factory gate (i.e., before it is added to the jacket). The use phase and disposal phase of the product are, in this case, kept out of the calculations.

The following section show the result of this cradle to gate analysis for respectively, 1kg of Gore short-chain DWR solution, 1kg of Non-Fluorinated DWR solution and 1kg of disused C8 based DWR solution.

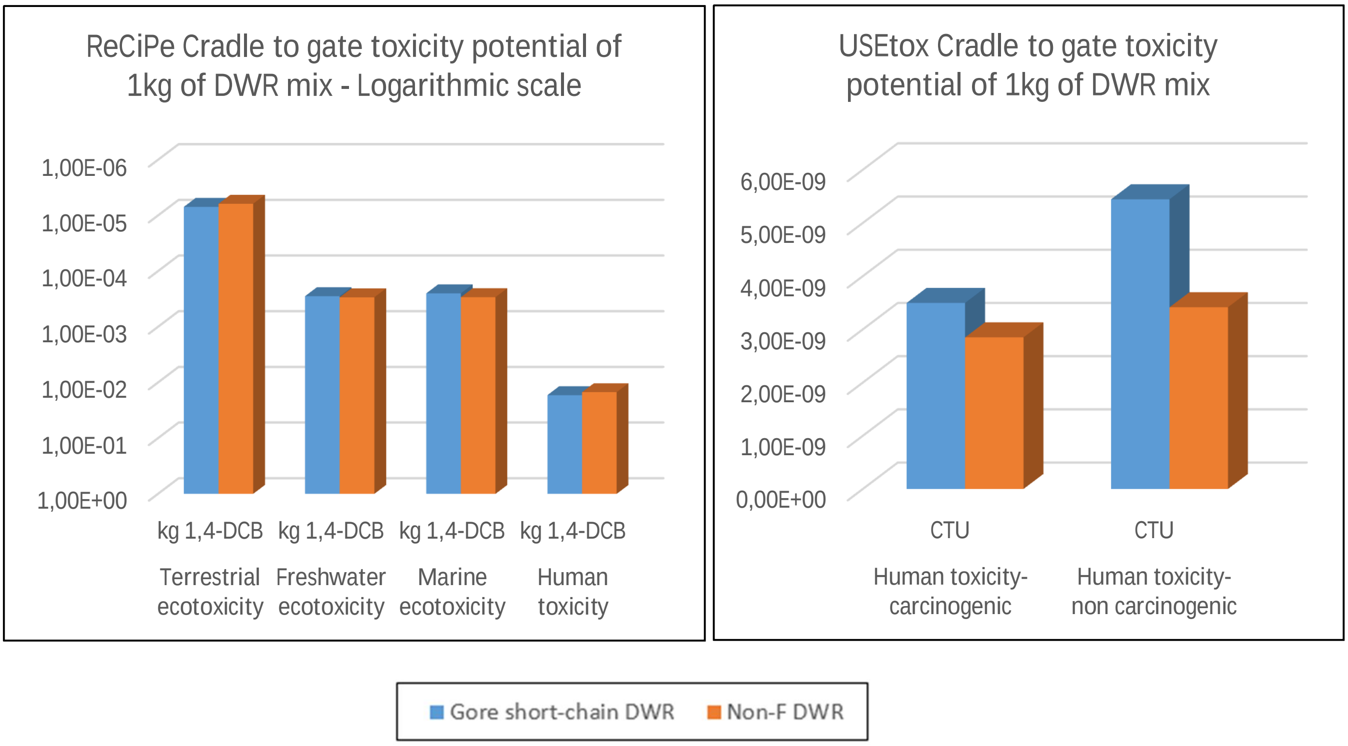


Figure 3: Overview of ReCiPe toxicity impact indicators, from cradle to gate for 1kg of DWR mix, for modelled DWR treatments
Figure 4: Overview of USEtox™ toxicity impact indicators, from cradle to gate for 1kg of DWR mix, for modelled DWR treatments

In a narrow cradle to gate view - one cannot draw a clear conclusion on this question as, for some impact indicators, the non-fluorinated treatments appear to be better, whilst for others, the non-fluorinated treatments' impact indicators appear to be worse than their fluorocarbon based equivalents. Based on this data, this study does not support the assumption that currently available alternative DWR treatments generally offer a better environmental and health profile when compared to Gore's fluorocarbon based DWR.

7.2.2 Cradle to grave toxicity potential of DWR treatments

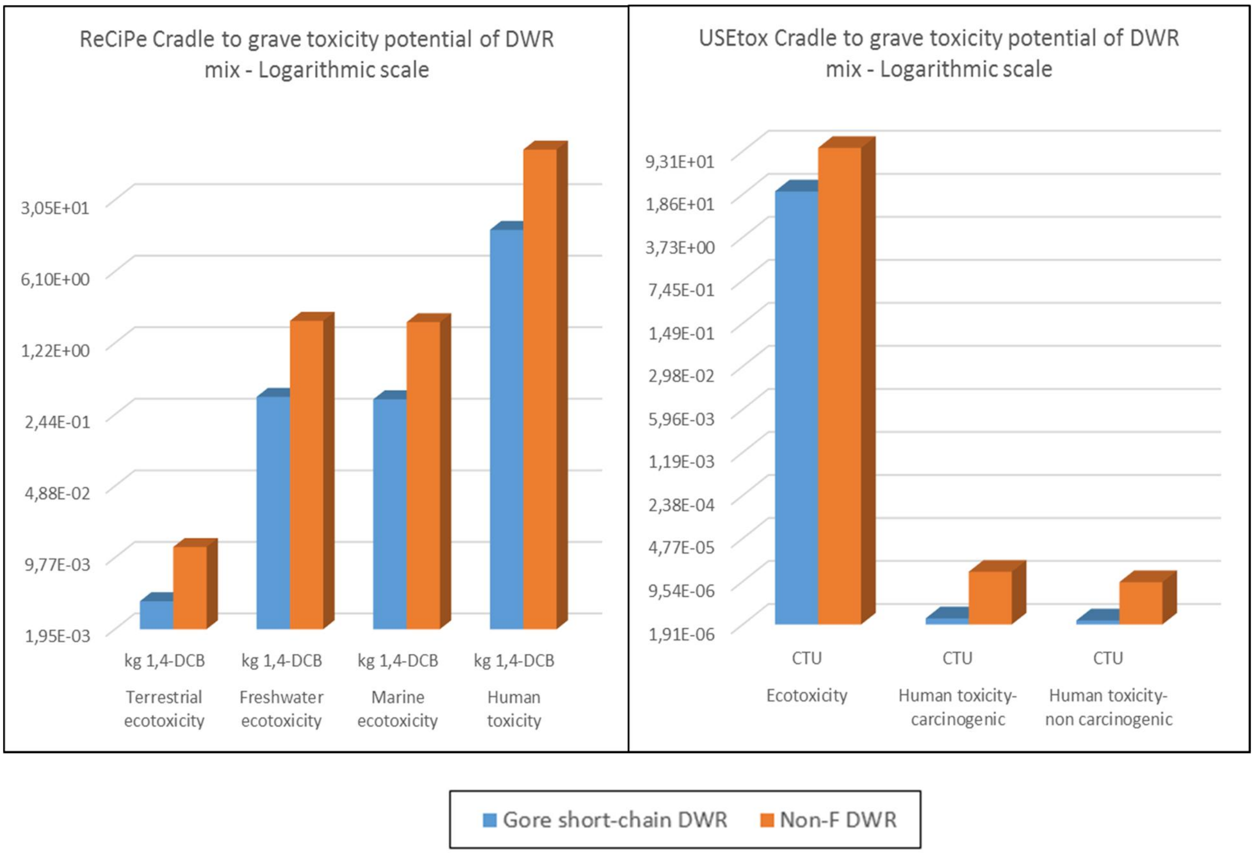


Figure 5: Overview of ReCiPe toxicity impact indicators, from cradle to grave, for DWR treatments on garments
Figure 6: Overview of USEtox™ toxicity impact indicators, from cradle to grave, for DWR treatments on garments

Focusing on the Non-Fluorinated DWR scenarios that were modelled in this study highlights a related perspective: the results overwhelmingly point to the use phase as the most significant contributor to the jacket's toxicity potential. The conclusions of this study also suggest that substituting a short-chain fluorinated treatment with a non-fluorinated DWR treatment, whose performance does not provide sufficiently long lasting water repellency in field use conditions, will result in increased adverse environmental and health effects.

With the technologies available today, consideration must be taken to use a long lasting DWR treatment and maintain its performance through regular consumer care to minimise the toxicity potential of a jacket. There appears to be no better way to keep this as small as possible while still providing the level of performance customers are expecting from their outerwear. However, all materials come with some toxicity potential.

Short-chain fluorinated polymer materials, used to replace long chain DWR treatments, have been criticized as being persistent in the environment, a feature that is often closely related to their technological strengths as materials providing unmatched durability. Choosing between alternative DWR technologies should be based – alongside with applying LCA – on risk assessment as a methodology globally accepted in industry and by regulators. It should be based on all the relevant factors that have historically guided risk assessment, including the cornerstone considerations of a substance's hazard and exposure potential. This study raises the question of whether it is reasonable to ignore identified toxicity impacts linked to a lower performing DWR treatment in favour of avoiding assumed hazards related to persistency.

7.2.3 Production & manufacturing

Additionally, this study confirms the previous findings that, Gore processes and its textile supply chain can have a significant influence. The jacket's production (Gore processes including PTFE and its supply chain, Textile supply chain, Accessories and manufacturing) represent together more than 53% of the jacket's Global Warming Potential; supporting Gore's current work stream of engaging with upstream suppliers and with Gore internal production to improve GORE-TEX® garments' environmental performance.

Appendix 1 - Water beading

Water beading prevents the outer textile layer from filling with water ("wet out"), which would compromise the comfort of the jacket and lead to the user feeling cold & clammy in the rain. This is what Gore calls "temporary failure" of the DWR since it can be reactivated with the application of heat.

Water beading ratings are based on a modified ISO 4920:2012 rating scale. The standard specifies a spray test method for determining the resistance of any fabric, which might or might not have been given a water-resistant or water-repellent finish, to surface wetting by water. Fabrics are rated zero to five, where zero is complete "wet out" and 5 is "perfect" beading. A rating of 3 or higher represents no wet out of the textile, a rating below 2 is significant >25% area wet out.

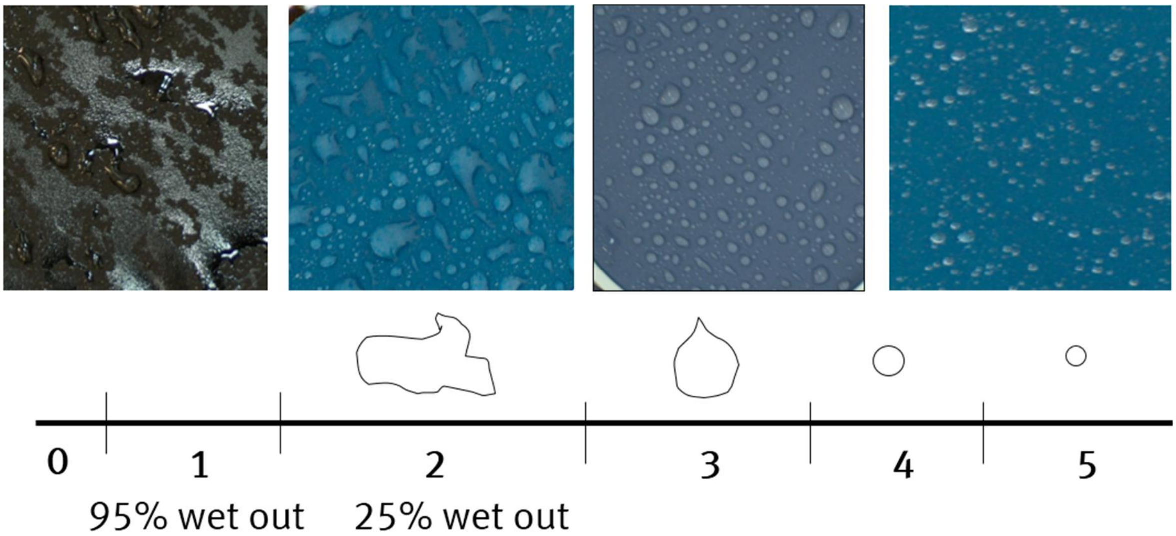


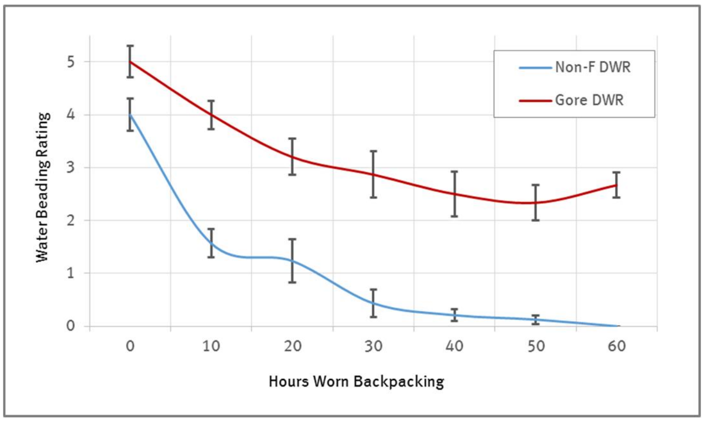
Figure 7: Wet out readings

Appendix 2 - Field trials.

The field trials were carried out on the west coast of Scotland. Its maritime climate with on average, 70 days per annum of >10 mm per day rainfall, makes it a perfect place for testing waterproof clothing. To assist Gore in this trial, the company recruited a group of independent volunteers made up of professional outdoor instructors local to the region; who are out on a daily basis guiding and instructing their clients, regardless of the weather and conditions. Activities ranged from day hiking & winter climbing to multi-day expeditions on foot or by canoe.

Tested jackets were evaluated for beading performance at 10 hour use intervals using Gore's rain room, Figure 8, where a rating of 3 or higher represents no wet out of the textile, a rating below 2 is significant >25% area wet out. Beading variability was determined by the standard error of the mean. The first interval of evaluation was after 10 hours of use (encompassing rain and dry weather conditions). Based on user log book entries the average time for non-F loss of beading was approximately 1 hour. After evaluation each jacket was thermally regenerated by tumble drying and returned to the user. At the 40 hour mark the jackets were laundered with detergent as well at each subsequent 10 hour interval. The results of the field trials were used to derive the use-phase scenarios of the LCA.

Note: Historical C8 based DWR chemistry was not included in the field trial due to its phase out by Gore Fabrics at the end of 2013.



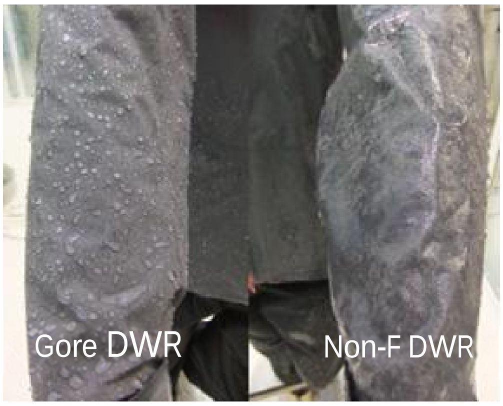


Figure 8. Field trial comparison of Gore short chain DWR and Non-F DWR (left) and representative image of split construction jacket at the 40 hour internal (right).