PROJECT MIDWOR Deliverable B1.2

Report on the industrial applications and characterization of DWOR and alternatives

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[1] **Nature of Deliverable**: **P**= Prototype, **R**= Report, **S**= Specification, **T**= Tool, **O**= Other.

[2] **Dissemination level**: **PU** = Public, **RE** = Restricted to a group of the specified Consortium, **PP** = Restricted to other program participants (including Commission Services), **CO**= Confidential, only for members of the Consortium (including the Commission Services)

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1. Introduction

The results of the survey from the preliminary action A1 helped identifying the textile application sectors more affected by the PFOA (perfluorooctanoic acids) and PFOS (perfluorooctane sulfonates) contaminants issue. According to these sectors, four fabrics suitable for five different textile applications were selected, which represent the main sectors affected by the long chain perfluorocarbon issue.

In the previous task, 14 Durable Water and Oil Repellent (DWOR) products selected (long chain fluorocarbons C8, short chain fluorocarbons C6, C6 fluorosilicones, silicones, perflurosilicones, renewable sourced, hyper branched polymers and paraffin based products) were applied on the selected fabrics on the pre-industrial scale (task B1.1), and their technical performance was assessed (task B1.3).

In this task B1.2, the results obtained from the pre-industrial trials will be confirmed at industrial level. The best finishing products, according to the final application, are selected taking into account de results of task B1.1. The application process of the selected repellent products has been performed on an industrial scale at 6 different textile manufacturing companies, members of the three clusters in the MIDWOR-LIFE consortium, reproducing the process performed on the laboratory scale, now with the industrial equipment.

The textiles treated at industrial scale have been characterized using the same European standards and essays than with the samples treated on the laboratory scale (task B1.3), in order to compare the results and validate the project concept.

The six textile manufacturing companies responsible for the industrial scale trials are:

Hidrocolor and E. Cima from Spain. Hidrocolor works for the knitwear dyeing and finishing sector, since 1978. E. Cima works for the synthetic fabrics sector. They produce a wide variety of synthetic products, like 3D fabrics, spacers, elastic fabrics, fleeces…

Inotex and Nanomembrane from Czech Republic. Inotex is specialized in textile auxiliary agents development and production, and short-yardage textile production, as well as, in research, development, service and transfer of textile technologies. Nanomembrane is specialized in the development of nanofibrous membranes for sports and outdoor clothing, as well as membrane materials for fashion clothing.

Biella Manifatture Tessili (BMT) and Tintoria Finissaggio 2000 (TF2000) from Italy. BMT is part of Marzotto Group, which is an Italian textile manufacturer. The company operates a wool mill and produces menswear fabric, suit cloth, and fine draperies for refined clothes. TF2000 works with novel fibres such as silk, cashmere and wool, as well as with cellulose fibres such as linen, cotton and viscose. They are focused on dyeing, finishing, bonding and printing of fabrics.

The present deliverable explains how the selected DWOR repellents have been applied on the different fabrics on an industrial scale and the results obtained (technical performance before and after ageing).

The next figure presents briefly the work done in preliminary actions, how this work has been used for implementation actions on the pre-industrial scale (Task B1.1) and how it has been transferred to the industrial scale (Task B1.2).

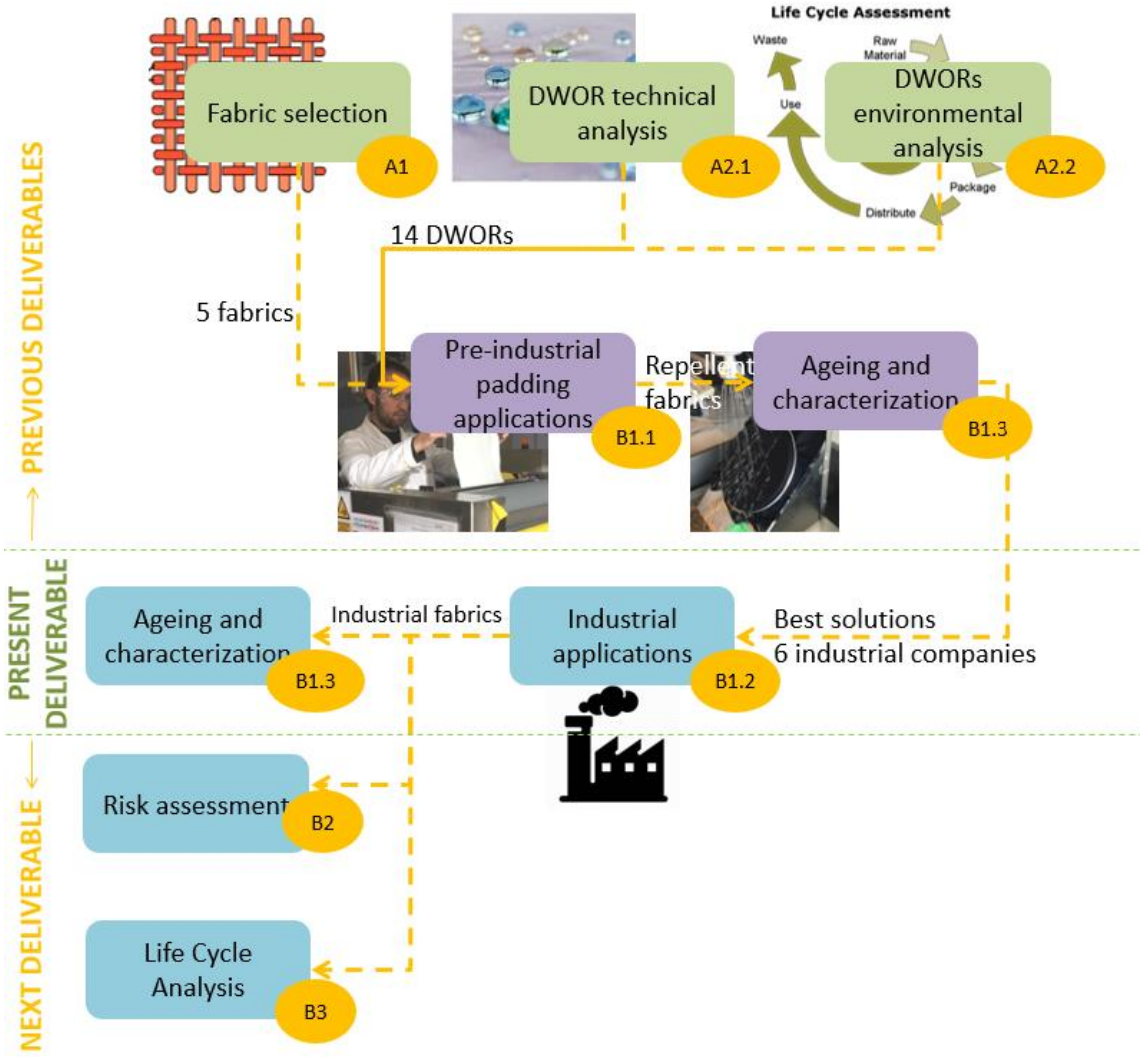


FIGURE 1. REPRESENTATION OF THE PROGRESS OF THE PROJECT.

2. Fabric selection for each textile manufacturing company

The six companies involved in the pilot scale trials are textile manufacturing companies focused on different sectors. This is the reason why each of them is responsible for a different type of fabric.

In the following figure are presented the different companies which agreed to collaborate in the MIDWOR project, and the fabric selected for each of them.

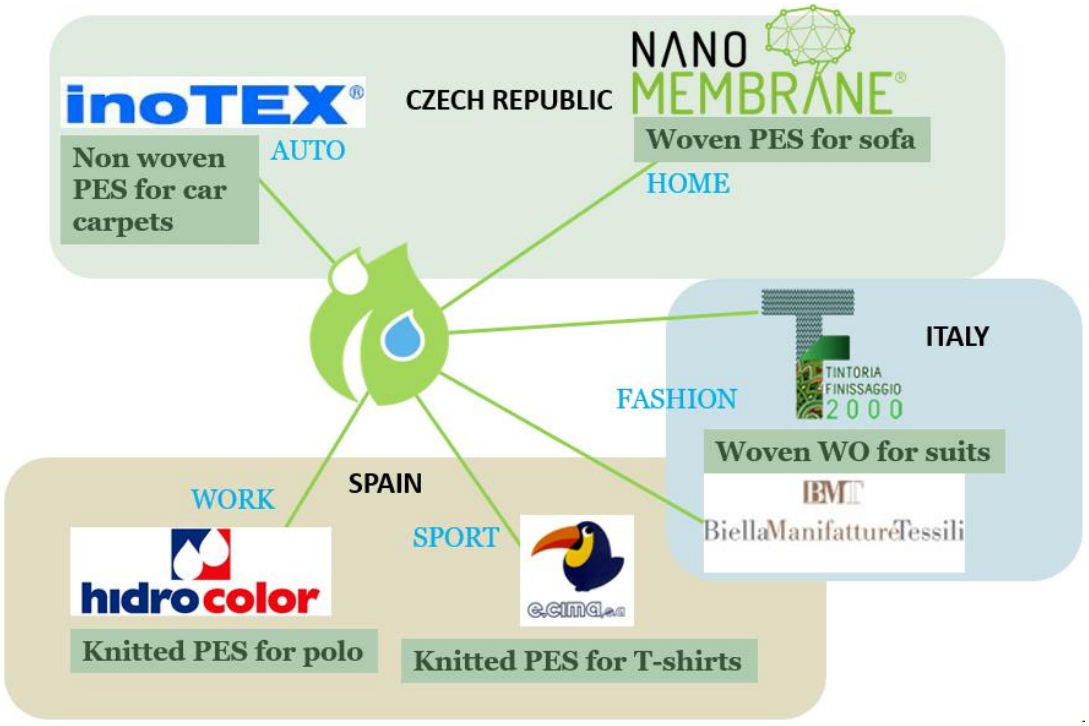


FIGURE 2. COLLABORATING COMPANIES AND FABRIC SELECTION

In the Czech Republic, Inotex is responsible for the automotive fabric, since some of the nonwovens employed in the automotive industry require a high level of water and oil repellency to achieve anti-stain properties. Nanomembrane is in charge of the textiles for upholstery, which are exposed to water and oil-based stains and require high abrasion and wear resistance.

In Italy, BMT and TF2000 are responsible for the fashion fabric, since in this sector water repellent finishing consumption is highly present. Fashion is one of the textile branches where more restrictions of PFOAs and PFOSs contaminants are claimed and many organizations are making pressure to avoid the use of long chain fluorocarbons in the clothing industry.

In Spain, both companies are responsible for the same fabric but for different application sectors. Hidrocolor is focused on the work wear sector, where the necessity to achieve high water and oil repellency is high. In most cases, work wear fabrics need to provide good water, oil and even petroleum repellency, which is up to date achieved with long chain fluorocarbon materials. E.Cima is focused on the sportswear sector, where

waterproof property can be applied in a wide range of textiles for outdoor sports in general such as tents, backpacks, jackets, etc. Oil repellency is required for example in products such as shirts, jackets, skirts, pants or luggage.

In the following table, a summary of the fabrics' properties is presented:

Sector	Automotive	Fashion	Upholstery	Work wear Sportswear
Application example	Fabric for carpets	Fabric for suits	Fabric for sofas	Fabric for polo shirt or t-shirt
Composition	100 % polyester	100 % wool	100 % polyester	100 % polyester
Structure	Punching nonwoven	Woven	Woven	Knitted
Weaving structure	-	Twill weave	Woven	Jersey piqué
Weight	210 g/m^2	180 g/m^2	250 g/m^2	175 g/m^2
Colour	Light grey	Dark blue	Grey	Dark blue

TABLE 1. FABRIC SELECTION FOR THE INDUSTRIAL APPLICATION

3. DWOR products selection for each company

The products studied at pre-industrial scale (Task B1.1) are presented in the following table:

Chemistry	Ref.
C8	C8_1
	C8_2
C6	C6_1
	C6_2
	C6_4
	C6_5
	C6_6
	C6_7
C6 fluorosilicone	C6 (FSi)
Perfluorosilicone	PFSi
Silicone	Silicone
Alkyl urethane	Renew.
Dendrimer	Dendrimer
Paraffin	Paraffin

TABLE 2. PRODUCT SELECTION FOR THE PRE-INDUSTRIAL APPLICATIONS

The results obtained from laboratory trials were analysed and presented to the different textile manufacturing companies. After discussing the results with each company, as well as their preferences, one conventional product and, at least, one alternative product were selected to be applied.

Since in the project selection there are only two C8-based products, and the product C8_2 obtained better results in most of the textile substrates, before and after ageing, this product was selected for all the companies involved in MIDWOR project.

This selection was done according to the interest of the company, once they have received the results, and taking into account that all the chemistries should be applied at least once on an industrial scale.

All the chemistries have been applied, except from paraffin and the alkyl urethane. The paraffin based product was discarded because its pilot application was done too late and the industrial selection was already decided, and the alkyl urethane product was not applied due to a lack of information regarding its composition.

3.1. Automotive fabric

The product selection for the automotive fabric, treated in Inotex, is presented in the following table:

Technology	Repellent product
Conventional	C8_2
Alternative	C6_1
	Silicone
	C6_In
	FC-free

TABLE 3. PRODUCT SELECTION FOR THE AUTOMOTIVE FABRIC

As it can be seen, two new products from Inotex were also included, apart from the products of the project selection: C6_In and FC-free. These products are in development stage in Inotex, where they are working on searching for the most efficient and effective alternatives.
The auxiliary products used with the repellent products presented in the Table 3 are listed in the next table:

Repellent product	Auxiliary product
C6_1	Extender (booster)
Silicone	Catalyst
C6_In	Crosslinking agent
FC-free	Crosslinking agent

TABLE 4. AUXILIARY PRODUCTS FOR THE AUTOMOTIVE FABRIC

The addition of some auxiliary products was recommended by the suppliers in order to improve the results obtained in the pre-industrial applications.

3.2. Fashion fabric

The product selection for the fashion fabric, treated in BMT and TF2000, is presented in the following table:

Technology	Repellent product
Alternative	C6_7
	Dendrimer
	C6_7

TABLE 5. PRODUCT SELECTION FOR THE FASHION FABRIC

The auxiliary products used with the repellent products presented in the Table 5 are listed in the next table:

Repellent product	Description
C6_7	Wetting agent
Dendrimer	Wetting agent
	Crosslinking agent

TABLE 6. AUXILIARY PRODUCTS FOR THE FASHION FABRIC

In order to achieve higher washing fastness of the C6_7 product, the addition of a wetting agent was suggested to the companies. The auxiliary products used with the dendrimer are the same as in the pre-industrial applications.

3.3. Upholstery fabric

The product selection for the upholstery fabric is presented in the following table:

Technology	Repellent product
Conventional	C8_2
Alternative	C6 (FSi)

TABLE 7. PRODUCT SELECTION FOR THE UPHOLSTERY FABRIC

3.4. Sportswear / Work wear fabric

The product selection for the sportswear and workwear fabric is presented in the following table:

Technology	Repellent product
Conventional	C8_2
Alternative	PFSi
	Dendrimer
Conventional	C8_2
Alternative	C6 (FSi)

TABLE 8. PRODUCT SELECTION FOR THE SPORTS/WORK WEAR FABRIC

The auxiliary products used with the repellent products presented in the Table 8 are listed in the next table:

Repellent product	Auxiliary product
Dendrimer	Wetting agent
	Crosslinking agent

TABLE 9. AUXILIARY PRODUCTS FOR THE SPORTS/WORK WEAR FABRIC

These auxiliary products were already used in the pre-industrial applications on this fabric.

4. Characterization

The characterization and ageing tests performed in this action, are the same as on the pre-industrial scale.

4.1. Characterization tests description

AATCC 22 and UNE EN ISO 4920: Water repellency – Spray test

This standard measures the resistance of fabrics to wetting by water or the water repellency of fibres. In Figure 3 the Spray Test Ratings are presented:

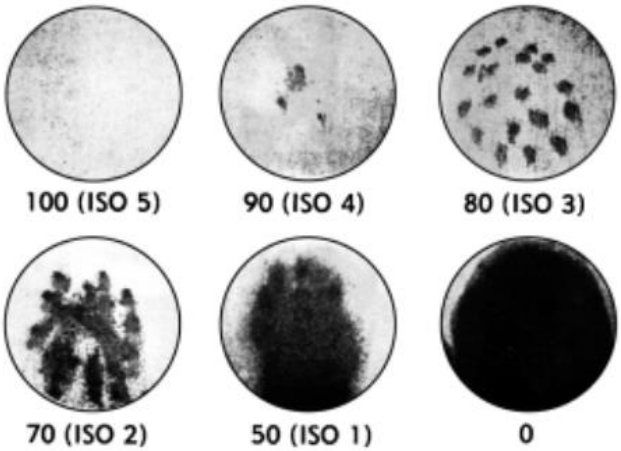


FIGURE 3. STANDARD SPRAY TEST RATINGS

- 100 (ISO 5): No wetting of the specimen face
- 90 (ISO 4): Slight random wetting of the specimen face
- 80 (ISO 3): Wetting of specimen face at spray points
- 70 (ISO 2): Partial wetting of the specimen face beyond the spray points
- 50 (ISO 1): Complete wetting of the entire specimen face beyond the spray points
- 0: Complete wetting of the entire face of the specimen

FIGURE 4. SPRAY TEST EXAMPLE

AATCC 118 and UNE EN ISO 14419: Oil repellency – Hydrocarbon Resistance Test

The AATCC Oil Repellency Grade is the numerical value of the highest-numbered test liquid which will not wet the fabric within a period of 30 sec. A grade of 0 is assigned when the fabric fails the Kaydol test liquid.

AATCC Oil Repellency Grade Number	Composition
0	None (Fails Kaydol)
1	Kaydol
2	65:35 Kaydol: n-hexadecane by volume
3	n-hexadecane
4	n-tetradecane
5	n-codecane
6	n- cecane
7	n-octane
8	n-heptane

TABLE 10. STANDARD TEST LIQUIDS – AATCC 118

In Figure 5 can be seen an example of the rating criteria:

- A: Passes – clear, well-rounded drop
- B: Borderline pass – rounding drop with partial darkening
- C: Fails – wicking apparent and/or complete wetting
- D: Fails – complete wetting

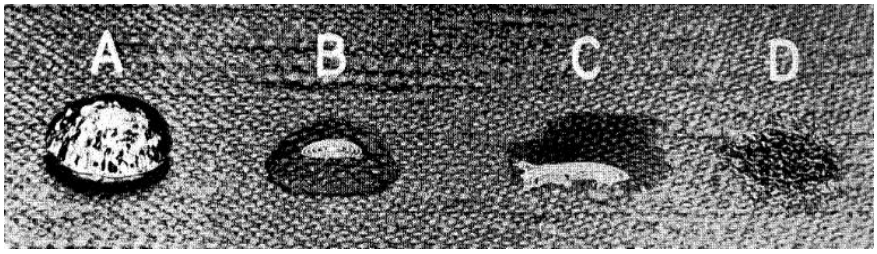


FIGURE 5. AATCC 118 GRADING EXAMPLE

4.2. Ageing tests description

The objective of ageing the treated samples is to determine the durability of the water and oil repellency under real use conditions. The ageing tests which have been done include: washing (except for wool), dry-cleaning (for wool) and ironing. The ageing tests conditions are detailed next:

Washing

Domestic washing has been performed using the standard UNE EN ISO 6330, with a temperature of 30ºC. 10 cycles have been applied in order to observe differences after and before washing but without exceeding the washing fastness of the finishing.

The samples have been dried in a flat way after washing, and conditioned 24 hours at 20ºC±2ºC and 65%±5% r.h[3] before the next evaluation (spray test and oil test).

Dry cleaning

Dry cleaning has been performed under the standard UNE EN ISO 3175-2. Only 1 cycle has been made as dry-cleaning is a very aggressive treatment and the fabric is destined to suits application.

The samples have been dried in a flat way after washing and conditioned 24 hours at 20ºC±2ºC and 65%±5% r.h before the next evaluation (spray test and oil test)

Ironing

Hand ironing has been performed after domestic washing or dry cleaning, at 150ºC. Then, the samples have been conditioned 24 hours at 20ºC±2ºC and 65%±5% r.h before the next evaluation (spray test and oil test).

The treated samples have been washed or dry cleaned and ironed. Spray test and oil test have been performed after each ageing test. However, not all ageing tests are done on all fabrics, since it depends on their final application (the automotive fabric has not been washed and the upholstery fabric has not been ironed).

[3] Relative Humidity

5. Results and discussion

In order to analyze the results, the water and oil repellency grades are presented for each fabric. The results obtained for each chemistry on an industrial scale are compared with those from lab trials.

Water and oil repellency have been determined for all the fabrics, and ageing has been done according to the fabric final application. The parameters studied for each fabric are presented in the tables at the beginning of each part.

In the following graphs, the grade number value is indicated on the ordinate axis for the spray test (according to UNE EN ISO 4920 standard) and the oil test (according to the AATCC 118 or UNE EN ISO 14419 standards). Maximum grade number according to the standard for Spray test and Oil test is 5 and 8, respectively.

The variability of the method is of 0,5 or 1 point approx. depending on the test area, the type of fabric and the type of finish.

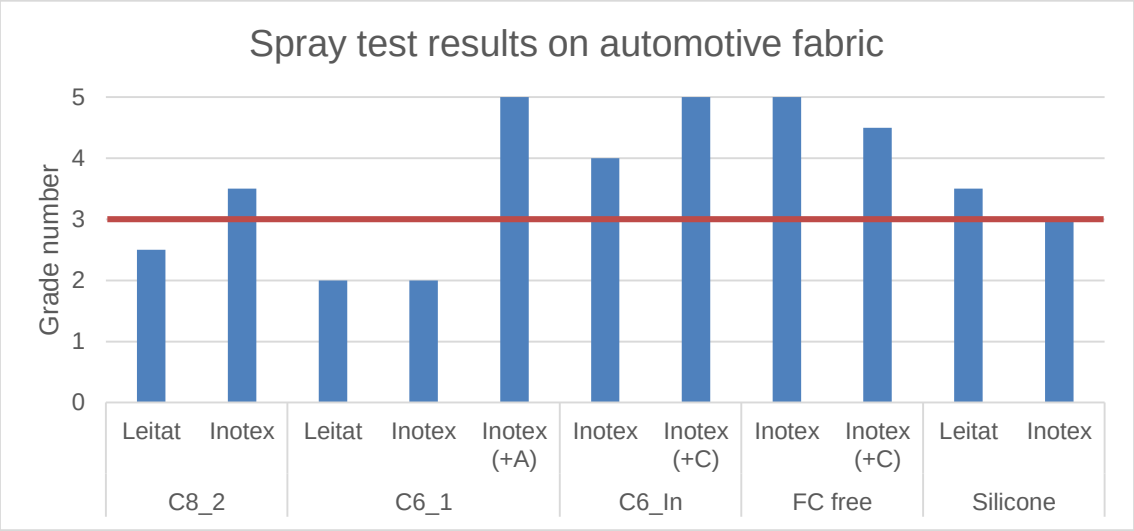
5.1. Automotive fabric

The next table presents the parameters tested on the automotive fabric (nonwoven for carpets).

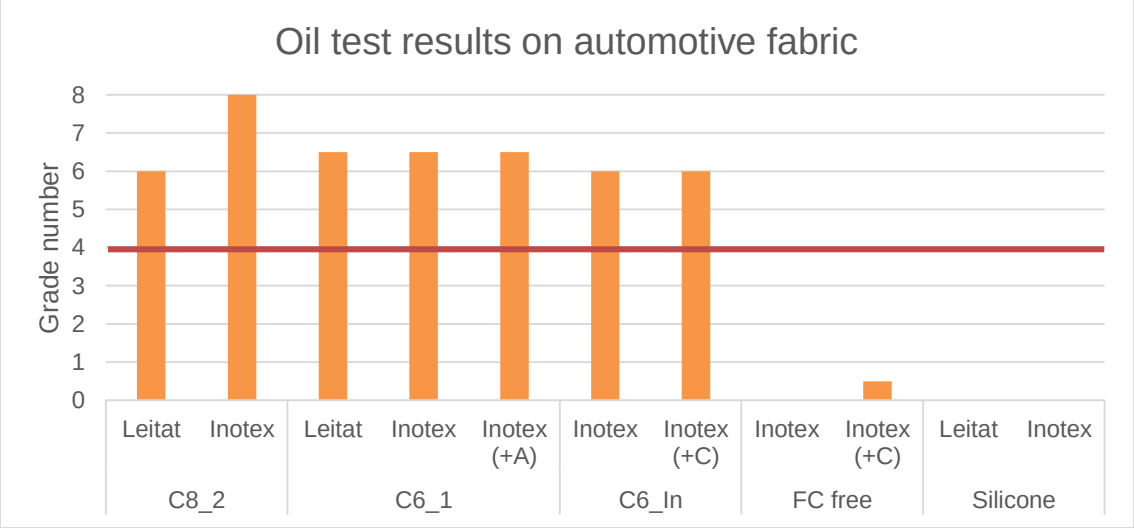
AUTOMOTIVE FABRIC		Comments
Analysis	Water and oil repellency	
Chemistries	C8, C6, silicone and FC-free	
Ageing	No ageing	No washing and ironing is required for nonwoven carpets

TABLE 11. PARAMETERS STUDIED FOR AUTOMOTIVE FABRICS

The following graphs compare the oil and water repellency of the different chemistries on the treated (unwashed, not ironed) fabric. The reference “(+A)” refers to an addition of an auxiliary product and “(+C)” refers to a higher concentration of the products in the treatment bath.



GRAPH 1. SPRAY TEST RESULTS ON AUTOMOTIVE FABRIC



GRAPH 2. OIL TEST RESULTS ON AUTOMOTIVE FABRIC

Discussion:

According to Graph 1, industrial results differ from those obtained in lab trials. The highest water repellency grade obtained in lab trials was 3,5 (from Silicone), however the new results from industrial trials reach grade 5.

Regarding the oil repellency (Graph 2) the results obtained on the industrial scale are close to those from lab trials in Leitat. As it could be expected, the non-fluorinated alternatives (Silicone and FC-free) do not present oil repellency, because of their higher surface energy.

The **C8_2** product seems not to be the best option on the polyester nonwoven. Although it achieved the highest oil repellency grade (8), its water repellency is much lower compared to other alternatives.

The **C6_1** product reaches the highest water repellency grade (5) when it is used combined with an extender product. However, the oil repellency is not modified by the addition of this auxiliary product. Comparing this product with **C6_In** product, from Inotex, the results are very similar, using in this case a cross-linking agent.

The **FC-free** product, from Inotex, has also achieved the highest water repellency grade, with the lower concentration. This a great result, since it means that fluorine is not necessary to achieve a high level of water repellency. Therefore, this product could be a potential substitute for the fluorinated alternatives.

Finally, the **silicone** product, which initially achieved the highest water repellency in the pre-industrial applications, is now far from the results of the other alternatives. However, its results are similar to C8, which has neither obtained a high water repellency.

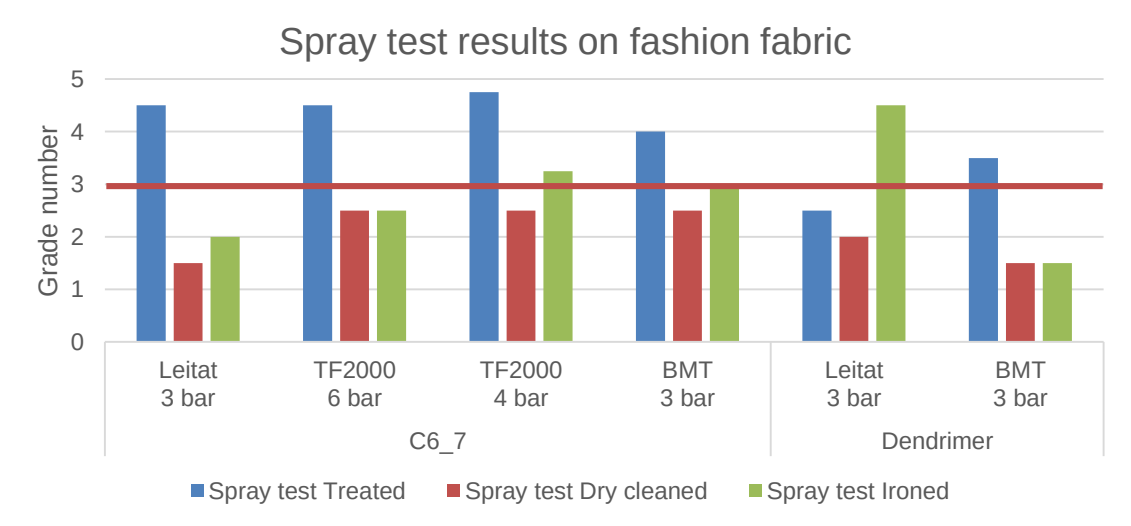
5.2. Fashion fabric

The next table presents the parameters tested on the suit fabric (woven wool fabric).

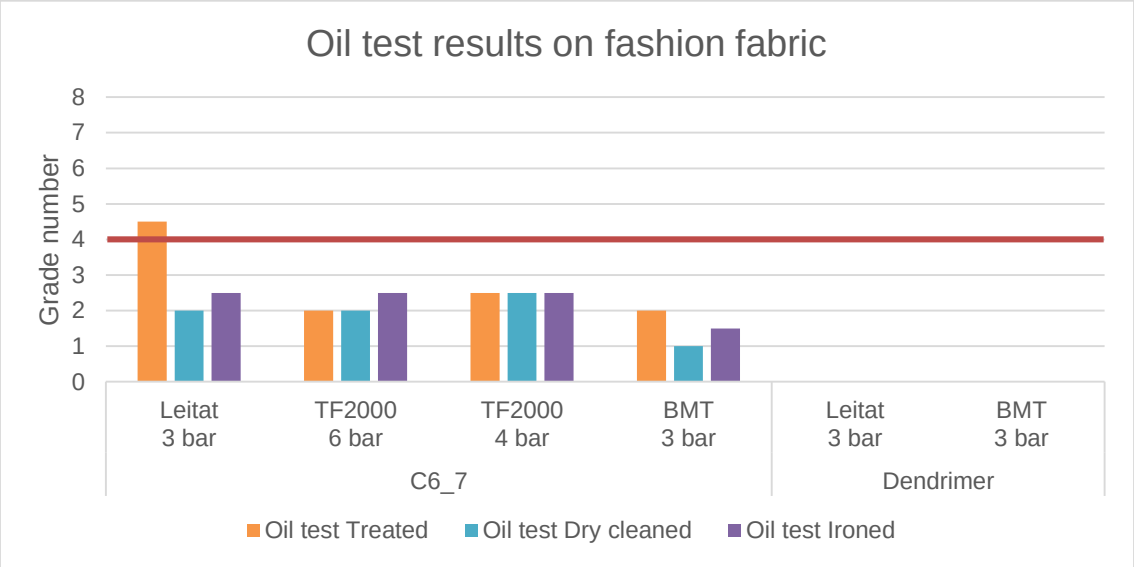
	SUIT FABRIC	Comments
Analysis	Water and oil repellency	
Chemistries	C6 and dendrimer	
Ageing	Dry cleaning Ironing	Domestic washing is not indicated for woollen fabrics

TABLE 12. PARAMETERS STUDIED FOR SUIT FABRICS

The following graphs compare the oil and water repellency of the different chemistries on the treated, dry cleaned and ironed fabric.



GRAPH 3. SPRAY TEST RESULTS ON FASHION FABRIC



GRAPH 4. OIL TEST RESULTS ON FASHION FABRIC

Discussion:

According to Graph 3, the water repellency results obtained in the industrial tests are similar to those obtained in the previous trials in the laboratory. However, there are some small differences.

The addition of a wetting agent in the industrials trials with the **C6-based product**, increased around 1 point the repellency grade after dry washing, compared to the lab results, where no wetting agent was used. This means that this auxiliary product increases the washing fastness of the treatment.

Another interesting fact is that decreasing the working pressure, or increasing the pick-up, does not have a visible impact on the water repellency grade.

Regarding the **dendrimer**, the results obtained at industrial trials agree with the supplier specifications, since this product is described as not resistant to dry cleaning, and the results show a low repellent grade after being dry cleaned.

According to Graph 4, the oil repellency results obtained in the industrial tests are lower than lab results. However, the results after dry cleaning and ironing the samples are very similar.

The pre-industrial treated samples were tested only once during characterization phase, due to the high amount of samples that needed to be tested. The samples from the industrial tests were tested three times, and in different fabric regions. Therefore, the results from pre-industrial trials may not be as accurate as those from industrial tests.

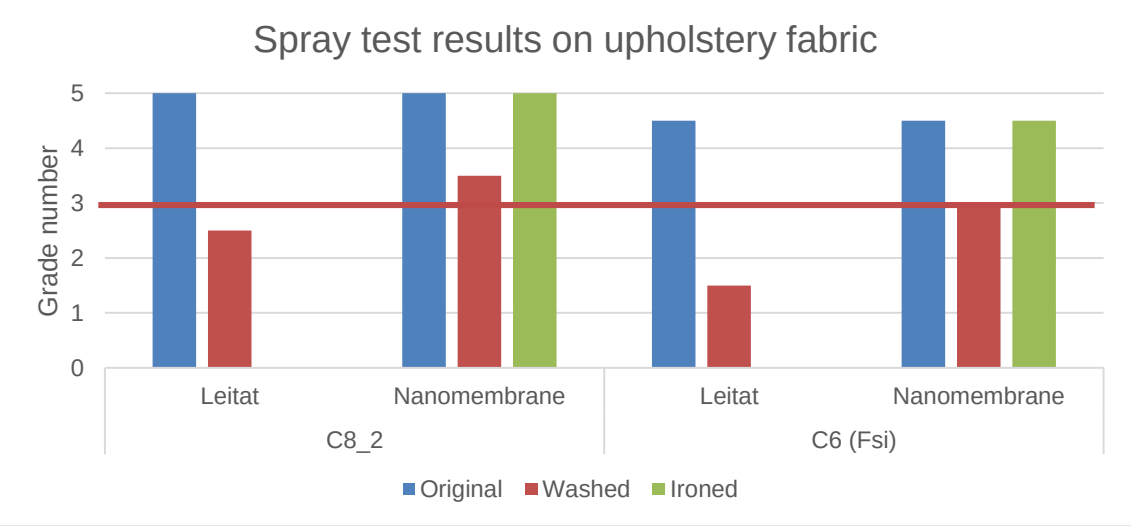
5.3. Upholstery fabric

The next table presents the parameters that will be tested on the upholstery fabric (woven polyester fabric), once the industrial application is performed in Nanomembrane.

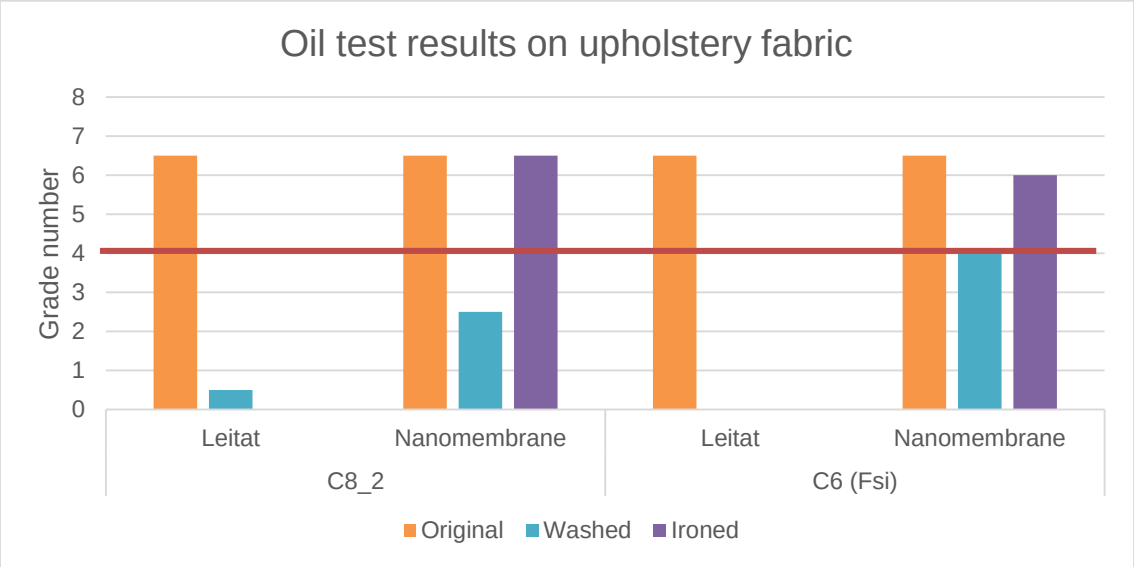
UPHOLSTERY FABRIC	
Analysis	Water and oil repellency
Chemistries	C8, C6 (FSi)
Ageing	Domestic washing and ironing

TABLE 13. PARAMETERS STUDIED FOR SUIT FABRICS

The following graphs compare the oil and water repellency of the different chemistries on the treated, washed and ironed fabric. During the pre-industrial characterization, ironing was not performed on the upholstery fabric, since it was considered not necessary. However, due to the low results obtained after the domestic washing of the samples, it was decided to iron the industrial samples.



GRAPH 5. SPRAY TEST RESULTS ON UPHOLSTERY FABRIC



GRAPH 6. OIL TEST RESULTS ON UPHOLSTERY FABRIC

As it can be seen in the previous deliverable, the repellency results obtained on this fabric were high but the washing fastness was very low. However, the results from the industrial applications show a higher washing fastness and a full recovery of the repellent property after ironing.

Only two different chemistries were applied on the upholstery fabric: a **long chain fluorocarbon**, and a **C6 fluorosilicone**. Both products show similar repellency results, showing again that the short-chain alternatives can achieve similar results than C8 and can be thus potential substitutes for both repellent properties.

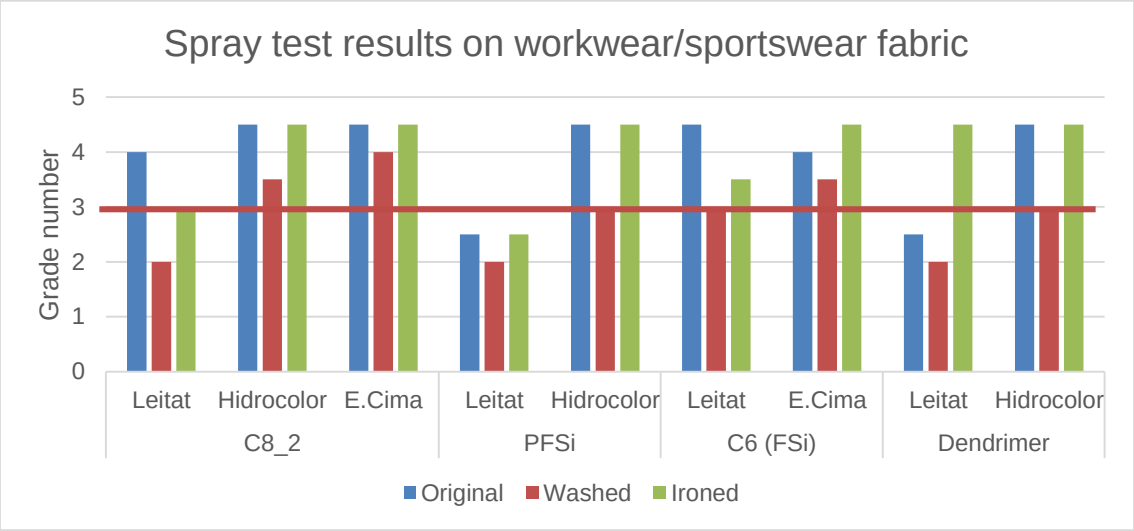
5.4. Sportswear / Work wear fabric

The next table presents the parameters tested on the sportswear/work wear fabric (knitted polyester fabric).

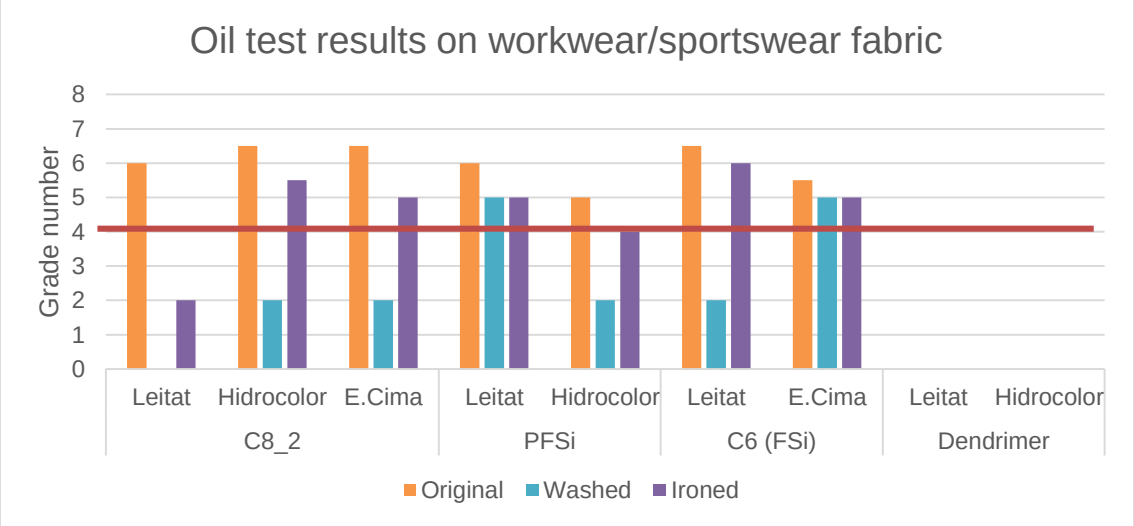
UPHOLSTERY FABRIC	
Analysis	Water and oil repellency
Chemistries	C8, PFSi, C6 (FSi) and dendrimer
Ageing	Domestic washing and ironing

TABLE 14. PARAMETERS STUDIED FOR SUIT FABRICS

The following graphs compare the oil and water repellency of the different chemistries on the treated, washed and ironed fabric.



GRAPH 7. SPRAY TEST RESULTS ON SPORTSWEAR/WORKWEAR FABRIC



GRAPH 8. OIL TEST RESULTS ON SPORTSWEAR/WORKWEAR FABRIC

Discussion:

According to Graph 7, the industrial results are better than those obtained in lab trials in Leitat. All the chemistries have reached grade 4.5 in the industrial tests, and it can be seen that the washing fastness is also higher. Moreover, it is proved that ironing restores fully the water repellent property on this fabric.

Regarding the oil repellency (Graph 8) the results obtained on an industrial scale are close to those from lab trials in Leitat, although there exist some variations.

The **C8 based** product has slightly improved its water and oil repellency. Moreover, the samples treated on the industrial scale show a greater washing fastness, and ironing

restores partially or even fully the repellent properties. The results obtained at Hidrocolor and E.Cima with this product are almost the same.

The **perfluorosilicone** shows a very good water repellency and it is fully restored after being washed and ironed. However, the oil repellency results obtained at Hidrocolor are lower than those from lab trials in Leitat.

For the **C6 hybrid fluorosilicone** the results are similar to those obtained from lab trials in Leitat. The water repellency is high and it's fully restored after washing and ironing. The oil repellency is also high, similar to perfluorosilicone, and it is resistant to washing.

Finally, the **dendrimer** based product shows a very good performance. It achieved the same water repellency grade as the C8 based product, and ironing fully restores this property. This product could be a potential substitute of fluorinated products, in order to obtain water repellency. However, it does not provide oil repellency due to its high surface tension.

6. Conclusions

The industrial demonstrations have been performed in 6 different pilot textile manufacturing companies, members of AEI TEXTIL, CS-POINTEX and CLUTEX. Six different chemistries have been tested on the four fabrics selected in MIDWOR-LIFE project, with the optimum concentration found in the previous task. The fabrics treated on the industrial scale have been then characterized in Leitat.

6.1. Chemistries

After performing the characterization of the fabrics treated in the textile manufacturing companies, the results obtained differ slightly from those obtained at pre-industrial demonstration, and are generally higher.

C8 chemistry has achieved high water and oil repellency on polyester nonwoven, woven and knitted fabrics. However, some chemistries have similar or better results than this long chain fluorocarbons, being therefore potential substitutes, especially if only water repellency is required.

The short-chain fluorinated alternatives have achieved very good results. The **C6-based** products have been tested in nonwoven polyester and wool fabrics, where they achieved high water repellency grade, similar or higher than C8, but their oil repellency was slightly lower.

The **hybrid C6 fluorosilicone** and the **perfluorosilicone**, which combine the technology of fluorocarbons and silicones, have been applied in the knitted and woven polyester fabric. The water repellency of the treated samples is very high, the same as C8 chemistry, and the oil repellency is also very close to this conventional chemistry. These chemistries have also achieved high washing fastness, since the repellent property has been fully restored after ironing.

Regarding the non-fluorinated alternatives, the **silicone** product, has only been tested on the nonwoven polyester fabric, where it has achieved a repellency grade similar to C8-based products, but lower than C6-based chemistries.

The **dendrimer** has shown very good results after industrial demonstration, where it was applied on the knitted polyester fabric. The water repellency grade and its washing fastness is the same as that achieved by C8 and C6-based products. This means that if the fabric requirement is only water repellency, the dendrimer can be a substitute for the fluorocarbon DWOR products. When this product was applied on the woollen fabric, the results were also similar to C6, but the washing fastness was lower, because this product is not resistant to dry cleaning.

6.2. Application sector

The fabric's characteristics do also have an important role in the effectiveness of the repellent finishing. In the following tables, the results for spray and oil test of all the products are shown. In bold are highlighted the results from industrial applications, and the rest of results are from pre-industrial applications in Leitat.

In the Tables 21 and 22, the results of water and oil repellency of the washed samples (except for the automotive fabric) are presented.

	Polyester nonwoven *(unwashed)*	Polyester knitted *(10 washing cycles + ironing)*	Polyester woven *(10 washing cycles + ironing*)*	Wool woven *(1 dry cleaning cycle + ironing)*
C8_1	2,5	3	2	2
C8_2	**3,5**	**4,5**	**5**	3
C6_1	**5**	1,5	1,5	
C6_2	2	1	1,5	
C6_4	2	2,5	2	2,5
C6_5	2,5	4	3	
C6_6	2	3	2	
C6_7	2	3	2	**3**
C6 (FSi)	2,5	**4,5**	**4,5**	
PFSi	2	**4,5**	0	
Renew.	2	2	1,5	
Silicone	**3**	2		
Dendrimer	2,5	**4,5**	2,5	**2**
Paraffin	2	0,5	2,5	2,5

TABLE 15. WATER REPELLENCY RESULTS OF MIDWOR-LIFE SELECTION
COLOUR CODE: GREEN – PASS (>3); YELLOW – BELOW 3; RED – NO REPELLENCY
*ONLY THE INDUSTRIAL SAMPLES HAVE BEEN IRONED

	Polyester nonwoven *(unwashed)*	Polyester knitted *(10 washing cycles + ironing)*	Polyester woven *(10 washing cycles + ironing)*	Wool woven *(1 dry cleaning cycle + ironing)*
C8_1	7	2	0	0
C8_2	**8**	**5,5**	**6,5**	0
C6_1	**6,5**	2,5	0	
C6_2	6	2	0	
C6_4	6	1	0	1
C6_5	6	2,5	2	
C6_6	6	1	0	
C6_7	6,5	5,5	0,5	**2,5**
C6 (FSi)	6,5	**5**	**6**	
PFSi	6	**4**	0,5	
Renew.	0	0	0	
Silicone	**0**	0		
Dendrimer	0	**0**	0	**0**
Paraffin	0	0	0	0

TABLE 16. OIL REPELLENCY RESULTS OF MIDWOR-LIFE SELECTION
COLOUR CODE: GREEN – PASS (>4); YELLOW – BELOW 4; RED – NO REPELLENCY
*ONLY THE INDUSTRIAL SAMPLES HAVE BEEN IRONED

In order to analyse the results, it needs to be taken into account that the industrial results are more reliable, due to the fact that the pre-industrial samples were characterized once and only one small sample was treated. However, during the industrial applications, longer lengths of fabrics were treated and the characterization was done on samples from three different regions of the fabrics.

The **automotive polyester nonwoven** has achieved high water repellency results with the fluorinated chemistries during the industrial applications, especially with the C6, which has achieved the highest water repellency grade (5). On the pre-industrial scale, these fluorinated alternatives achieved low water repellency, and it was first related to the irregular and hairy surface of the textile. However, after the industrial tests, it can be seen that this surface does not affect the formation of the fluorocarbon comb-like structure.

Regarding the oil repellency of the nonwoven, the results are similar to those from pre-industrial trials. A high repellency is obtained with the fluorinated alternatives, especially with the C8, which has achieved the highest grade (8).

If only water repellency is needed for the automotive nonwovens, the silicone and the dendrimer could be possible substitutes for the fluorinated DWOR products. If the requirements include oil repellency, it would be necessary to select one fluorinated alternative, and in this case the best result was obtained with the C6-based products.

The **upholstery fabric**, which initially showed a poor washing fastness during pre-industrial applications, has achieved a high repellency grade and washing fastness with the C8 and the C6 (FSi) on the industrial scale. Thus, the C6 (FSi) could be a substitute for the C8 if oil repellency is truly demanded. If not, a non-fluorinated alternative would be enough.

It would have been interesting to apply a non-fluorinated alternative on the industrial scale, in order to see if there was also an improvement on the results of this chemistry. However, it was not possible, and the results from the pre-industrial applications are quite low.

The **suit woollen fabric** has achieved good water repellency results with both of the chemistries that have been tested (C6 and dendrimer), but the washing fastness is not as good as with polyester fabrics, due to the difficulty of the chemical bonding of the treatments with the surface. Moreover, the oil repellency obtained with this fabric is much lower than that obtained with polyester fabrics.

The **sportswear / work wear knitted polyester fabric** has achieved a high water repellency (grade 4,5) with all the chemistries (C8, C6, perfluorosilicone and dendrimer), as well as very good washing fastness, since the repellent property has been fully restored after ironing.

Regarding the oil repellency of the treated fabrics, the fluorinated chemistries have around 1 point less repellency than the C8, which have achieved grade 6.5. The washing fastness of C6 fluorosilicone is the highest.

Therefore, the dendrimer based product can substitute the fluorinated DWOR products for water repellency with similar performance than conventional C8, being a potential substitute of this technology. However, if oil repellency is also required for protective wear (i.e. refinery workers…), fluorinated chemistries are needed, and C6 or fluorosilicone can be good substitutes for the C8.