H2020 FETHPC-1-2014

Enabling Exascale Fluid Dynamics Simulations
Project Number 671571

D4.2 – Exploitation Plan Revision 1

(Also contains D4.4 – Innovation Management Report, D4.7 - Dissemination and Communication - Activities and Results, D4.10 – Collaboration Report - Update 1)

WP4: Dissemination and Exploitation

Document Information

Deliverable Number	D4.2, D4.4, D4.7, D4.10
Deliverable Name	Dissemination, Exploitation, Collaboration and Innovation Management Report
Due Date	31/03/2017 (PM18)
Deliverable Lead	USTUTT
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Keywords	Dissemination, Exploitation, Innovation management, Collaboration, Standardisation
WP	WP4
Nature	R
Dissemination Level	PU
Final Version Date	31/03/2017
Reviewed by	Erwin Laure, Philipp Schlatter
MGT Board Approval	31/03/2017

Document History

Partner	Date	Comments	Version
USTUTT	14.12.2016	Frist draft	0.1
IC, USTUTT, SOTON, KTH	20.02.2017	Inputs to tables	0.2
KTH	1.3.2017	Document review	0.7
USTUTT	16.3.2017	Update after review	0.9
KTH	31.3.2017	Final version	1.0

Executive Summary

This deliverable is a merge of several deliverables of WP4 (D4.2, D4.4, D4.7, D4.10) which were all planned for PM18. The merge was approved by the Project Officer in order to avoid the submission of many individual documents with inevitable redundancy among them. It contains updated versions of the Exploitation Plan D4.1, Dissemination and Communication Plan D4.6 and Collaboration Report D4.9 as well as a plan and report on Innovation management D4.4. It reports on the first 18 months of activities in all these areas and list WP4 plans for the rest of the project. Some highlights of this deliverable are the 16 presentations of the project at conferences and events and the excellent traffic on the website, surpassing the goal set. Further on, the document contains a detailed calendar of past and future events and describes progress achieved with respect to Exploitation results, IPR and Technology Readiness Levels. The document also includes a brief report on the market outlook in HPC technology and CFD software. Finally, this deliverable outlines the intentions of ExaFLOW in regards to standardisation activities.

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1 Introduction

The primary aim of this document is to report on activities of WP4 that took place in the first 18 months of the project and plan on exploiting project results, disseminating those, as well as establishing collaborations with other projects and organisations to secure the sustainability and continuity of the research in scaling towards the exascale.

As it is impossible to plan precisely for the longer term at this point of time, this document will undergo continuous updates until the end of the project and so will be considered a living document. The aim of this, apart from more accurate planning, is to ensure that changes in the ambitions of ExaFLOW and the engagement opportunities found may be documented in a coherent manner throughout the project. The next timed deliverables will represent a snapshot of the document.

The engagement described consists of a number of routes, such as through collaboration with EC and other EU projects, and designed to foster co-operative working and results sharing. In addition to the formal groups we recognise that there will be a number of opportunities for bi-lateral interactions between ExaFLOW and other activities. This document reports on these engagements.

Alongside the mandated H2020 collaboration we acknowledge and pursue collaboration with other projects, funded by other-than-the-EC funding schemes, i.e. local and national governments and international sources. Again this document reports on these engagements.

Finally, ExaFLOW plans to contribute to standardisation processes where applicable. Through partnerships with other projects, ExaFLOW will connect with relevant stakeholders such as technology platforms, standardisation bodies and governance stakeholders. These partnerships and strategic actions will position ExaFLOW at an important juncture between research, infrastructure building and impact generation.

2 Dissemination (D4.7)

2.1 Goals and tools of dissemination

In the ExaFLOW project both dissemination and communication are managed as a continuum. This is because the two are aligned around strategic timing, and targets, leverage social media and are monitored for success (with KPIs). Moreover, cross-fertilization of dissemination and communication is important and cost-effective (e.g. blogging or tweeting in parallel to publishing or presenting results) because although the means and audiences are distinct, the overall impact can be multiplied.

An overall dissemination strategy was drawn in the Initial Dissemination Plan in deliverable D4.6. We stated there the identified target groups and the most

appropriate means to target them. We also defined the level of interaction that is necessary through time from awareness over understanding up to action/collaboration. Dissemination is of similar importance for the academic/scientific communities as well as for the industrial players. For the latter group the goal is that dissemination activities transition into collaboration and finally exploitation activities towards the end of the project.
It is important to note that ExaFLOW complies with all guidelines outlined in the "The EU guide to communication" published by the Research and Innovation Directorate-General of the European Commission.
In the paragraphs below we report on Dissemination KPIs and show progress achieved using each dissemination tool separately.

2.2 Progress with dissemination KPIs

To monitor the dissemination progress of ExaFLOW, a number of Key Performance Indicators (KPIs) has been identified, for the project (Table 1). We have added a new KPI to the set of dissemination KPIs for this report: the number of blog entries per year. We are aiming for at least 2 entries per partner per year. That way we manage to increase the traffic on our website. The EB monitors the progress of the project against these KPIs on a monthly basis and reports on them in the project reports.

KPI	Target	Progress M1 – M18
Journal papers (see section 2.8)	8	2
Conference proceedings (see section 2.8)	20	4
Conference presentations (see section 2.10.1)	25	16
Whitepapers (see section 2.8)	2	0
Press releases (see section 2.6)	2	1
Presence at events (see section 2.10.1)	2	6
Trainings (see section 2.9)	1	1
Website visits (see section 2.3)	3000 p.a., 40% spend > 2 min on site	13439 in 2016, avg. session 00:03:25
Social media (see section 2.5)	Twitter account with bi-weekly updates	Twitter account with weekly updates and special campaigns for the blog posts
Blog entries (see section 2.4)	15	8

Table 1 – Dissemination KPIs for the project

2.3 Website

The website of the project has been updated with short scientific papers describing the use cases, which made these pages the most popular pages of the website (see figure below).

Figure 1 - Most popular pages on the ExaFLOW website

Extra traffic has been attracted to the website with bi-weekly blog posts

2.4 Blogging/ Newsletter

After the all-hands meeting in London in September 2016, the consortium decided to start a series of blog publications on topics relevant to ExaFLOW work, as well as on topics of major interest to specific partners. In 3 months we managed to reach the target set during the meeting in London and release 6 blog entries (1 blog entry every 2 weeks). The topics of the blog entries are the following:

- ExaFLOW at the 8th annual general meeting of asc(s; posted on 2016-12-07
- Implementation of h-type refinement in Nek5000; posted on 2016-11-15
- OpenSBLI codegen framework for modelling with finite difference methods; posted on 2016-11-15
- Nektar++ Aorta Test Case on ARCHER: Improving I/O Efficiency for ExaFLOW Use Cases; posted on 2016-11-02
- ExaFLOW Resilience at HPDC'16 Symposium; posted on 2016-10-17
- Weak Dirichlet Boundary Conditions and Hybrid DG on Groups of Elements; posted on 2016-12-14
- Performance evaluation of explicit finite difference algorithms with varying amounts of computational and memory intensity; posted on 2017-01-19
- Data compression strategies for exascale CFD simulations; posted on 2017-02-02

2.5 Social media

Social media has been used to increase traffic on the website. We used twitter campaigns for each new blog post on the website, twitting about each post for two weeks in a raw. This had very positive effects and indeed increased the traffic on the website allowing us to surpass our target for the number of visitors. Moreover, partners helped create conversations in twitter by posting about new software releases and publications.

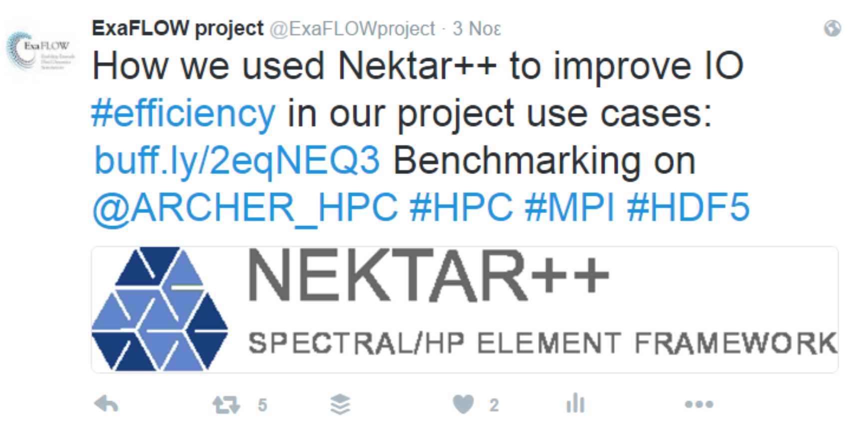

Figure 2 - Tweet sample from the twitter campaign for new blog entries

Noteworthy is that ExaFLOW follows the official Twitter account for the Horizon 2020 programme @EU_H2020 and participates in the community of projects on social media, using the newly created hashtag #ResearchImpactEU when announcing "breaking news".

2.6 Press releases

In the end of 2015 and during the summer of 2016 there were 5 mentions of the ExaFLOW project in the press:

- Scientific Computing World, 28 October 2015, Europe spends to strengthen its HPC: https://www.scientific-computing.com/news/analysis-opinion/europe-spends-strengthen-its-hpc
- Inside HPC, 28 October 2015, European Commission Steps Up Funding of HPC: http://insidehpc.com/2015/10/european-commission-steps-up-funding-of-hpc/
- HPCwire, 12 July 2016, ISC Workshop Tackles the Co-development Challenge: https://www.hpcwire.com/2016/07/12/isc-workshop-tackles-co-developments-thorny-challenges/
- Scientific Computing World, 3 August 2016, Exploring energy efficiency: https://www.scientific-computing.com/news/analysis-opinion/exploring-energy-efficiency
- Inside HPC, 5 August 2016, Adept Project Explores HPC Energy Efficiency: http://insidehpc.com/2016/08/exploring-energy-efficiency/

In November 2016 ExaFLOW published an official press release, timing it strategically just before the SC16 Conference. The main goal of this press release was to announce the presence of the project at the conference and point interested audience to the booths of two ExaFLOW partners: EPCC and HLRS. Links to the publications are provided below:

- Inside HPC, 8 November 2016, ExaFLOW Funds CFD Research for Exascale: http://insidehpc.com/2016/11/bringing-europes-cfd-community-one-step-closer-to-exascale/

- HPCwire, 9 November 2016, ExaFLOW Project Secures Funding: https://www.hpcwire.com/off-the-wire/exaflow-project-secures-funding/
- Scientific Computing World, 10 November 2016, Bringing Europe's CFD community one step closer to exascale: https://www.scientific-computing.com/news/bringing-europe%E2%80%99s-cfd-community-one-step-closer-exascale
- CFD online, 8 November 2016, Bringing Europe's CFD community one step closer to exascale: https://www.cfd-online.com/Forum/news.cgi/read/101657

2.7 Printed materials

Posters were used during the presentations of the project at different events and over a hundred flyers were distributed at two major HPC events during 2016: ISC16 and SC16. Updated versions of both the flyer and poster might take place during year 2 or 3, to showcase results of the project.

2.8 Publications and whitepapers

Below are listed the publications that members of the ExaFLOW project have authored during the first year of the project:

- Jacobs, C. T., Jammy, S. P., Sandham, N. D. (2017). OpenSBLI: A framework for the automated derivation and parallel execution of finite difference solvers on a range of computer architectures. *Journal of Computational Science*, 18:12-23, DOI: http://doi.org/10.1016/j.jocs.2016.11.001
- Jammy, S. P., Jacobs, C. T., Sandham, N. D. (In Press). Performance evaluation of explicit finite difference algorithms with varying amounts of computational and memory intensity. *Journal of Computational Science*. DOI: http://doi.org/10.1016/j.jocs.2016.10.015
- Michael Bareford, Nick Johnson, and Michèle Weiland. 2016. On the trade-offs between energy to solution and runtime for real-world CFD test-cases. In *Proceedings of the Exascale Applications and Software Conference 2016* (EASC '16). ACM, New York, NY, USA, Article 6, 8 pages. DOI: http://dx.doi.org/10.1145/2938615.2938619
- D. Moxey, C. D. Cantwell, G. Mengaldo, D. Serson, D. Ekelschot, J. Peiró, S. J. Sherwin and R. M. Kirby, Towards p-adaptive spectral/hp element methods for modelling industrial flows, under review in proceedings of the International Conference on Spectral and High-Order Methods, 2016.
- A. S. Nielsen and J. S. Hesthaven, 2016. Fault Tolerance in the Parareal Method. *Proceedings of the Fault Tolerance for HPC at eXtreme Scale Workshop* at the 25th ACM Symposium on High-Performance Parallel and Distributed Computing
- Offermans, N., Marin, O., Schanen, M., Gong, J., Fischer, P., Schlatter, P. On the Strong Scaling of the Spectral Element Solver Nek5000 on Petascale Systems in Proceedings of the Exascale Applications and Software Conference 2016. DOI: https://doi.org/10.1145/2938615.2938617

- M. Vymazal, D. Moxey, C. Cantwell, S. Sherwin and M. Kirby: "Towards combined CG-DG for elliptic problems", proceedings of SIAM 2017 (under review)
- Spencer Sherwin, Jean-Eloi Lombard, David Moxey, Joaquim Peiro Rodrigo Moura, Gianmarco Mengaldo: "Implicit LES Spectral/hp Element Modelling of Flow Past Complex Geometries Related to Formula 1", proceedings of ICOSAHOM 2016
- Chris Cantwell: "Towards resilience at exascale: How to work with a supercomputer which breaks every few minutes" presented at SC16 in Salt Lake City, November 2016

2.9 Training

One training has been delivered so far on Nektar++ in the form of a workshop in June 2016 by IC. Similarly, a Summer School on numerical methods in CFD (see http://www.flow.kth.se/?q=node/255) was organized by KTH in April 2016, where one day was devoted to Nek5000 and its implementation. In the future we plan to set up at least one more special training around the use of CFD on HPC and more precisely an Exascale machine. The trainings will take into account training activities in Europe such as the PATC and national activities and thus will be available on a demand base to everyone interested.

2.10 Dissemination and collaboration events

2.10.1 Report on dissemination and collaboration events

Below is the table of collaboration actions (Table 2), in which partners have participated since the beginning of the project. It is compiled based on partner inputs.

Date	Location	Event description
23 September 2015	Rome, Italy	European eXtreme Data and Computing Initiative workshop in Rome for FET projects and Centres of Excellence (CoE) related to HPC
23 February 2016	Leinfelden-Echterdingen, Germany	Key note presentation and poster presentation at the ASCS workshop "Simulation Driven Design for Computational Fluid Dynamics"
8 March 2016	Reading, UK	Presentation at the European Centre for Medium Range Weather Forecasts
16-17 March 2016	Sendai, Japan	Uwe Küster presented ExaFLOW as pasrt of his presentation on "Spectral structures for nonlinear operators on arbitrary compact spaces" at the 23th Workshop on Sustained Simulation Performance (WSSP)

26-29 April 2016	Stockholm, Sweden	Exascale Application & Software Conference
9-12 May 2016	Prague, Czech Republic	European HPC Summit Week organised by European Extreme Data & Computing Initiative
12 May 2016	Leinfelden-Echterdingen, Germany	Presentation of the ExaFLOW project at the ASCS general assembly 2016
31 May - 4 June 2016	Kyoto, Japan	The 25th international symposium on high performance parallel and distributed computing (HPDC'16)
7-8 June 2016	London, UK	Nektar++ workshop organised by ICL
8-10 June 2016	Lausanne, Switzerland	Platform for Advanced Scientific Computing Conference (PASC'16): EPFL talk titled "Space-Time Parallelism for Hyperbolic PDEs"
19-23 June 2016	Frankfurt, Germany	ISC High Performance 2016
24-28 June 2016	Rio, Brazil	ICOSAHOM: International Conference on Spectral and High Order Methods Methods
21-26 August 2016	Montreal, Canada	ICTAM: The wing test case was presented in the context of the ExaFLOW project by Philipp Schlatter
7 – 9 September 2016	London, UK	Presentation by SOTON about OpenSBLI at the UK Fluids Conference at Imperial College London.
13-18 November 2016	Salt Lake City, USA	SC 2016, International Conference for High Performance Computing, Networking, Storage and Analysis
23 November 2016	Oxford, UK	Seminar presentation by SOTON about OpenSBLI at the University of Oxford.
21-23 November 2016	Toulouse, France	1st TILDA Symposium and Workshop on Industrial LES & DNS., CERFACS. Presentation by SOTON on "High-order simulations of shock-wave/boundary-layer interactions: Current state of the art and software future-proofing" by Neil D. Sandham, Satya P. Jammy and Christian T. Jacobs
5-6 December 2016	Stuttgart, Germany	Patrick Vogler and Ulrich Rist presented ExaFLOW in their presentation on "Data compression strategies for exascale CFD

		simulations". 24th Workshop on Sustained Simulation Performance (WSSP)
5-6 December 2016	Stuttgart, Germany	Uwe Küster presented ExaFLOW in his presentation on "Spectral decomposition of nonlinear Trajectories" at the 24th Workshop on Sustained Simulation Performance (WSSP)
24 February 2017	Kobe, Japan	Presentation of ExaFLOW at the 7th AICS International Symposium

Table 2 – Past collaboration events overview (M1-M18)

2.10.2 Plan for dissemination and collaboration events

Below is the table of planned collaboration actions (Table 3), in which partners will participate in the future. It is compiled based on partner inputs. Highlights are the events to be organised by ExaFLOW: a workshop at the ParCFD Conference and a minisymposia session at PASC.

Date	Location	Event description
5-6 April 2017	Hanau, Germany	Poster presentation at the Automotive CAE Grand Challenge 2017
15-19 May 2017	Barcelona, Spain	European HPC Summit Week 2017
15-17 May 2017	Glasgow, UK	ParCFD 2017: ExaFLOW will organize the workshop "Towards Exascale in High-Order Computational Fluid Dynamics". Also SOTON will present project work on error indicators and OpenSBLI developments
June 2017	Leinfelden-Echterdingen, Germany	Presentation of the ExaFLOW project at the ASCS general assembly 2017
18-22 June 2017	Frankfurt, Germany	ISC High Performance 2017: ExaFLOW will organize the workshop "Interdisciplinary CHallenges Towards Exascale FLuid Dynamics"
26-28 June 2017	Lugano, Switzerland	PASC 17: ExaFLOW will organize the minisymposia "Enabling Exascale Fluid Dynamic Simulations"
10-14 July 2017	Pittsburgh, USA	Participation in a minisymposium on exascale at the SIAM Annual Meeting
30 July – 3 August 2017	Waikoloa, Hawaii	ASME FEDSM: Panel and Keynote on Exascale Methods in industrial CFD

12 - 17 November	Denver, USA	SC 2017, Supercomputing Conference

Table 3 – Future collaboration events calendar

3 Collaboration activities (D4.10)

3.1 Report and plan on collaboration activities

3.1.1 Collaboration on European and national levels

3.1.1.1 Collaboration with EU projects

In this section we provide currently identified EU funded research projects, which the ExaFLOW project can potentially cooperate with, as well as exploit specific components or approaches.

We provide two tables, describing the finished (Table 4) and still running (Table 6) projects, respectively. Each table provides the basic data about the project, and the relevant outputs that could be combined with ExaFLOW's objectives and outputs.

The list in Table 4 is based on the FP7 projects. The consortium has been in contact with the EPiGRAM, and will build on their results on optimizing communication kernels in Nek5000. Also, the consortium intends to contact the groups/alliances/communities formed after the finalisation of each project (if any) in order to contribute to the reuse and sustainability of results.

Project	Research area	Relevant outputs/What is to be re-used	Partner
CRESTA	Co-design	Initial work on AMR, exploitation of GPUs	KTH, HLRS, EPCC
EPiGRAM	Programming Models	Efficient usage of MPI, hybrid models, experiences with PGAS approaches	KTH, EPCC
IDIHOM	Industrial application of high order methods	Parallelisation for explicit DG methods and mesh generation	ICL

Table 4 – Finalised FP7 projects with results potentially exploitable by ExaFLOW

Table 5 shows the still running EU projects that are to be contacted and where ExaFLOW technology and ideas and information can be shared in order to increase the impact of the ExaFLOW project. The list is based on H2020 projects and will be updated further when new projects are funded.

Project	*Research area*	Relevant outputs/What is to be re-used	Partner
Intertwine	Programming Models	Efficient use of hybrid programming models	KTH, EPCC
NextGenIO	Memory & Storage	New memory and storage concepts - relevant for ExaFLOW's I/O and fault tolerance work	EPCC
SAGE	Memory & Storage	New memory and storage concepts - relevant for ExaFLOW's I/O and fault tolerance work	KTH
ESCAPE	Accelerators	Application of Accelerator technology to explicit DG methods	ICL

Table 5 - H2020 projects that could increase the impact of ExaFLOW

3.1.1.2 Collaboration with EU technology platforms

Several members of the consortium are already involved in the European Technology Platform for High Performance Computing (ETP4HPC) technology platform, helping shape its Research Agenda. These partners will constitute the channel to advocate for ExaFLOW's interests. The objective of the strategic research agenda (SRA) of ETP4HPC is to outline a roadmap for the implementation of a research programme aiming at the development of European HPC technologies. The approach followed to structure the SRA has been to combine ETP4HPC members technical and market knowledge (internal) with that coming from external experts and sources alike. In its activities ETP4HPC gets inputs from other important HPC networks such as PRACE. At the same time input is obtained from HPC end-users and ISVs.

During 2016 ExaFLOW has contributed to ETP4HPC and their SRA, through completing surveys and providing material for their Bof at SC'16.

3.1.1.3 Collaboration with national level projects

As far for projects or initiatives allowing for collaboration on a national level the ICL and SOTON are part of the UK Turbulence Consortium (UKTC). During the first year of the project Imperial College has done a number of simulations under the UKTC using ARCHER resources. Neil Sandham of the University of Southampton is the Principal Investigator and will pursue this opportunity for collaboration in the months to come.

KTH is the lead partner of the Swedish e-Science Research Center, SeRC and the Linné FLOW center. Philipp Schlatter is director of the Linné FLOW Centre, and Dan Henningson the Director of the Swedish e-Science Research centre. Through SeRC, collaborations on efficient implementations and exascale technologies will be pursued, while ExaFLOW is connected to the Linné FLOW Centre both through the research areas of "e-Science" and "Turbulence"; the latter is mainly relevant for the physical interpretation of the ExaFLOW test cases (wings, jet in crossflow).

3.1.2 Collaboration with the wider world

This section refers to collaboration of ExaFLOW with projects geographically outside EU. ExaFLOW will collaborate with non EEA projects where there is mutual benefit from so-doing. This engagement is likely to be a lightweight 'monitoring' and exchange of public domain information but may extend further.

The above set of guidelines will enable partners to make appropriate judgements as and when appropriate opportunities for collaboration arise. At the current time the following organisations have been identified outside the EEA with which ExaFLOW can collaborate.

- NCSA, UUIC: collaboration on Nek5000
- University of Utah: Mike Kirby Collaborators on Nektar++
- Honda, Cray and NEC: collaboration as members from the ASCS network
- RIKEN AICS: collaboration on extreme scale simulations

4 Exploitation activities (D4.2)

4.1 Market outlook

HPC technologies and computer-aided engineering (CAE) software are helping manufacturers drive faster time-to-market by quickly resolving design challenges, forecasting real world performance, and testing fewer prototypes. HPC innovations are revolutionizing the manufacturing industry with scalable, high-performance software and higher-quality products. Companies are striving to accommodate these transformative technologies; however, the performance, memory, and storage shortcomings of legacy systems are no longer sufficient to power the complex simulations required by today's manufacturers. As the demand for compute capacity steadily rises, companies are looking to optimized server platforms to accelerate IT transformation and maximize productivity.

4.1.1 CFD market trends

Computer simulations in a context of scientific modelling, simulation of technology for performance optimization or simulation of testing nowadays represent an everyday activity in most of the research and design organisations around the world. Such simulations can be used to appraise the performance of systems too complex or too expensive to test in real life, explore new technologies, or to simply accelerate the design phase of a new product. An example is a computational fluid dynamics (CFD) simulation, where computers are utilized to simulate the interaction of liquids and gases with bodies of interest.

CFD tools are able to predict the flow of the fluid, calculate the resulting forces and simulate the chemical reactions, fluid-structure interactions, ice-accretion, estimate mass, heat transfer and much more. They are widely used in automotive, aerospace, electronics, defence, material and energy industries, helping engineers and researchers to test and improve mistaken designs even before they get manufactured.

The effectiveness and impact of CFD on the design and analysis of engineering products and systems is largely driven by the power and availability of modern HPC systems. During the last decades, CFD codes were formulated using message passing (e.g., MPI) and thread (e.g., OpenMP) software models for expressing parallelism to run as efficiently as possible on current generation systems. However, with the emergence of truly hierarchical memory architectures having numerous graphical processing units (GPUs) and coprocessors, new CFD algorithms may need to be developed to realize the potential performance offered by such systems.

Some of the main growth drivers in the CFD market are:

1) The requirement to develop **products of higher quality** is therefore one of the major growth drivers in the CFD market[1]. CFD vendors try to avoid inaccurate prediction of fluid flow behaviour for highly complex geometries.
2) Need for the **reduction of time for CFD analysis**. In other words, the trend is to decrease the time an engineer spends preparing and running the simulation, letting him focus on the post-processing phase and analysing the key results of the simulation.
3) **Availability of more powerful high performance computing** enables the end user to obtain results of hundreds of simulations at the same time or to run computationally demanding simulations of higher fidelity. [2]
4) The **shift from manual to automatic optimization** workflows is accelerated by integrating geometry parameterization and mesh morphing tools into the optimization cycle[3,4], which allow for an automatic optimization loop.
5) **CFD tools embedded with a CAD features** enable a fast transition from design to manufacturing. By eliminating the data transfer gap between CAD and CFD applications the product development cycle time is reduced and simultaneously its efficiency increases.

4.1.2 HPC market

The market for high performance computing is huge and growing. IDC estimates growth in the HPC sector will continue to outpace that of the overall IT market for many years to come. Intersect360 Research projects in its latest five-year forecast that spending from 2016 through 2020 for aggregate HPC market will grow at a compounded annual growth rate (CAGR) of 5.2 percent. The current projected growth rate will put the total market value at $36.9 billion by the end of 2020. The forecast uses 2015 as a starting point, which saw $28.6 billion spent on HPC products and services, according to the Intersect360 data, a 2.7 percent bump

[1] Computational Fluid Dynamics (CFD) Market - Global Industry Analysis, Size, Share, Trends, Growth and Forecast 2015 - 2023, Transparency Market Research
[2] https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140003093.pdf
[3] https://www.caeses.com/
[4] http://www.esteco.com/modefrontier

from 2014. Servers continue to be the largest segment, claiming $10.6 billion of that total.

IDC claims that the growth in HPC system revenues and a big bump in spending by hyperscalers and cloud builders is what propelled the overall server market up 8 percent in 2015 to $55.1 billion; worldwide server shipments across all sizes, architectures, and segments were up 4.9 percent to 9.7 million machines.

HPC spending by industry and commercial businesses continue to drive the market with a five-year growth rate of 6.8 percent. Growth in both government and academia are projected to be less than half of that, with CAGRs of 3.0 percent and 3.2 percent, respectively. The slower expansion of public spending in HPC is attributed to continued government austerity, which the report says looks like it could become a long-term trend.

4.2 Progress on delivering the exploitable results

The exploitable results of the project have been developed in such a way that it is possible to exploit them as standalone solutions. This approach of clearly driven developments was intentional so that the project outcomes would reach a maximum marketability and penetrate niche markets effectively. Here we list the exploitable results and the progress achieved for each with year 1 of the project. Next to the exploitable results we list the partners who plan to exploit them during the project as part of their individual exploitation plans, depending on the current needs of each organisation.

Exploitable results	Progress during M1-M18
ER1: Novel formulations for error estimators and resilient algorithms in realistic turbulent situations suitable for Exascale <u>Priority for:</u> **KTH, IC, SOTON, EPFL** Secondary for: UEDIN, USTUTT, McLaren, ASCS	Two-level preconditioner for pressure solver was optimised for nonconforming meshes and implemented in Nek5000. Together with implemented spectral error indicator and improved interface to p4est and ParMETIS libraries it allows for performing simulations with AMR. To improve coarse grid solver an AMG library HYPRE was integrated with Nek5000 tools and tested. Work on more sophisticated error estimator based on adjoint equation has been started.
ER2: Novel mixed CG-HDG algorithms <u>Priority for:</u> **IC, EPFL** Secondary for: KTH, SOTON, UEDIN, USTUTT, McLaren, ASCS	IC provided theoretical formulation for the combined CG-HDG algorithm and implemented its first stage (weak boundary conditions for CG discretization) in Nektar++. Expected performance was analysed and described in a report together with the algorithm.

ER3: Novel I/O strategies based on feature extraction <u>Priority for:</u> **UEDIN, USTUTT** Secondary for: KTH, IC, SOTON, McLaren, ASCS	The DMD-like mechanism for analysis of time dependent data was further developed and refined with respect to the theory and to a program for filtering of data. The program is enabled to read some formats, especially the VTK-format. It writes data in VTK-format for the visualization of animated data by Paraview. The program is not yet parallelized and not yet optimized.
ER4: Efficient Open Source Pilot Implementations <u>Priority for:</u> **KTH, IC, SOTON, UEDIN, USTUTT, McLaren, ASCS**	The new developments with regards to automated code generation techniques and error indicators have been incorporated into an open-source package called OpenSBLI. An initial version of this package was released in November 2016 under the GNU GPL license, with documentation and other information available via the website: https://opensbli.github.io The I/O routines in Nektar++ have been alanysed and alternative output options have been provided to reduce the time taken in load and checkpoint phases. In Nek5000, work has been undertaken to remove dependence on MATLAB for AMG and replace the required setup phase with one implemented in the serial Hypre library which carries an open-source license and can be parallelised to reduce runtime. Further, library code used by Nek500 has been upgraded for better performance (p4est and ParMetis) and to allow an h-type AMR framework from the CRESTA project to be used and extended. Finally, a replacement implementation of the communication library used by both Nek5000 and Nektar++ has been prototyped which should allow scaling to a greater number of processes with minimal overhead.
ER5: Energy-efficiency driven algorithm designs <u>Priority for:</u> **UEDIN, USTUTT** Secondary for: KTH, IC, SOTON, McLaren, ASCS	UEDIN has begun to plan a quantification of the relative efficiencies of different algorithms or implementations of the algorithms, such that if a user is being billed for energy, they could make use of this service. UEDIN foresees the potential of an advisory/consultancy service based on this capability

Table 6 - ExaFLOW project exploitable results

4.3 IPR and Licensing

The ExaFLOW consortium defined all matters related to confidentiality and IPR handling in the Consortium Agreement. This agreement formalises project management procedures, IPR issues, and exploitation of results. This agreement ensures that the IPR of third parties will be respected by registering and tracking all use of third party components to ensure that license conflicts are not generated. The IPR of participants will also be protected by ensuring that the impact of the licenses of any third party software is analysed prior to its use (particularly concerning GPL and other viral open source licenses). All background owned by the institutes is clearly stated in the project's Consortium Agreement and the IPR policies clarified. IP created during the project will be the property of the partner who creates it, however, all IP created during the project will be available to other partners for use on the project without payment. Use of that property following the conclusion of the project will be subject to the normal considerations. All deliverables produced by the project that do not include financial information or security-related issues will be made public, and the project follows an open source policy for the technologies and interface developed in the project to facilitate technology transfer to the business sector and encourages the uptake of the results in third-party products.

The initial background included comprises the existing CFD methods as implemented in the pilot codes as well as use case geometries. This particularly includes:

- Nek5000 code, available under GPL license at https://nek5000.mcs.anl.gov/
- Nektar++ code, available under the MIT license at www.nektar.info
- McLaren front wing geometry, protected by McLaren, will be made available under NDA to the academic consortium members.
- NACA 4412 airfoil geometry, standardised geometry published by the National Advisory Committee for Aeronautics (NACA) Report 460, 1935.
- Jet in crossflow geometry, published by Peplinski, Schlatter and Henningson, Eur. J. Mech. B/Fluids (2014).
- Opel Astra rear part geometry, protected by ASCS and its member Adam OPEL AG, could be made available under NDA to the consortium members.

Four new releases/updates during first 18 months are:

- SBLI code, currently available for collaborators from the University of Southampton. An open-source release which features automated code generation capabilities, called OpenSBLI, has been released under the GNU General Public License on GitHub. See https://opensbli.github.io
- ExaGS a new low latency communication kernel for Nek5000, will be released under an open-source license.
- Nek 5000 has moved to GitHub (https://github.com/Nek5000)
- Nek 5000 v16 was released in 2016

The licensing of the project results has been considered by the consortium from the very beginning of the project in a joint effort made by technical and exploitation teams. The consortium has decided that the project should be "as open as it can be". However, due to the manifold underlying licenses as well as the commercial partners ASCS and McLaren, there are obstacles which lead to a more complex licensing and IPR management. As a result, in the table below we list the licence types the consortium considers applying to each of its exploitable results.

Exploitable results	Licence type
ER1: Novel formulations for error estimators and resilient algorithms in realistic turbulent situations suitable for exascale	Open publication
ER2: Novel mixed CG-HDG algorithms	MIT licence
ER3: Novel I/O strategies based on feature extraction	License of surrounding application
ER4: Efficient Open Source Pilot Implementations	Open source
ER5: Energy-efficiency driven algorithm designs	Copyright of the consortium

Table 7 - ExaFLOW project exploitable assets' licences

4.4 Industrial stakeholders outreach

We plan to identify and contact stakeholders demonstrating to them the value of the results through example tools, documents and code as well as giving an introduction into "How to Adopt" the ExaFLOW project exploitable results. We will seek the possibility to jointly initiate a sustainability path, thus establishing and nurturing relations and collaborations with third parties.

Exploitation is of clear importance to the impact generation, in particular with regards to uptake of open source project results. The results of ExaFLOW will be communicated to industrial beneficiaries, both through the industrial links of the partner organisations and the ETP4HPC. Table 8 below lists the main industrial contacts of the project partners.

Partner	Main Industrial Contacts
KTH	SAAB, Scania, Vattenfall, Huawei
IC	McLaren, Airbus, BP, British Gas
SOTON	Airbus, Vestas
UEDIN	Rolls Royce, ICON CFD, Prospect FS, BAE Systems
HLRS	Porsche, Daimler, RECOM
EPFL	HyperComp Inc (US)
ASCS	Porsche, Daimler, Opel, HONDA, TECOSIM, Altair, CD-adapco, MentorGraphics, ESI

Table 8 - Main Industrial Contacts

Moreover, ASCS has established a series of workshops for keynote speakers on the subject of automotive simulation using the HPC technologies. One of the main aims of the workshops is the promotion of the results of Exaflow, with an accent on the last developments of innovative CAE and HPC methods and the creation of synergies between the companies active in this field.

4.5 Individual exploitation reports and plans

The paragraphs below show individual exploitation reports for year 1.

KTH

KTH will integrate the results of the project into the NEK5000 code, which is used in a number of academic and industrial research projects and one of the most used codes on the KTH HPC resources. Thanks to the open source nature of NEK5000 the results will also be readily available to the wider research community and KTH will continue developing the code after the end of the project. KTH is particularly committed to exploit ER1 and ER4 and ER2, ER3, and ER5 will likely also have impact on KTH's future development of NEK5000. KTH will also exploit the results via its HPC Center, PDC, which will make NEK5000 publicly available on its resources and use the results, specifically ER1 and ER2 in technology transfer activities with its many academic and commercial CFD users. A first tangible exploitation result is the development of a proposal for a Swedish Center of Excellence for High Performance CFD Applications in Engineering to the Swedish Innovation Agency (Vinnova). This proposal, which comprises the KTH groups participating in ExaFLOW, two other Swedish universities, and a number of key Swedish Engineering industries aims to directly apply the ExaFLOW results to industrially relevant CFD problems. Unfortunately, the proposal was not retained by Vinnova but discussions among the partners are ongoing on how the goals of this project could be reached with other funding opportunities. During the first year of the KTH achieved the following:

- Two-level preconditioner for pressure solver was optimised for nonconforming meshes and implemented in Nek5000. Extension to hybrid Schwarz-multigrid preconditioner will be done in 2017. The code will become publicly available after merging our code to official Nek5000 release
- Interface to p4est and ParMETIS libraries was re-implemented to improve code efficiency.
- To improve coarse grid solver an AMG library HYPRE was integrated with Nek5000 tools and tested.
- The spectral error indicator is currently used to identify under-resolved mesh regions and work on more sophisticated error estimator based on adjoint equation has been started
- In cooperation with UEDIN development of new communication kernel for Nek5000 and Nektar++ has been started

IC

IC will integrate the results of the project into the Nektar++ code, which is used in a number of academic and industrial research projects. Components of this code are also linked to the NEK5000 code and so, as necessary, results will also be updated into this codebase. Thanks to the open source nature of Nektar++ and NEK5000 the results will also be readily available to the wider research community and IC will continue developing the code after the end of the project. The main focus will be on ER1, ER2, and ER4, with ER3 and ER5 likely playing a role as well. During the first year of the IC achieved the following:

- IC implemented the first part of the combined CG-DG algorithm in Nektar++ and this will become publicly available as soon as the code is properly tested and passes review.
- IC is looking at enabling accelerators in Nektar++. Initial coding effort to assess the most feasible approach has been done and will become more extensive in 2017. IC regularly discusses porting parts of Nektar++ to multicore accelerators with experts from Intel and Sandia National Labs through our collaborator prof. Kirby (Univ. Utah). This effort is a part of our work on task 2.1
- Performance comparison of Nektar++ and Nek5000 including timings for selected test cases has been performed. IC identified main opportunities for improvement (especially on algorithmic level, for example preconditioners) and will address these in coming months.
- IC is looking at fault tolerance together with EPFL.

SOTON

SOTON integrates the results of the project into the compressible flow SBLI code, which is used for a number of mainly academic research projects and is one of the main codes of the UK Turbulence Consortium. New features have already been made available during Year 1 of the project via the OpenSBLI open source release[5] so that they are available to the wider community and the code will be further developed after the end of the project. Besides improvements in the code we also expect to exploit large-scale applications developed during the project to demonstrate advanced flow modelling of industrially relevant problems. The main focus will be on ER1, and ER4, with ER2, ER3 and ER5 likely playing a role as well.

UEDIN

The University of Edinburgh, through its supercomputing centre EPCC, has set exascale computing research as its key computational science research priority over the next decade. Power efficiency of HPC and software scalability on a massive scale are two crucial parts of the research that needs to be undertaken on the path to exascale. UEDIN firmly believes that a long-term solution can only be found in close collaboration with experts from across all computing and science segments; thus ER3, ER4 and ER5 are of particular interest to UEDIN. ExaFLOW is

[5] OpenSBLI main website: https://opensbli.github.io ; Project source code on GitHub: https://github.com/opensbli ; Documentation: https://opensbli.readthedocs.org

an important component in our strategy to achieve our goal of moving HPC into the exascale era. For UEDIN, multiple exploitation channels exist for the output of ExaFLOW. These include publications, the production use of the software developed in the project, continued research and development of the software and ideas developed during the project, and the transfer of the results into the scientific and industrial domain. In more detail we will:

• Publications: publish our research results in academic journals, and in presentations and papers at conferences;

• Production use: offer the ExaFLOW algorithms and prototype implementations to the users of UEDIN HPC services, and exploit the expertise gained in understanding power usage of HPC algorithms in our day-to-day work as a supercomputing centre.

• Continuing R&D: take the results forward in subsequent and on-going projects and other activities such as novel hardware design projects with vendors, based on knowledge gained from efficient algorithm design and implementation; Technology-transfer: use the results in our work with our many academic and commercial customers who use CFD applications in their daily business.

USTUTT

ExaFLOW is helping USTUTT-IAG and -HLRS in first instance by allowing for further scaling of CFD codes. HLRS as provider of facilities for large scale capability jobs has a vital interest of the further development of scalability of computational fluid dynamic codes because these take the major part of the computing cycles of all machines of the centre and thus are a major consumer of resources and energy. USTUTT-IAG will be able to increase the overall performance of their analysis by the proposed approach (by providing and using techniques of doing faster IO and by showing ways of extracting the physically and technically relevant flow features of an unsteady flow). This approach which will at the end lead to a reduction of storage needs is also a vast interest for USTUTT-HLRS as this will avoid unnecessary investments in excessive increases of storage capabilities. Furthermore, USTUTT-HLRS will gain valuable knowledge understanding the implications of the appearance of large sized non-volatile memory for large scale computing. Finally, the energy efficiency aspects of ExaFLOW will provide another aspect for the Green IT and energy reduction activities of HLRS to reduce costs and minimize the environmental impact. In addition USTUTT-HLRS will use its synergies with the Institute of High Performance Computing (IHR) at the university and embed the research and technical objectives as subject in its lectures and of doctorate thesis work. Furthermore the results and experiences of this project will enrich USTUTT-HLRS´ training activities which will be enhanced and increased with the construction of a dedicated training centre and the release of new, improved training plans.

EPFL

EPFL will focus on the development and analysis fault tolerant and resilient algorithms at the exascale, including the development of suitable approaches for in-situ model development and fault detection strategies. EPFL will also be involved in the development of new scalable solvers and their implementation. The developments will be transitioned to the Nektar++ code and, through shared code base, to NEK5000.

McLaren

The application of time average RANS CFD simulation is the lead technology behind McLaren Racing's aerodynamics design. A natural evolution of this important design tool is the introduction and wider application of transient flow modelling to achieve even greater aerodynamic performance. For this type of modelling to be applied to a full car simulation undertaking complex manoeuvring conditions within a suitable timescales for design will require exascale levels of compute based on the tools provided by Exaflow. Successful application of this technology is therefore seen as not only a key enabler in McLaren Racing's race winning objectives but will also feed into their other applications of luxury automotive car design and technology transfer through McLaren Advanced Technology division.

ASCS

As an applied research institute the ASCS is interested in the results of ExaFLOW in order to maintain the position of a transfer platform in the field of future-oriented virtual vehicle development. The current very strong trend of increasing computing time in CFD simulations using scale resolving modelling methods benefits the penetration of new exascale technologies in the automotive sector. The ASCS wants to increase the awareness and knowledge of exascale solutions for this application. The gained expertise will be the basis for further conception and implementation of research projects in the field of CFD simulations for the future-oriented vehicle development process. Furthermore the conflation of forces engaged in research with industrial practice for the purpose of reciprocal exchange on current issues, the dissemination of scientific results relating to modelling and simulation in exascale environments, to be used in practical applications including the method-oriented support of users is focused with this project.

5 Innovation management (D4.4)

5.1 The innovation management process

This section presents the ExaFLOW project innovation management process, which is also depicted in Figure 2. It consists of an innovation cycle with four steps: Idea generation, Architecture development, Technical Implementation and Increase in TRL. During this process the Executive Board (EB) of the project makes sure that feedback from the market, the end users and the scientific and open source communities makes its way to the development teams. The WP4 leader who is part of the EB is informed regularly on the progress made in regards the

Exploitation Results of the project and updates the IPR status of each ER and/or other components/outputs of the project.

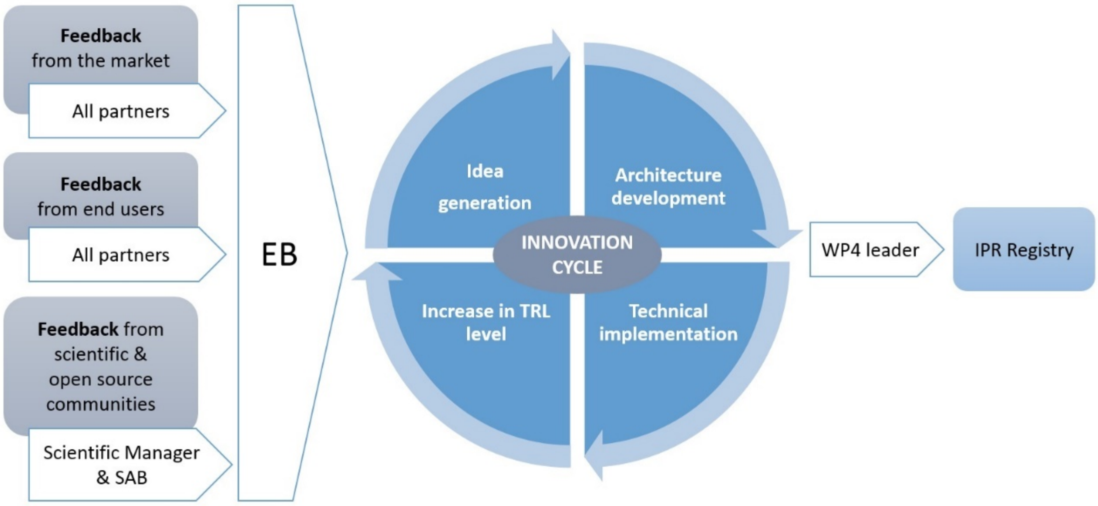

Figure 3 ExaFLOW Innovation Management Process

5.2 Progress with innovation metrics

The goal of ExaFLOW is to address key algorithmic challenges in CFD to enable simulation at exascale, guided by a number of use cases of industrial relevance, and to provide open source pilot implementations.

ExaFLOW produces a number of clearly defined innovations in the area of exascale computing and CFD. In the table below we describe the progress made in year 1 (Y1) of the project in regards each innovation.

Innovations	**Success Metrics**	**Progress M1 – M18**
Innovation 1: Mesh Adaptivity, Heterogeneous Modelling, and Resilience	Reduction of simulation costs of up to 50%.	Two-level pressure preconditioner was adapted for nonconforming meshes and implemented in Nek5000. It was tested together with spectral error indicator in AMR simulation of small 2- and 3-dimensional cases. Scaling data for realistic test cases will be presented in the next WP deliverables.
Innovation 2: Strong scaling at	Improved absolute performance will be greater than, or	Theoretical formulation completed. The first half of the algorithm was implemented in

Exascale through a mixed CG-HDG	comparable to, existing individual schemes for current levels of parallelism and improved for larger levels of parallelism available on exascale systems.	Nektar++ with minor functionality features remaining to be filled in. Expected performance improvement (second part of the algorithm) was theoretically analysed, but the overall benefits of the CG-DG scheme are likely to be smaller than initially expected.
Innovation 3: I/O data reduction via filtering	Reduction of operation time for the complete workflow, i.e. simulation (data generation), data processing and data I/O	Some data compression and decomposition methods have been developed at USTUTT. More details will be described in the next WP deliverable. The project partner SOTON has provided data to test the developed methods before I/O.
Innovation 4: Energy Efficient Algorithms	Quantifiable reduction of the total energy consumption and instantaneous power draw for the co-design applications. We expect 20% reduction (depending on the application).	UEDIN has performed a baseline analysis of the co-design applications in terms of power and energy use to allow us to target inefficiency hotspots in the code.

Table 9 - Innovations of the ExaFLOW project and their metrics

All ExaFLOW innovations are clearly targeted to enhance the efficiency and exploitability of an important class of applications on large-scale (Exascale) systems.

5.3 Progress of TRL

The ExaFLOW project will reach technology readiness level TRL 6 - technology demonstrated in relevant environment for its development. The starting point of the project is new methods and algorithms that currently are at TRL 2 - technology concept formulated with the concepts formulated in this proposal.

WP1 will fully develop those concepts and provide initial proof-of-concept implementations, pushing the TRL to level 3 - experimental proof of concept. The further software engineering efforts in WP2 will push the TRL to level 4 - technology validated in lab. The project's access to state-of the-art HPC systems will allow to validate all developments in relevant environments, reaching TRL 5 - technology validated in relevant environment. The guidance of the project receives from the industrial and academic use cases as defined in WP3 the demonstration of the results in those use cases on systems relevant for industrial and academic usage finally pushing the results to TRL 6 - technology demonstrated in relevant environment.

6 Standardisation

The objective of the standardisation activities is to assess, track and contribute to relevant standardisation possibilities and acts as a collaboration gateway to relevant standardisation bodies.

The project partners will embrace and enhance open standards where possible in order to allow for the best possible exploitation of the project results. While for the developments proposed in this project there are no standardization bodies as such, the community is impacted through large community events like ECCOMAS, ERCOFTAC, EUROMECH, ICOSAHOM, and ICCFD, which will particularly be targeted by the dissemination activities described below. This is complemented through national efforts like the UK Turbulence Consortium (UKTC). In addition, the developments of ExaFLOW will use and follow the developments of standards and community best practices for exascale computing such as MPI, OpenMP, OpenACC/CUDA, etc. At a later stage, depending on the outcomes produced by the project, the consortium will decide its strategy for standardisation.

7 Conclusions – Next steps

This deliverable is a merge of several deliverables of WP4 which were all planned for PM18. It contains updated versions of the Exploitation Plan D4.1, Dissemination and Communication Plan D4.6 and Collaboration Report D4.9 as well the plan and report on Innovation management D4.4. It reports on the first 18 months of activities in all these areas and lists the plans for the following 18 months.

The overall goal of activities in WP4 is to plan for academic as well as commercial pre-competitive sharing of knowledge and its preservation in the form of standards where possible. This goal has been achieved during the first year of the project as we have met our targets.

In order to amplify the impact of our dissemination, collaboration and exploitation activities, we improved our strategies in comparison to the initial planning presented in the first deliverables of WP4 document, after testing how these worked.

In this document we also outlined our innovation management process and connected it to the different management bodes of the project.

Finally, as for standardisation activities, these will be set in motion as soon as the more project results come into light.