Report about industries perspectives on nanofluids market uptake

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Nanouptake COST Action

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nano uptake™

Title: Report about industries perspectives on nanofluids market uptake

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Section 1

1.1 EXECUTIVE SUMMARY

The **aim** of this report from Nanouptake is to review the situation of nanofluids in the industrial sector as well as the main challenges to its implementation.

The **methodology** used has been double.

Primary sources:

- Workshops with a group of experts from the sector from academia and industry fields.
- Online questionnaire made to a group of subscribers from the Nanouptake network.

"An insight to the situation of nanofluids' market uptake"

The **results** obtained indicate that networking and research communities are key to overcome barriers in the implementation of nanofluids in the market. Moreover, it is also pointed out that is needed a common and agreed nanofluids legislation and safety guides.

Section 2

2.1 INTRODUCTION

2.1.1 BACKGROUND

Nanouptake (Overcoming Barriers to Nanofluids Market Uptake) is a COST Action that aims to strengthen the scientific coordination and collaboration of the network of leading nanofluid R+D+i centers and industries to develop and foster the use of nanofluids as advanced heat transfer/thermal storage materials to increase the efficiency of heat exchange and storage systems.

By developing of nanofluids up to higher Technological Readiness Levels (TRL) and overcoming commercial application barriers, **Nanouptake** will contribute to achieve the European Horizon 2020 Energy and Climate objectives (Societal Challenges 3: Secure, efficient and clean energy; and 6: Climate action, environment, resource efficiency and raw materials).

Among its objectives is fostering the development of a joint research agenda in order to assess the economic and performance viability of using nanofluids in thermal systems.

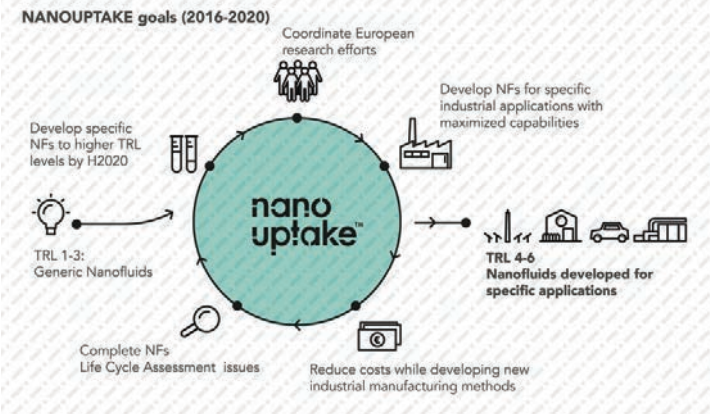


Illustration 1: Infographic with Nanouptake goals.

2.1.2 OBJECTIVES

Aligned with the objectives of Nanouptake, this report aims to better involve the industry partners in the discussion, analysing the perspectives about nanofluids market uptake, trying to achieve this secondary objectives:

- Promote the development of a joint agenda to bring **nanofluids closer to the energy industry/market.**
- Create **new synergies and encourage cooperation** of several nanofluids research institutions and industries across Europe.
- Perform a **collaborative SWOT analysis** about the industrial implementation of nanofluids.

2.1.3 METHODS

The assignment of this report has been composed of the following phases:

- **Strategic meeting**

To achieve these challenges, a strategic meeting with the Nanouptake Core Group and industries was organised. Diagnosis workshops were carried out to obtain a complete analysis of the situation.

- **Online questionnaire**

Once the information from the meeting was gathered, a questionnaire was created to identify the main concerns and expectations on bringing nanofluids closer to the energy industry.

- **Produce the report and cross-check with the Nanouptake Core Group.**

2.1.4 STRUCTURE OF THE REPORT

After this introduction, which aims to context the report, section 3 addresses the results of the strategic meeting in Birmingham. In section 3.2 a SWOT analysis is explained with the main conclusions from the workshop.

Section 3.3 points out the main challenges for the use of nanofluids in industry, as well as the proposal of collaborations to overcome them.

Section 4 gather the results of the survey answered by experts in order to identify their perception of positive and negative factors for the use of nanofluids in the industry, with the aim of finding solutions.

Section 5 offers final conclusions and section 6 includes an annex with complementary information, as the questionnaire.

Section 3

3.1 STRATEGIC MEETING

3.1.1 OBJECTIVES

The **aim** of the meeting was to identify the present barriers for the nanofluid implementation in the industry and encourage cooperation of several nanofluids research institutions and industries across Europe to advance in overcoming them. Workshops were carried out to analyse the progress of the project and to promote joint objectives.

3.1.2 PARTICIPANTS

Representatives from eleven research institutions from the European network Nanouptake (www.nanouptake.eu), led by the Universitat Jaume I, and representatives of four industries, met in the University of Birmingham (United Kingdom) the 1st of February of 2019 (table 1).

Table 1: Institutions represented on the strategic meeting in Birmingham.

NANOUPTAKE CORE GROUP				
Universitat Jaime I, Spain	**Rzeszow University of Technology**, Poland	**Università degli Studi della Campania *Luigi Vanvitelli*,** Italy	**Lund University**, Sweden	**Gheorghe Asachi Technical University of Iasi**, Romania
Université Rennes 1, France	**University of Birmingham**, United Kingdom	**ILK Dresden gGmbH**, Germany	**University of Vigo**, Spain	**Universidade de Lisboa**, Portugal
Wroclaw University of Science and Technology, Poland	**INDUSTRIES**			
	Synano-cooling	**JJ Bioenergy**	**End user company**	**Plin-Nanotechnology**

Illustration 2: Participants of the Strategic Meeting of Nanouptake COST Action in Birmingham.

3.1.3 METHODS

Primary research was conducted to obtain accurate data and qualitative assessments about the industry direction and to identify gaping holes in the implementation of nanofluids in the energy sector. Data was obtained through the following workshops:

- **SWOT analysis**: implementation of nanofluids in the industry.
- **Future strategies and collaborations.**

The audio of the meeting was recorded and photos were taken to document and analyse the key findings.

3.2 SWOT ANALYSIS

3.2.1 PROCESS

The **objective** of the workshop was to identify the main strengths, weaknesses, opportunities and threats on the commercial application of nanofluids as seen by researchers and industry participants. It was also expected to obtain proposals of contributions from Nanouptake to the given situation.

The **session** was distributed as following

Introduction and assignment:

With the aim of obtaining a visual SWOT analysis, each participant received a post-it to include one idea on each category: strengths, weaknesses, opportunities and threats. Industry representants received pink post-its, researchers received yellow ones and those who represented Nanouptake received green post-its. Instructions were given as well as support information with an orientation table (table 2).

Table 2: Support information for the analysis.

STRENGTHS	WEAKNESSES
Capabilities Competitive advantages Resources, assets and people Innovative aspects Price, value, quality Advantages	Lack of capabilities Reliability of data
OPPORTUNITIES	**THREATS**
Market development Industry trend Bussiness / product development Innovations & technology development	Obstacles to be faced Competitors Political & economical effects Legislative effects Loss of resources

Chart completed with the inputs of participants:

Participants completed the SWOT chart with their post-its.

Analysis of results:

After a review of the proposed chart, an analysis was followed and a debate was opened among participants.

Illustration 3: Pictures from the SWOT workshop in Birmingham.

Analysis of possible contributions from Nanouptake:

To conclude, participants shared their ideas about possible contributions from Nanouptake to overcome the barriers highlighted on the analysis. Those contributions may:

- Correct Weaknesses
- Adapt to /Adjusting the threats
- Maintain Strengths
- Explore the opportunities

3.2.2 RESULTS

With the contributions of all participants the chart was completed (table 3).

Table 3: Chart completed with the post-its of all participants.

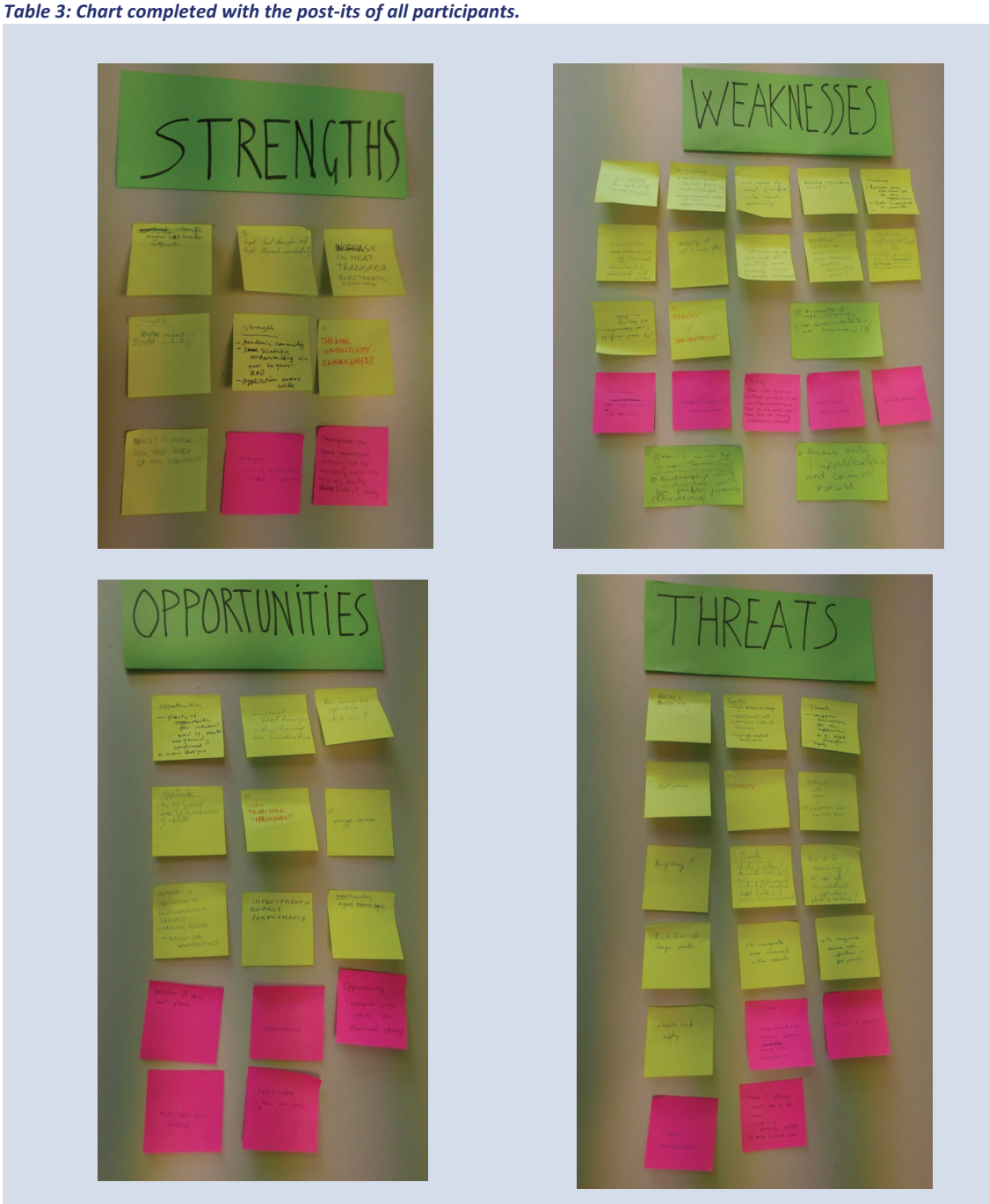


Illustration 4: Workshop in the strategic Meeting in Birmingham.

After the meeting, the notes from the post-its were written down (table 4) and the audios were listened to acquire the key ideas from the workshops.

To maintain the visual effect from the chart of the workshop, the ideas given by the industry representants are written in red in table 4, and the contributions suggested to Nanouptake are written in green. Moreover, with all the ideas received a cloud of words was created in order to take a glimpse of the concepts that were used the most (illustration 5).

Illustration 5: Cloud of words obtained from the contributions to the SWOT Analysis.

Table 4: Replies obtained in the SWOT analysis workshop of the strategic meeting in Birmingham.

INTERNAL FACTORS	
STRENGTHS (+)	**WEAKNESSES (-)**
- Higher heat transfer coefficients. - High heat transfer rate / high thermal conductivity. - Increase in heat transfer / electronic cooling. - Thermal conductivity enhancement. - Academic community. - Some scientific understanding via over 20 years R&D. - Wide application areas. - Expected impact in industry. - Ability to reduce size and price of the equipment. - Variety of solutions. - Number of applications. - Strengthen the bond between the industry and the university, since this is a very specific field of study.	- Low stability. - Low replicability. - Increased pumping power. - No long term studies for e.g. heat exchangers. - Environmental concern not clear. - Safety and health issues. - To improve the concept of “nanofluid” in the research community. - Higher mechanical energy. - Business cases not there yet for some applications. - Data inconsistent or unreliable - Lack of “coordinated” capabilities - Reliability of existing data and correlation (theory based) schemes - Lack of reliable source of nanofluids (with predictable properties and in large amount) - Devices operated with nanofluids must be more severely closed to avoid nanofluid escapes. - Stability at rest and under flow - Corrosion / Maintenance of chemical devices like heat exchangers not clear - To avoid nanofluids (paper, disseminations…) that they are non-stable - Stability / Sedimentation - Not high performance case sensitive - Materials / nanofluid characterization - Timing: Sometimes there is a different perception of the workflow between how fast we can work and how fast the industry wants / needs results. - Long-term performance - Legislation - Aerospace applications (no sedimentation, no humans) (absence of gravity) - Focus only in one application and cover all the process - Focus in nanoparticles that are not toxic - Parternship with industries for public financing (specific combination of Nanofluid and device)

EXTERNAL FACTORS	
OPPORTUNITIES (+)	**THREATS (-)**
- Industry is switching to environmentally friendly working fluids (perfect for nanoadditives) - Plenty of opportunities for industrial trial if results are genuinely confirmed. - New designs - Increase heat transfer when based on conduction - New unexpected applications. Which one? - Energy saving - Heat transfer improvement - Market “growing” - Industry awareness of capabilities - Improvement in energy performance - Good research topic - Integrate with CPCM for thermal storage. - Creation of new work places - New markets - Performance - More efficient process	- Health safety - High price - High pressure drop - Additional cost - Potential risk of fouling - Lack of market readiness - Competition of technologies for the applications e.g. Heat transfer - Safety - Toxicity - Reduced life span for the equipment and for the fluid - Recycling? - How to be convincing? To use nanofluids in industrial application, what is missing? - Production at large scale - To recognize some real application in few years. - To incorporate more chemists in the research - Difficulties for prototypes / demonstration (TRL’s > 5) - Not proving economical impact of nanofluids - Health and safety issues (nanobased) - Health & safety - Reproducibility - Corrosion effects - Health issue complexity - Health and safety - There is always more to be done - LCA is a pushing matter we need to deal with - Waste management

3.2.3 KEY FINDINDGS AND POSSIBLE ACTIONS

Once the SWOT grid was completed, the results were read and commented.

First of all, positive factors were analysed, then negative.

To conclude, there was an open debate to propose possible actions from Nanouptake to overcome the highlighted negative aspects and to foster the positive ones.

Illustration 6: Pexels.

- **Positive factors**

Regarding the positive factors, some issues were referred repeatedly. Some of them were related to **energy saving**, **efficiency**, **performance** and **heat transfer**. Those issues were referred equally by research institutions and industry representants.

On the other hand, other key factors mentioned several times were **thermal conductivity** and some **properties enhancement** that can produce some reduction in the price and the size of the equipments.

Moreover, it was also highlighted that the **variety of fields** is so high that many applications may appear, so it opens the opportunity to **combine the knowledge** from other fields and to use its advances and developments. Some examples were referred, for instance solar applications due to their positive impact in the renewable energy field.

- **Negative factors**

One of the negative issues more repeated, by industry and academic institutions representants, was **health and safety**, followed by **waste management**. There was an agreement about consideration of the **lack of legislation** that affects issues as health and safety, toxicity, environment, waste management or recycling.

Research institutions also named on many occasions the relevance of the **lack of information** and consistent data or of **long term studies**. Moreover, they also reiterated their concern about **stability**, **sedimentation and corrosion**. Corrosion effects were also pointed out by industry representants.

On the other hand, researchers also insisted on the **lack of real applications identified** to be applied in few years. Industry representants highlighted that sometimes is different the perception of the workflow between how fast research institutions can work and how fast industry needs results.

- **Proposals for Nanouptake**

Illustration 7: Pexels

To conclude, participants shared their ideas about possible contributions from Nanouptake to improve this scenario taking into account the network and its capabilities.

Some of the aspects that were aimed to respond were:

- To find real applications.
- Get arguments to justify the implementation of nanofluids in industry.
- Face health and safety issues.
- To identify stability and sedimentation problems to get reliability on nanofluids.

One of the first ideas that appeared was to explore the opportunity of **aerospace applications** (e.g. satellites). With the absence of gravity, sedimentation problems would be avoided. Moreover, with no humans involved, it would be possible to prevent health and safety issues.

Regarding corrosion effects and maintenance, two ideas have appeared:

- To obtain more grants to **research** on that field.
- To **focus on nanoparticles** that are no toxic, no corrosive and **no dangerous** for health.

Participants were asked to propose subjects of interest about nanofluids research. To encourage research, **partnership** with industries for public financing was recommended (specific combination of nanofluid and device).

It was also suggested to focus only on one application and cover all the process, including issues of concern as corrosion or stability.

The idea of focusing on **common topics** globally was also highlighted. These common topics would be:

1) health and safety

2) environmental valuables / recycling – reference to “circular economy”.

Illustration 8: Strategic meeting in Birmingham, February 2019.

3.3 FUTURE STRATEGIES & COLLABORATIONS

3.2.1 PROCESS

The **aim** of the workshop was to define future strategies and collaborations with the contributions from participants of the four industries that assisted to the meeting: (Synano-cooling, JJ Bioenergy, Plin-Nanotechnology and an End User company).

The **session** was distributed as following:

Introduction and assignment:

Three questions were proposed to the participants from industries to be shared in common. The questions were:

- What do I do now?
- What I want to do in the future?
- What do I need to achieve it?

For the last question they were asked to propose maximum 3 items. To smooth the development of the task, a table was handled to each industry (table 5).

Table 5: First assignment of the Future Strategies workshop in the strategic meeting.

Industry	What do I do now?	What I want to do in the future?	What do I need to achieve it?
Industry 1			1. 2. 3.
Industry 2			1. 2. 3
Industry 3			1. 2. 3.
Industry 4			1. 2. 3.

Task and sharing of the answers:

Participants completed their chart and shared their answers in common

Contributions to the needs of other industries:

Post-its were handled to all participants. They were asked to fill the post-it with the name of their institution and possible contributions from them to the items shared by all the industries as needs to achieve their goals (table 6).

Table 6: Second assignment of the Future Strategies workshop in the strategic meeting.

What do I need to achieve it? CONTRIBUTIONS FROM PARTICIPANTS	
Industry 1 1. 2. 3.	**Industry 2** 1. 2. 3.
Industry 3 1. 2. 3.	**Industry 4** 1. 2. 3.

Open debate to add possible contributions from Nanouptake:

The last minutes were dedicated to a debate to add possible contributions from Nanouptake. These contributions were summarized in post-its.

3.2.2 RESULTS

Each industry completed its own chart with post-its with answers to their questions. The answers of each industry were written down with a computer and screened during the meeting (illustrations 9 and 10 and table 7).

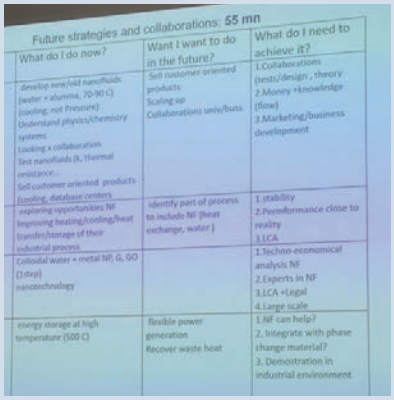


Illustration 9: Screening of the results of the workshop.

Illustration 10: Analysis of the results in the meeting.

Table 7: Results of the first assignment.

Industry	What do I do now?	What I want to do in the future?	What do I need to achieve it?
JJ Bioenergy	Energy storage at high temperature (500º)	• Flexible power generation. • Recover waste heat.	1. To increase the knowledge of nanofluids in order to identify if nanofluids may help to achieve the goals of (their) industry. 2. Integrate with phase change material. 3. Demonstration in industrial environment.
Synano Cooling	Develop new / old nanofluids. Water + aluminia, 70-90C. Cooling, not pressure. Understand physics and chemistry of systems. Looking for collaboration. Test of nanofluids (k, thermal resistance...). Selling customer oriented products (cooling, database centres).	• Selling customer oriented products. • Scaling up. • Collaboration with university / business.	1. Collaboration: Test, design, theory. 2. Money + knowledge. 3. Marketing and business development.
PLIN nanotechnology	Commission R&D. Colloidal water + metal NP, G, GO (1 step). Nanotechnology.	• Collaboration • Products to extend our portfolio as a company	1. Techno-economical analysis regarding nanofluids. 2. Experts in nanofluids. 3. LCA + legal. 4. Large scale.
End user Company	Exploring new opportunities of nanofluids. Improving heating / cooling / heat transfer / storage on their industrial process. Improve efficiency of the process.	• Identify part of the process to include nanofluids (heat exchange, water).	1. Stability. 2. Performance close to reality. 3. LCA.

After the screening, the rest of participants completed the chart of each industry with the contributions that may do.

The possible **contributions from Nanouptake** that were suggested in the open debate were summarize in post-its. These contributions are:

- H2020 project proposal with Nanouptake experts.
- Attend INCf 2019 to explore present applications.
- Attend ICNf to know nanofluids present research.
- STSM inside Nanouptake.

3.2.3 CONCLUSIONS

The **collaboration** between universities and industries was remarked as essential in order to overcome barriers in the implementation of nanofluids in the market.

Contributions from Nanouptake were suggested, highlighting the importance of **networking**, **research** and of **sharing knowledge** in order to advance in the market uptake of nanofluids.

Moreover, specific collaborations between companies and researchers were dealed individually between different parties, due to confidentiality reasons.

Illustration 11: Pexels.

3.4 TESTIMONIALS

"It was a great pleasure to participate in Nanouptake meeting in Birmingham. It was an exceptionally valuable gathering with very interesting researchers and new opportunities. The positive result of the meeting is that our company widens the research on nanofluids and reshapes the long-term goals"

Synano-cooling

"After the initial years of Nanouptake COST Action, the Strategic Meeting with the Core Group together with representatives of different industries has been a great opportunity to share the potential of the nanofluids in the energy applications and also the put in common the challenges that researchers and industries have to face to advance in this field"

UJI

"It was great to participate at such a complex meeting during Nanouptake COST Action: the Strategic Meeting with the Core Group together with representatives of different industries. It was a very good opportunity to share new ideas towards the nanofluids potential applications in the energy area and also to discuss some environmental aspects. The ideas exchanged with industry were extremely helpful and I acknowledge once again the relevance of such a meeting".

Gheorghe Asachi Technical University of Iasi

Section 4

4.1 QUESTIONNAIRE ANALYSIS

4.1.1 OBJECTIVES

The **objectives** of the questionnaire are:

- to identify the main concerns and expectations on bringing nanofluids closer to the energy industry as seen by experts in the field
- to analyse the perspectives about nanofluids market uptake, trying to better understand and plan future steps.

4.1.2 METHODS

An online questionnaire was designed highlighting the key findings of the Strategic Meeting once it was concluded and the results were gathered.

The survey was carried out in 2019 and consists of 22 questions divided into three sections. The aim of the first section, the introduction, is to obtain the profile of the people answering the questionnaire.

The second section is leaded to obtain an accurated SWOT analysis regarding the possible industrial implementation of nanofluids. So that, firstly were introduced the questions related to positive factors (strengths and opportunities) and then the negative ones (weaknesses and threats). Each one of the four sections of the SWOT included a multiple choice question followed by an open question that offered the possibility to participants to include new approaches not mentioned previously on the questionnaire.

The last section aims to gather ideas for the future with three open questions (the complete questionnaire is available on **section 5**).

4.1.3 PARTICIPANTS

The questionnaire was sent to over 260 individuals, suscribers to the Nanouptake network. Finally, 77 answers were received.

It must be emphasised, that these results do not necessarily give a complete picture of the institutions and countries involved. However, it is expected that the survey is a sufficient sample out of the population and gives reliable information.

4.1.4 RESULTS

Introduction: Profile of the participants

The answers received from 77 participants come from 24 countries. The majority of the participants (72.7%) are members of Nanouptake and belong to an organisation that works with nanofluids (85.7%).

Institution

Almost all the participants are members of an R+D+i institution (77%) or of a company (15%) **(figure 1)**.

More than a half of the institutions (52%) are located in Europe, 28% in Asia (in India 16%, 4% in the United Arab Emirates and 3% in Japan). Almost a quarter are located in America (13% in USA, in Canada, Brazil and Mexico a 3% of institutions in each one) **(figure 2)**.

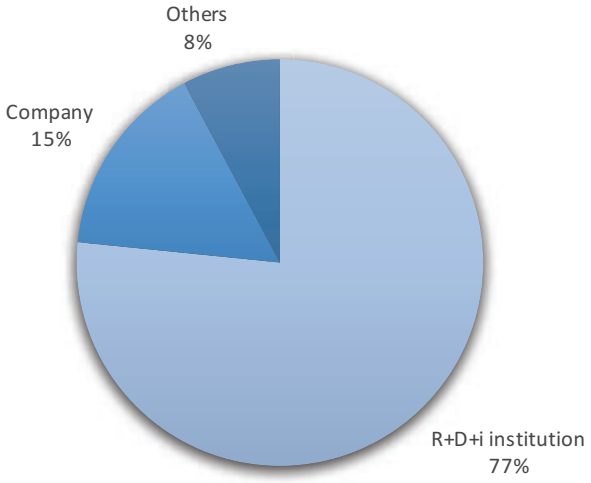


Figure 1: Institution

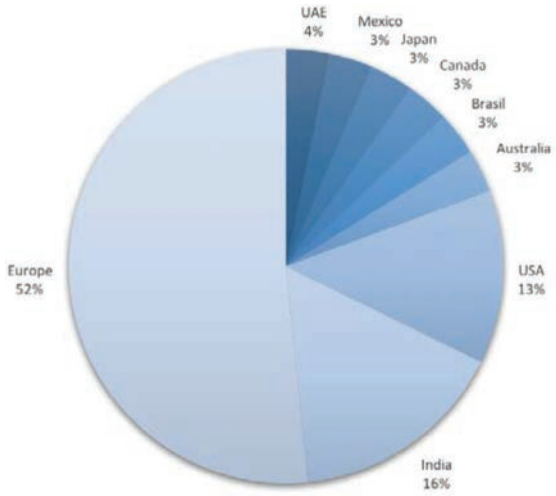


Figure 2: Country of the institution

SWOT analysis

STRENGHTS

The majority of the participants (70%) consider **termophysical properties** of the fluid the **main strength** (positive internal factors) of industrial implementation of nanofluids in the energy sector, followed by **energy saving** (62%).

More than a half of respondants considered the improvement of **thermal efficiency** on industrial processes (57%), **thermal conductivity** enhancement and higher **heat transfer coefficients** (both

56%) as main strenghts. Almost a half of the participants considered as a main strenght **tailored working fluids** for different applications.

On the other end of the scale, the area **least** perceived as a strength was the possible **heat capacity enhancements** (30%) **(figure 3)**.

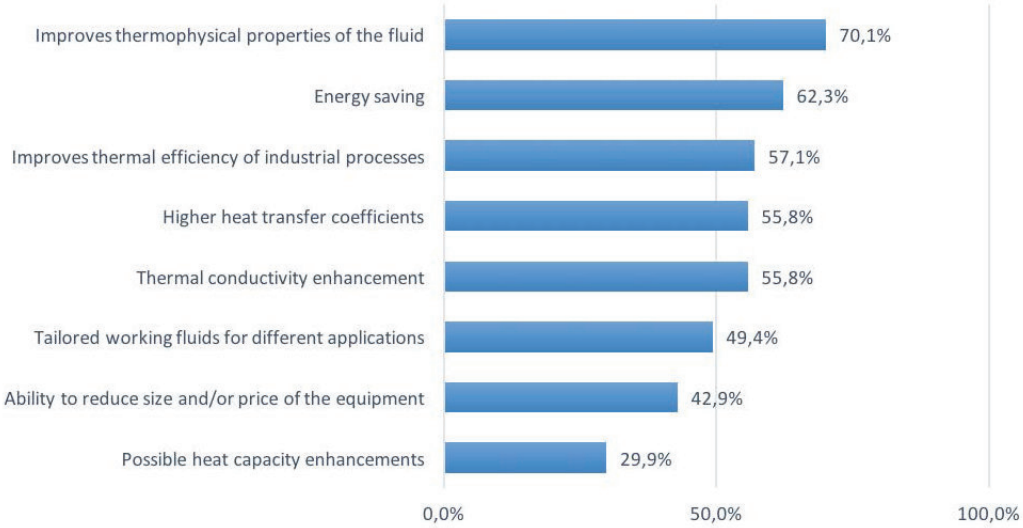


Figure 3: Main strengths of industrial implementation of nanofluids in the energy sector.

When asked about other possible strengths not previously mentioned that could be important, up to 17 participants proposed ideas.

The replies highlighted the importance of the **improvement of the thermophysical properties**, together with some others as **optical** or **catalytic** properties of the base fluids. Other answers remarked the **solar energy harvesting** potential together with the **solar absorption** enhancement of nanofluids. An interesting contribution about the nanofluids strength was: *"Nanofluids give more degrees of freedom to new thermal management systems' design, which are important when physical limitations to heat exchangers area reached and improvements are needed"*

Almost a half of the participants (47%) consider that the strenghts are medium, and only a 9% consider them low **(figure 4)**.

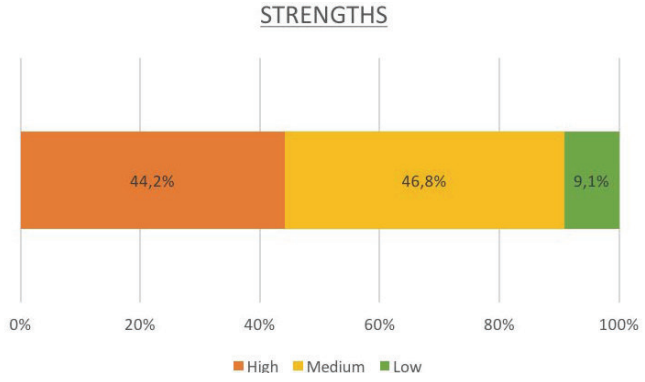


Figure 4: Perception of the strengths.

OPPORTUNITIES

According to the results, the **main opportunity** on the implementation of nanofluids in the energy sector is the possibility to **apply them to a wide variety of industrial areas** (73%), followed by the possibility of **new markets** (52%) and by the **academic research** (44%). Almost a quarter of the respondants consider the possible funding the main opportunity **(figure 5)**.

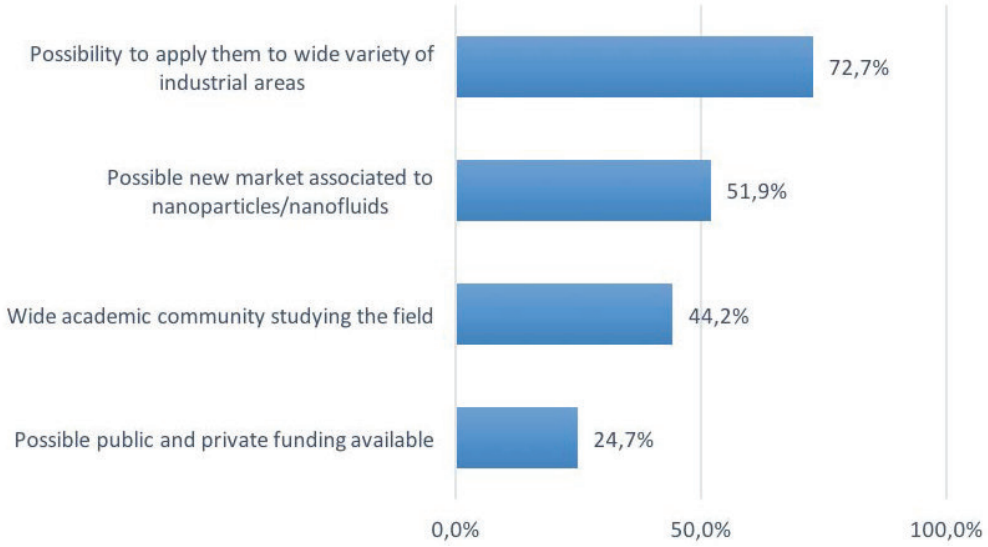


Figure 5: Main opportunities of industrial implementation of nanofluids in the energy sector.

When asked about other possible opportunities not previously mentioned that could be important, some participants proposed ideas. From this answers, the majority were related to **possible applications** like space, defense, solar collectors and renewable energies. Additionally, some replies highlighted the interesting opportunity to simply **replace the present base fluid** for the nanofluid to obtain a better efficiency without investment in the equipment replacement.

The majority of participants are optimistic about the opportunities as 40% considers them high, 44% medium and only 15% consider them low **(figure 6)**.

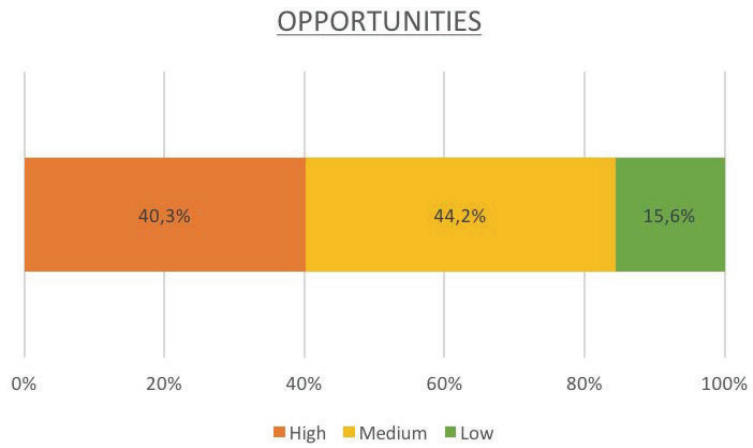


Figure 6: Perception of the opportunities.

WEAKNESSES

The majority of the participants (70%) consider the **poor long term stability** (at rest and during system operation) the **main weakness** on the implementation of nanofluids in the industry, followed by the effects of **higher viscosity**: increased pressure drop and pumping power (60%).

Less than a half consider the main weakness the lack of universally accepted theoretical models (45%), disagreement between different experimental data (43%), possible problems during use (43%), high production cost (38%) and disagreements between experimental findings and the theoretical model predictions (32%) **(figure 7)**.

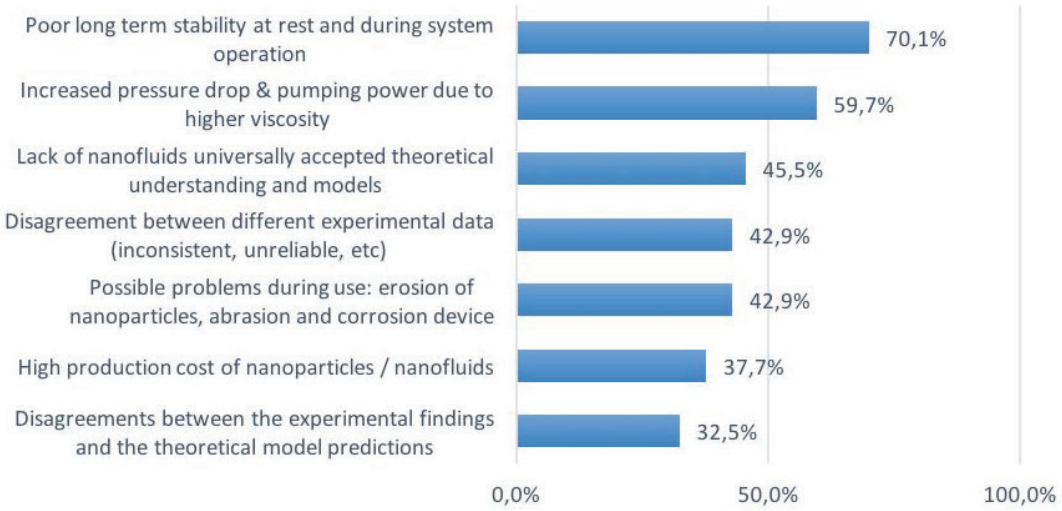


Figure 7: Main weaknesses of industrial implementation of nanofluids in the energy sector.

When asked by not previously mentioned weaknesses, participants shared some ideas. Most of them were related to the **lack of proof of concept** of selected nanofluids for given applications, **lack of experimental protocols** to reduce the inconsistent experimental data and **lack of long term studies** of nanofluids in operating systems.

More than a half of participants (61%) consider weaknesses medium, 26% high and 13% low **(figure 8)**.

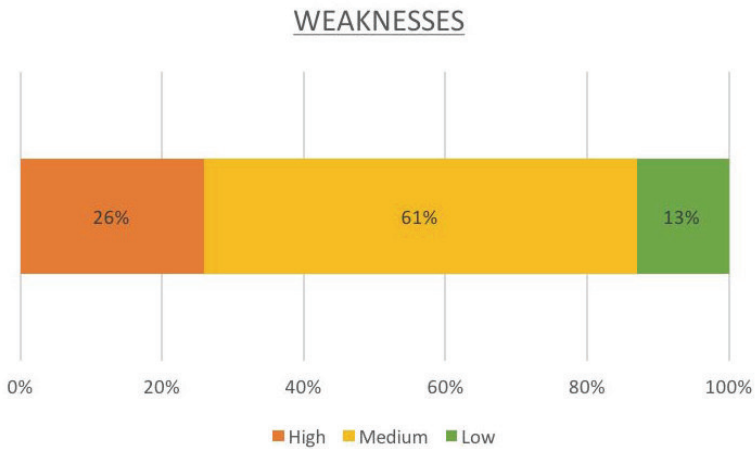


Figure 8: Perception of weaknesses

THREATS

According to the results, **health, safety and environmental** issues are the main concern (62%), followed by the **lack of tests** in specific industrial applications (60%) and by incomplete nanofluids **Life Cycle Analysis** (57%).

Less than a half consider the main threat the **characterisation of nanofluids under industrial application conditions** (47%), the lack of clear **legislation** (40%) or of developed nanofluids **industrial manufacturing methods** (31%) and of **coordinated efforts** from different research fields (27%). To conclude, only 23% considered the **lack of funding** to develop specific nanofluids to higher TRL levels **(figure 9)**.

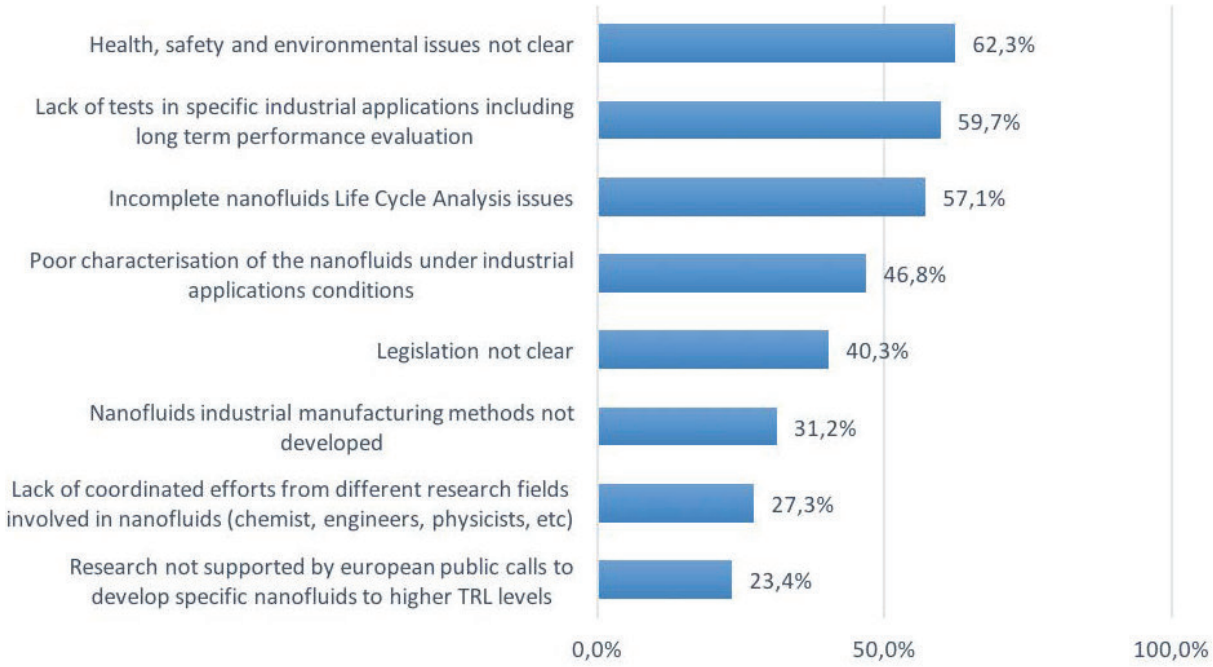


Figure 9: Main threats of industrial implementation of nanofluids in the energy sector.

Few ideas were proposed by participants when asked about other possible threats not mentioned previously. It was highlighted the threat of **competing technologies** and the traditional industrial **attitude towards innovation**. It was also pointed out the **lack of institutions** involved in all the nanofluids process, from nanoparticle preparation to nanofluids stage development. It was also mentioned the lack of involvement of chemical specific knowledge when dealing with compatibility between nanoparticles and base fluids that could improve the nanofluids stability from the beginning.

The majority of participants (73%) consider that the threats are medium, 19% consider them high and only 8% consider them low **(figure 10)**.

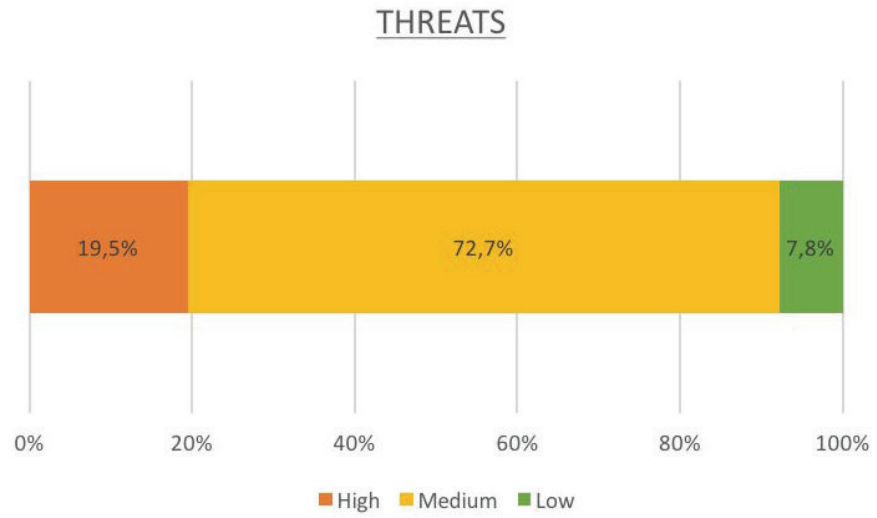


Figure 10: Perception of threats.

The majority of participants are optimistic about positive aspects, considering higher the strengths (44%) and opportunities (40%) than the weaknesses (26%) and threats (19%).

On the other hand, the amount of participants that consider the aspects low is similar in positive aspects (strengths 9% and opportunities 16%) and negative (weaknesses 13% and threats 8%) **(figure 11)**.

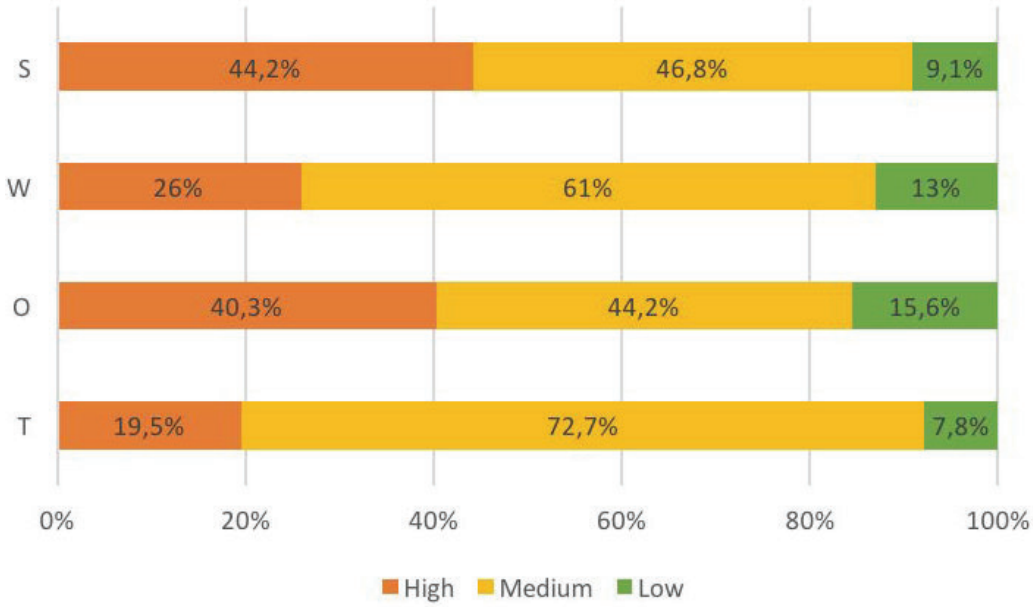


Figure 11: Comparison of the perception of strengths, weaknesses, opportunities and threats.

IDEAS FOR THE FUTURE

IDEAS TO OVERCOME THE THREATS

Three main ideas were grouped from the 35 replies in the survey:

- To work in **close collaboration with the industry**, understanding of the industrial needs and identifying a specific application to orientate the nanofluids research. Once this case study and proof of concept has been selected, to develop all the staged of research, from the initial chemical compatibility study of nanoparticles and base fluid, to basic characterization, but also including many tests under large scale and industrial conditions and with long term operation,
- To **promote bigger and publicly funded research communities** in nanofluids, coordinating joint communication, research and development from different fields (scientists, chemists, physicists, engineers, biologists, doctors, industry, etc) and also combining different focus (from fundamental research, including nanoparticle/nanofluids production, toxicology, environmental and LCA investigation up to industrial applications),
- To advance in a common, agreed and **universal nanofluids legislation and safety guides**. Additionally, specific normative and specialised laboratories to measure nanofluids' real performances. A standard is needed easy to understand by developers and industry or final users.

IDEAS TO PROMOTE THE INDUSTRIAL IMPLEMENTATION OF NANOFLUIDS IN THE ENERGY SECTOR

Some of the issues raised among the 31 replies of the questionnaire were the following:

- **More dissemination** and public funding of only reliable nanofluids research results (improving the quality of the research published in the public domain), creating awareness and trustable applications of nanofluids on the different industrial fields.
- **More collaborations and partnerships** between industrial sector and academia and research, for example organizing specific meetings, exhibitions, conference or workshops with different sector of the involved industry, joint and collaborative projects at European level, etc.
- Design, implementation and long term **reliable testing in real operating conditions** of nanofluids in specific prototype industrial applications and pilot plants (instead of only in lab scale), increasing the TRL in promising applications.

IDEAS FOR EUROPEAN NANOFLUIDS NETWORKS (AS NANOUPTAKE) TO PROMOTE THE INDUSTRIAL IMPLEMENTATION OF NANOFLUIDS IN THE ENERGY SECTOR

Many ideas arose from the 42 replies in the survey. Some of the shared ideas are already being done by Nanouptake as:

- Promoting and enhancing **international networking**, collaborations, cooperations brain storming, partnerships and feedback of both industry and academia and also among the researchers in the field of research.
- **Sharing and exchanging** experiences, knowledge, ideas, findings, equipments, test benches and materials that could lead to further results.
- Providing **expertise knowledge** and giving advices for specific industrial investigations.
- Establishing **technology transfers** and also showing, expanding and promoting nanofluids results.
- Enhancing key partnerships for **future industry - academia joint projects** in the field
- **Searching nanofluids applications** different from thermal exchange that are promising as for example two-phase cooling or optical, catalytic, magnetic and electronic improved properties of low concentration nanofluids

Additionally, some **relevant testimonies** have been selected here from the replies:

- Industrial implements mainly depend on provided basic research and outcomes. Which could be acceptable for all industries having easy methods and cost effective with more stability of product. Nanouptake is giving such a basic and acceptable research for all researches and industries which is very appreciable.
- Nanouptake helps advertising the research that has been carried out, help researchers on the field to work together towards the same direction, and brings industry into the topic for future collaborations
- European networks such as Nanouptake are key to join the necessary efforts that will allow the better understanding and design of advanced nano-enhanced thermal fluids.

Figure 12: Pexels

Furthermore, there are also some interesting **ideas that the network could improve** in the future:

- **Disseminate** the nanofluids results in:
1. European industries related with energy
2. meetings/conferences organized by (and for) companies or societies of companies
3. periodic summary for the industry sector of most interesting papers of the network

- **Promote industrial tests and trials**, and show up the results very quick, this will make a call effect wave.

- To orientate the efforts of the network towards the **development of a nanofluid commercially attractive product**, identifying research institutions among the network for specific outcomes at the different steps in this development.

- Set up a **centralised and autonomous organisation** with physical presence and permanently employed staff to tackle problems and setup industrial collaborations from the Nanouptake network.

Figure 13: Pexels

4.1.5 CONCLUSIONS

In conclusion, it is evident that a large proportion of experts considers that the opportunities and strengths of the implementation of nanofluids in the market overcome the threats and weaknesses.

Among the **positive aspects**, those that were highlighted are:

+ Improvement of the **thermophysical properties of the fluid**
+ Possibility to **apply nanofluids to a wide variety** of industrial areas

However, a significant number of **negative aspects** were outlined, being remarkable the concern about the **poor long term stability** and about **health, environmental and safety** issues.

The findings of this survey indicates that networking and research communities are key to overcome barriers in the implementation of nanofluids in the market. Moreover, it is also pointed out that is needed to advance in a common and agreed nanofluids legislation and safety guides.

Section 5

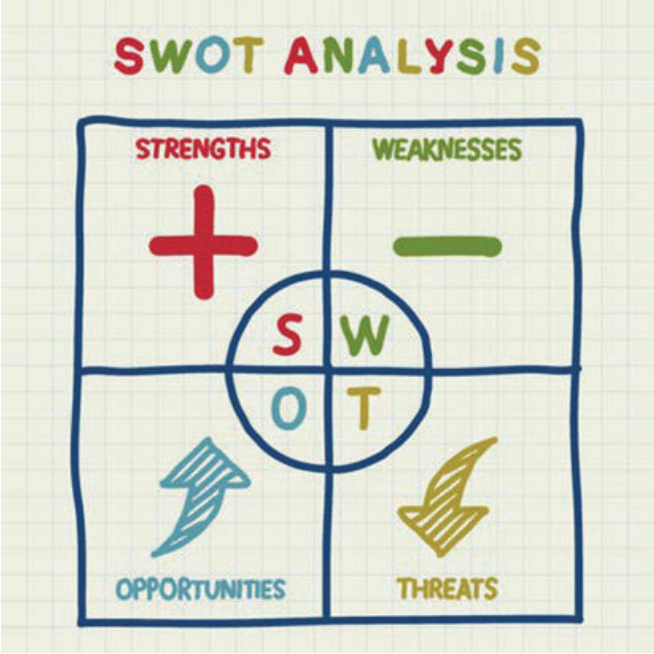
5.1 ANNEX

5.1.1 NanoIndustry Questionnaire

NanoIndustry questionnaire

Thank you for agreeing to take part in this questionnaire from the Nanouptake Cost Action (www.nanouptake.eu). The questionnaire is based on a SWOT analysis regarding the possible industrial implementation of nanofluids. Our aim is to gather your thoughts and opinions on this subject, compiling the global results in a Nanouptake public report.
This questionnaire will only take about 5-10 min to complete. Please be assured that all your responses are anonymous and will be kept in strictest confidentiality.

* Required



Introduction

1. **Name of the person filling the form:**

2. **Are you a member of the Nanouptake Cost Action (www.nanoupake.eu) ? ***
Mark only one oval.

- Yes
- No

3. **Are you a member of an R+D+i institution or a company?** *
Mark only one oval.

- ◯ R + D + i institution
- ◯ Company
- ◯ Others

4. **What is your position in the institution / company?**

_____

5. **What is the field of your institution / company?**

_____

6. **Country where the academic institution or company is situated:** *

_____

7. **Does your organisation deal with nanoparticles/nanofluids?** *
Mark only one oval.

- ◯ Yes
- No

SWOT analysis about the industrial implementation of nanofluids in the energy sector.

8. **In your opinion, the main STRENGTHS (positive internal factors) of the industrial implementation of nanofluids in the energy sector are: (multiple choice)** *

Check all that apply.

- [ ] Improves thermophysical properties of the fluid
- [ ] Tailored working fluids for different applications
- [ ] Thermal conductivity enhancement
- [ ] Possible heat capacity enhancements
- [ ] Higher heat transfer coefficients
- [ ] Ability to reduce size and/or price of the equipment
- [ ] Improves thermal efficiency of industrial processes
- [ ] Energy saving

9. **Please explain any other STRENGTH not mentioned above that could be important:**

_____

_____

_____

_____

_____

10. **In your opinion, the STRENGTHS of the possible implementation of nanofluids in the energy sector are: (choose one)** *

Mark only one oval.

- ◯ Low
- ◯ Medium
- ◯ High

11. **In your opinion, the main OPPORTUNITIES (positive external factors) of the industrial implementation of nanofluids in the energy sector are: (multiple choice)** *
Check all that apply.

- [ ] Possibility to apply them to wide variety of industrial areas
- [ ] Possible new market associated to nanoparticles/nanofluids
- [ ] Wide academic community studying the field
- [ ] Possible public and private funding available

12. **Please explain any other OPPORTUNITY not mentioned above that could be important:**

_____

_____

_____

_____

_____

13. **In your opinion, the OPPORTUNITIES of the possible industrial implementation of nanofluids in the energy sector are: (choose one):** *
Mark only one oval.

- ◯ Low
- ◯ Medium
- ◯ High

14. **In your opinion, the main WEAKNESSES (negative internal factors) of the industrial implementation of nanofluids in the energy sector are: (multiple choice)** *
Check all that apply.

- [ ] Poor long term stability at rest and during system operation
- [ ] Increased pressure drop & pumping power due to higher viscosity
- [ ] Possible problems during use: erosion of nanoparticles, abrasion and corrosion device
- [ ] High production cost of nanoparticles / nanofluids
- [ ] Disagreement between different experimental data (inconsistent, unreliable, etc)
- [ ] Disagreements between the experimental findings and the theoretical model predictions
- [ ] Lack of nanofluids universally accepted theoretical understanding and models

15. **Please explain any other WEAKNESS not mentioned above that could be important:**

_____

_____

_____

_____

_____

16. **In your opinion, the WEAKNESSES of the possible industrial implementation of nanofluids in the energy sector are: (choose one)** *

Mark only one oval.

- ◯ Low
- ◯ Medium
- ◯ High

17. **In your opinion, the main THREATS (negative external factors) of the industrial implementation of nanofluids in the energy sector are (multiple choice)** *

Check all that apply.

- ☐ Nanofluids industrial manufacturing methods not developed
- ☐ Poor characterisation of the nanofluids under industrial applications conditions
- ☐ Lack of tests in specific industrial applications including long term performance evaluations
- ☐ Incomplete nanofluids Life Cycle Analysis issues
- ☐ Research not supported by european public calls to develop specific nanofluids to higher TRL levels
- ☐ Lack of coordinated efforts from different research fields involved in nanofluids (chemist, engineers, physicists, etc)
- ☐ Legislation not clear
- ☐ Health, safety and environmental issues not clear

18. **Please explain any other THREAT not mentioned above that could be important:**

19. **In your opinion, the THREATS of the possible industrial implementation of nanofluids in the energy sector are: (choose one)** *

Mark only one oval.

- Low
- Medium
- High

Ideas for the future

20. **Do you have any ideas on how to overcome the nanofluids THREATS?**

21. **Do you have any idea to promote the industrial implementation of nanofluids in the energy sector?**

22. **How do you believe that a european nanofluids network (as for example Nanouptake) could help to promote the industrial implementation of nanofluids in the energy sector?**

Thank you!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