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ECSEL-funded projects and their impact: Case studies of Austrian companies

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1 Introduction

With the Joint Technology Initiatives (JTI), industry-led technology programmes were launched at the European level in 2007/2008, which were implemented together with industry associations, the European Commission and member states based on a comprehensive set of rules and regulations. In this context, the ARTEMIS and ENIAC programmes and the current successor programme ECSEL, implemented as Joint Undertaking (JU), have been of great importance for the development of new technologies focused on information and communication technologies (ICT) and electronics.

Austria has been extensively involved in the programmes from the start, with substantial public funding provided by the Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK, former BMVIT). In the last 10 years, a large number of projects involving Austrian organisations have been acquired successfully, with a total volume of between 60 and 100 million euros per project.

Although evaluations at the general and sectoral levels have provided findings on the impact of the programmes, there is little evidence of the specific impact of participation in ENIAC/ARTEMIS/ECSEL at the enterprise level.[1] In the framework of the present project, case studies were conducted in selected enterprises to investigate the specific impact of ENIAC/ARTEMIS/ECSEL projects on technological development and innovation. In the context of the case studies, the direct and indirect effects were identified and the contribution to economic development (growth, employment, securing the location, opening up markets, etc.) was captured. The case studies should together demonstrate the challenges and complexity of implementing technological innovations in the high-tech sector.

[1] See for instance *European Commission (2017): Final Evaluation of the ARTEMIS and ENIAC Joint Undertaking (2008-2013) Operating under FP7, A report prepared for the European Commission, DG Communications Networks, Content & Technology*.

The following questions are addressed in this report:

- Which projects have been carried out under the ECSEL/ARTEMIS/ENIAC JU and how are they characterised?
- What was the role of the ECSEL/ARTEMIS/ENIAC JU projects for technological development and innovation, and how can they be located within the company's development and technology roadmap?
- What were the specific motives for participating or applying in the ARTEMIS/ENIAC/ECSEL JU?
- Which specific R&D questions were addressed by the funded projects? What barriers were overcome?
- What are the specifics of ECSEL/ARTEMIS/ENIAC JU projects compared to other funded research projects (e.g. Austrian Research Promotion Agency FFG, H2020)?
- In which phases of the innovation process (e.g. Technology Readiness Levels - TRL) can the funded ECSEL/ARTEMIS/ENIAC projects be located?
- What direct benefits and outputs have been achieved through the ARTEMIS/ENIAC/ECSEL JU projects (building technological know-how, networking, risk reduction, human capital development, follow-up investments, patents, etc.)?
- What indirect effects can be identified (reputation, image, long-term partnerships, etc.)?
- How have the R&D activities been commercialised?
- What effects arise with regard to securing the location in Austria?

Four companies, i.e. Infineon Technologies Austria, ams, AVL and TTTECH, have been selected. These are the top industrial firms concerning the number and volume of successfully acquired ARTEMIS/ENIAC/ECSEL projects. The firms can be seen as outstanding high-tech-firms regarding R&D ratio and innovation output. The organisations are also densely embedded in R&D networks on the European level and have the positions 8, 45, 15, and 35 among all European participants in all funded ARTEMIS/ENIAC/ESCEL projects until 2014.[2] The development path of the individual companies examined are described in the form of success stories.

[2] See *European Commission (2017): Final Evaluation of the ARTEMIS and ENIAC Joint Undertaking (2008-2013) Operating under FP7, A report prepared for the European Commission, DG Communications Networks, Content & Technology*.

2 Infineon Technologies Austria: The 300mm thin wafer technology

2.1 Infineon Technologies Austria at a glance

Infineon Technologies AG, with its headquarters in Munich, is with its Business Segments/Divisions Digital Security Solutions (DSS), Automotive (ATV), Industrial Power Control (IPC) and Power & Sensor Systems (PSS), a world leader in semiconductor solutions. Its market position is first in Automotive and Power and second in Security ICs. As of September 2019, the Infineon group has 41,400 employees worldwide, thereof 18,600 in Europe. It runs 37 R&D locations and 17 manufacturing locations. The revenue for the 2019 financial year was 8.023 million Euro.

Infineon Technologies Austria AG (IFAT), one subsidiary in the Infineon group, shows dynamic growth in revenue and employees over the past few years. In 2019, Infineon Austria generated sales of over 3 billion euros and employed around 4,600 people. Besides Germany, Infineon Austria is the only subsidiary within the group that combines R&D, production and global business responsibility. Infineon Austria bears global responsibility for 13 product lines in the divisions "Automotive", "Power & Sensor Systems" and "Industrial Power Control".

At the location in Carinthia, Villach, an approximate 1.6 billion euros are currently invested; in part in a new, fully automated 300mm chip factory, and in part in a new R&D building. Investments are also being made to expand research locations in Linz and Graz.

The location Villach is a competence center for exceptionally thin (down to 40µm) silicon wafers. It runs serial production of power semiconductors in 300- millimetre and thin wafer technology, and comprises manufacturing competencies for micro-electromechanical systems. It is one of the Industry 4.0 pioneers in Austria, and serves as the group’s global competence centre for power semiconductors. This primarily includes the power switches based on the new materials Silicon Carbide (SiC) and Gallium Nitride (GaN).

Infineon Austria is one of the strongest industrial research companies in Austria. Its R&D expenditure in the 2019 was 525 million Euro which accounts for 17% of total revenue. It employs about 2,000 people in R&D and filed 214 patent applications in the last fiscal year.

2.2 300mm wafer power technology: A strategic project series in ECSEL

The 300mm technology for power electronics, developed by Infineon Austria, was realised with ENIAC/ECSEL projects from the beginning. The development of the cost-saving 300mm technology for power electronics and its digitised production is a central thematic driver over the entire course of the ECSEL project history at Infineon Austria, as reflected in the ENIAC/ECSEL projects since 2012. Most ECSEL projects by Infineon Austria focus on manufacturing issues, significantly lead to ongoing improvements in process and production technology, and enable decisive cost and resource savings.

Figure 1 depicts the entire project series of Infineon Austria in manufacturing technology. Infineon Austria has been or is involved in 12 ENIAC/ECSEL projects, 7 of which are or have been managed by Infineon Austria staff, a further 3 by Infineon Germany or Dresden. Only the ECSEL projects "HiPerform" and "Arrowhead Tools" are not managed by employees at Infineon locations. The projects are pursuing three strategic project sequences in which the ENIAC/ECSEL R&D projects are linked with each other in a sustainable, thematic way for overarching future topics.

The “300mm and thin wafer technology for power semiconductors” encompass the projects EPT300 (ENIAC), EPPL (ENIAC) and “eRamp”. EPT 300 delivered the base and first milestone on the way to realise production of 300mm thin wafers in Austria.

The 300mm technology, initially developed for deep submicron CMOS, was not entirely new in the semiconductor industry. By the late 1990s, companies were trying to pack the circuits on a 300mm large wafer instead of the traditional 200mm wafer, expecting a significant increase in productivity. In power electronics this transformation was not possible at that time as the required silicon substrate wafers (specific doping) were not available. Since Infineon Austria was successful increasing the diameter of the wafer from 150mm to 200mm in the past, Infineon Austria exploited and developed the needed technology for manufacturing power electronics on 300 mm wafers by overcoming the unsolved challenges. In addition, as the 300mm technology is now standard, all equipment manufacturers are also focusing their process and equipment development mainly on 300mm technologies.

To illustrate the difference, a typical chip in a computer handles about up to 2 kVolt. In contrast, semiconductors for power electronics process up to 6-5 kVolt, which requires different material and wafer handling systems to enable the manufacturing of 40µm thin wafers. Having a long R&D experience and strong confidence in its development team, Infineon made an important strategic decision to take the high risk and develop a 300mm thin wafer technology for power electronics and the manufacturing technology for a large-scale production of the 300mm power wafers. This decision was foundational to the future of the Villach site. Two capabilities were important to master the challenge regarding 300mm technology:

- Knowledge about the basic material used
- Expertise in metallization to build the final semiconductor

Villach had already previously proved its ability to realise innovations crucial for the existence of a semiconductor lab in Austria, also within the Infineon group. Within internally financed small projects, first tests were conducted to assess whether such a production would be feasible at all. Some innovative ideas were implemented, and it was possible to deliver proof of concept and a prototype that appealed to top management. 2010 marked the start of a long journey with many projects to follow, including the launch of the ENIAC EPT300 project.

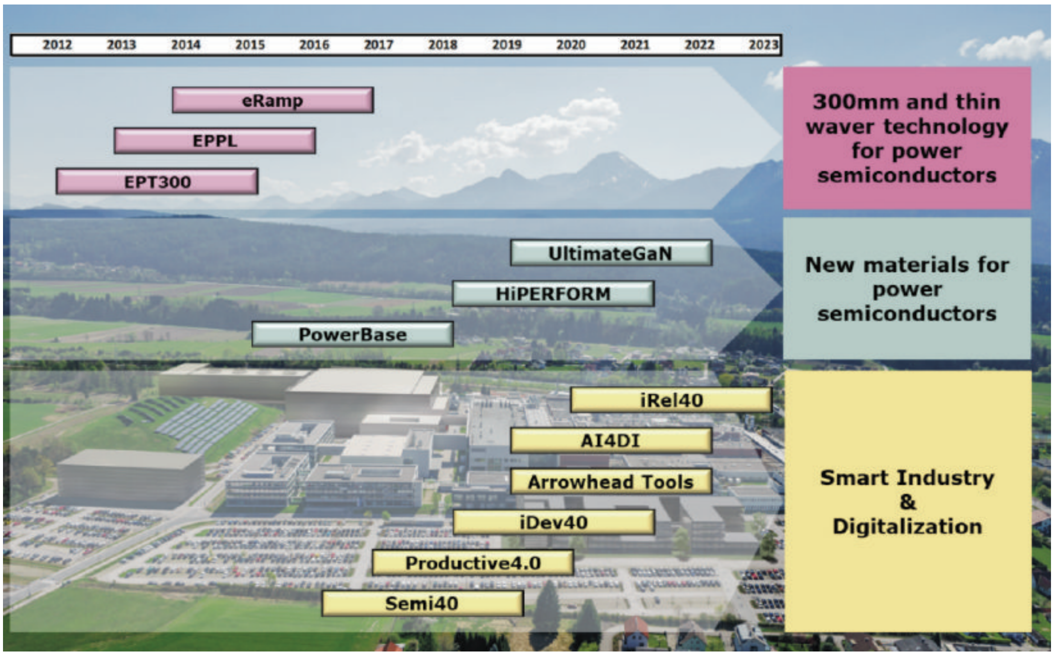
In the EPT300 project, the integration of various suppliers was an important step and allowed for the shaping of a new value chain for the creation of 300mm manufacturing. Spurred also by their international R&D efforts, they signalled to suppliers that a 300mm power wafer production will be developed. Infineon Dresden participated in this project as well, which allowed questions concerning the automatisation of production and Infineon Austria to be jointly addressed. The overall aim of EPT300 was to develop the base for manufacturing power transistors on 300mm wafers having the same performance (1:1) as when produced on a 200mm wafer, but more cost-efficient. In the subsequent project EPPL, the aim was then to further develop the technology for large-scale manufacturing.

The necessary material development has been carried out in the corresponding ECSEL project series "New Materials for Power Semiconductors", which is of high strategic relevance for the site in Villach/Austria, as these wide band gap materials will be used in production. As mentioned, Infineon focused here on the exploration of Silicon Carbide (SiC). PowerBase, HiPERFORM and UltimateGan were acquired successfully within ENIAC and ECSEL. The product "CoolGaN™ 600V switches" was developed and launched on the market by Infineon based on the already completed ECSEL project "PowerBase". Compared to Integrated Circuits, power semiconductors are characterised by higher operation currents and voltages resulting in specific requirements for efficiency and cooling of the chip.

Infineon also engaged early with the digitalisation of production (“Smart Industry & Digitalisation") within the ECSEL projects Semi40, Productive4.0, iDev40, Arrowhead Tools, AI4DI and iRel40. In the ECSEL project "Semi40", for example, intelligent algorithms have been developed which should subsequently enable energy savings of around 10 percent in factory cooling processes.

The three strategic project series are closely related and intertwined, especially the two strategic project series "300mm and thin wafer technology" and "Smart Industry & Digitalisation", which are in a consistent chronological sequence.

Figure 1: Strategic ENIAC/ECSEL project series of Infineon Austria



Source: Infineon Technologies Austria

Infineon Technologies not only explicitly pursues strategic project series to ensure sustainability in R&D topics important for the company's future, but also explicitly strives for project coordination of ENIAC/ECSEL projects to achieve the maximum impact of ECSEL R&D projects for the company. Infineon has already assumed the role of project coordinator in ENIAC/ECSEL projects 15 times. The total project cost of the ENIAC/ECSEL projects that Infineon has coordinated in Germany and Austria is to date around 1 billion euros.

As consortium leader, Infineon has the possibility to manage the strategic content of the R&D projects and to strongly influence the selection of key partners. The consortium, especially regarding research institutions but also including complementary industrial partners, is put together along the value chain and Infineon has the possibility to gain exclusive and ongoing access to the information created. Consortium leadership significantly increases the added value for Infineon Austria in the ECSEL R&D projects since Infineon can have a central say in the project and can align the direction of the content with its own corporate strategy.

2.3 The role and effects of ENIAC and ECSEL projects

Infineon Austria argues that the ECSEL projects go hand in hand with the strategic company topics. Its R&D projects, and thus also the ECSEL R&D projects, must fit in with Infineon Austria's strategic fields and provide targeted support. These strategic areas are also reflected in the 13 product lines for which Infineon Austria bears global responsibility: These are product lines in the divisions "Automotive" (2 product lines), "Power & Sensor Systems" (8 product lines) and "Industrial Power Control" (3 product lines). The ECSEL projects centrally support the corporate strategy in terms of content and fit with the company's internal technology roadmap.

Without the funded ENIAC/ECSEL projects, the R&D investments in such central future topics would have been hardly realisable. Above all, such strategic project series offer Infineon the opportunity to research and develop with the national and international community along the entire value chain. ECSEL projects enable Infineon Austria to safeguard the competitiveness of existing investments in R&D and production capacities, and thus secure and create jobs at the Austrian site.

However, according to Infineon Austria, R&D funding goes beyond the mere financing of R&D ("Funding is much more than cash"). Public money significantly reduces risk for Infineon Austria, helping it realise R&D projects. But money is definitely not the only reason Infineon is involved in ECSEL projects. Infineon Austria and other project partners have previously gone into ECSEL projects without national co-financing because the expected added value for the company through the cooperative, international project outweighed the drawback of lacking national public funding.

In the projects, certain research partners (predominantly universities and research institutions) specifically address high-risk topics that Infineon itself cannot (yet) address but is interested in. The intellectual property (IP) rights are then held by these research partners, but Infineon has exclusive access to the knowledge gained and can buy in if it becomes commercially interesting.

In ECSEL projects, Infineon can also cover research fields with a lower technology readiness level (TRL), which cannot otherwise be addressed as an industrial partner, as they would still be too risky from an industrial perspective. There is a regular exchange within the consortia, people learn from each other, give each other feedback on content and, if successful, can also go into business. Infineon receives the information gained in the project, but pays the research institutions for the use of the IP rights.

In addition, potential customers of Infineon Austria are also involved in such R&D projects, and Infineon is also allowed to inspect preliminary developments of potential customers based on personal trust. ECSEL R&D projects also strengthen this personal trust in the B2B area and by working with potential customers in R&D projects the probability of Infineon Austria's products being successful and marketable is increased. Through such ECSEL R&D projects, Infineon also gains system know-how in the respective application area and can thus cooperate with the Original Equipment Manufacturers (OEMs) on equal footing and be better informed about customer needs. Personal trust is a decisive factor for successful cooperation in R&D and consequently for the realisation of innovations and products. Pre-commercial ECSEL projects contribute significantly to building trust, especially in the business to business (B2B) area.

ECSEL projects likewise increase the visibility and reputation of the company in the innovation ecosystem, not least among potential employees. These projects help to recruit employees, which are of particular relevance to Infineon's growth course, especially regarding the expansion of the R&D locations in Villach, Graz and Linz.

2.4 ECSEL compared to other research funding programmes

Infineon is involved in both ECSEL and H2020 projects with distinctive motivations and effects. In H2020 the funding rate is higher, which is interesting for research institutions, as funding rates of up to 100% are possible. However, the oversubscription is a factor of 6 to 10, i.e. the success rate is low.

By comparison, ECSEL projects are not only larger and allow for numerous partners in research and industry ("ECSEL are the battleships"), but the success rate is also significantly higher for Infineon. This success is also because of tailor-made consortia along the value chain and a clear strategic orientation of the Infineon ECSEL projects along their own technology roadmap and a high level of in-house competence for such complex R&D projects, also regarding the consistent design of an integrated, European ECSEL research project and project proposal.

In addition, the comparatively low funding level in ECSEL projects and the corresponding need for higher financing from private funds ensures a targeted project progress and an output orientation that is more likely to deliver a concrete benefit for subsequent, marketable product innovations from industry. From an industrial point of view, the pressure to generate "impact" is comparatively higher in ECSEL projects than in H2020 projects. For Infineon Austria, ECSEL JU is an essential European funding tool for advancing complex technological developments along the TRL 3 to 7 decisively and in cooperation along the value chain.

National funding formats such as the "Basic Programme" of the Research Promotion Agency FFG are very important for Infineon Austria as a complement to ECSEL projects. These projects are aimed at targeting product development and allow for a higher level of secrecy compared to ECSEL projects. The national thematic funding programmes "Production of the Future" and "ICT of the Future" are seen also as complementary and make it possible, for example, to prepare strategic R&D topics at the national level before they are further developed at European level.

According to Infineon Austria, the addition of the ECSEL projects is very high also because of the strategic connection to their own technology roadmap. Due to their design, the number, competence and role of the different project partners, the possibility to address different but related– and especially risky– sub-themes, ECSEL projects have an important function for Infineon's own R&D strategy. Through ECSEL projects, Infineon Austria can add R&D personnel, recruit qualified staff, and benefit from the expertise and competence of other partners. In addition, ECSEL projects also have positive structural, network and reputation effects. These strengthen the competitiveness and reputation of the company in Austria as an innovation location and have positive, sustainable effects on the Austrian innovation ecosystem in the topic area.

ECSEL projects have correspondingly a positive impact on the growth of equipment and material manufacturers in Austria, who cooperate with Infineon in such ECSEL projects and can subsequently open up new business areas and orders. The production technology orientation of many of the ECSEL projects toward automation, robotics, AI and digitisation is explicitly aimed at securing and strengthening the production location in Austria and Europe over the long term.

2.5 Key findings

Infineon in Villach is a competence centre for power electronics within the Infineon group and the R&D ECSEL projects in 300mm thin wafer technology, manufacturing technology and power semiconductors have been crucial for the expansion and conversion of the Austrian Infineon research and manufacturing site. The 300mm technology for power electronics, developed by Infineon Austria and specifically realised from the beginning also via ENIAC/ECSEL projects, was one of the decisive factors for the continued existence of the Infineon location in Villach and is now being expanded in terms of production technology. This breakthrough innovation has been a key for the decision to build up a new 300mm thin wafer factory and R&D center in Villach with a total investment of about 1.6 billion euros.

ENIAC/ECSEL projects have significantly accelerated and enabled the development of 300mm power semiconductor technology. For Infineon Austria, ECSEL JU is an essential European funding tool for advancing complex technological developments along the TRL 3 to 7 decisively and in cooperation along the value chain.

Most ECSEL projects by Infineon Austria focus on manufacturing issues, significantly lead to ongoing improvements in process and production technology, and enable decisive cost and resource savings. Infineon Austria is pursuing three strategic project series in manufacturing technology in which the ENIAC/ECSEL R&D projects are thematically linked to each other for overarching future topics. Here the further development of the 300mm technology for power electronics is a central thematic driver over the entire course of ECSEL project history, represented in ENIAC/ECSEL projects since 2012. In addition, technologies based on new materials were developed which are in the beginning of a launch into a growing market.

Infineon Technologies not only pursues strategic ECSEL project series to ensure sustainability in R&D topics important for the company's future, but also explicitly strives for coordination of ENIAC/ECSEL projects to achieve the maximum impact of ECSEL R&D projects for the company. Infineon Austria has been and continues to be involved in 12 ENIAC/ECSEL projects, 7 of which are/were managed by Infineon staff.

The national Austrian R&D funding in ENIAC/ECSEL projects, amounting to 22.4 million euros, has since triggered around 139 million euros in R&D project investments (including EU funding) at Infineon Austria over the past 12 years. According to Infineon Austria, a total leverage of about 1:2 can be determined, i.e. one third public R&D funding (national and EU) triggers two thirds of operational investments in ECSEL R&D projects. This also results in patents that are registered for the Austrian site. In 2019 for example, Infineon Technologies Austria was filing 214 patents.

ECSEL projects enable Infineon Austria to safeguard the competitiveness of investments in R&D and production capacities, and thus to secure and create jobs at the Austrian site. The addition of ECSEL projects is very high because of the strategic connection to the Infineon Austria technology roadmap. ECSEL projects have an important function in Infineon's own R&D strategy. Without the collaborative ECSEL projects, Infineon could not pursue the strategic future topics with the same speed, breadth, depth, added information value, and knowledge gain.

Infineon Austria can also recruit high-quality staff through ECSEL projects and benefit from the expertise and competence of other partners. There are also positive structural, network and reputation effects of ECSEL projects, which strengthen the competitiveness of the company at the innovation location in Austria and have positive, sustainable effects on the Austrian innovation ecosystem.

3 ams: Towards 3D integrated sensors

3.1 ams at a glance

AMS designs and manufactures high-performance sensor solutions for applications requiring the highest level of miniaturisation, integration, accuracy, sensitivity and lower power. Products include sensor solutions, sensor Integrated Circuits (ICs), interfaces and related software for mobile, consumer, communications, industrial, medical, and automotive markets. AMS advanced developments drive worldwide leading applications requiring small form factor, low power, highest sensitivity and multi-sensor integration being present with optical sensors in the most advanced smartphones.

AMS' headquarters are in Premstätten near Graz, Austria with a state-of-the art 200mm CMOS manufacturing line including optical interference filter and post-processing capabilities. Key research and development facilities are based at the headquarters covering technology R&D and IC design development departments together with 18 design centers worldwide. In Rüschlikon, AMS operates an R&D centre developing advanced optical components and packages for the highest level of sensor miniaturisation. ams` state-of-the art VCSEL (vertical cavity surface emitting laser) emitter solutions providing industry leadership in VCSEL array power density, conversion efficiency and pitch.

Employing worldwide over 9,000 people, AMS operates direct sales offices in all major regions of the world. AMS revenue in 2019 exceeded 2 billion USD with a major contribution from advanced consumer and mobile sensor device solutions. ams is the majority shareholder of OSRAM Licht AG, with a vision to create a global leader in optical sensor solutions and photonics. AMS is listed on the SIX Swiss stock exchange.[3]

[3] More information about AMS can be found at www.ams.com

3.2 Developing and commercialising 3D integrated sensors

ams has focused its R&D strategically on innovative sensor development and integration (e.g. through packaging). Micro sensors are becoming increasingly intelligent, with more software and algorithms. The company pursues the strategy to secure manufacturing know-how at the Styrian location and the corresponding IP. This is done through its own pre-development and R&D projects in Austria and Europe. Further development and integration of sensors/chip components is also done in Austria. This prevents suppliers from being able to offer critical (manufacturing) knowledge to competitors of ams at a later time. The 200mm Waver FAB is located in Styria (Austria), a large development centre mainly for automotive and medical devices. Many tests for certification are also carried out in Styria. In contrast, the up-scaling of large-volume production takes place mainly in Asia (in locations/clean room factories e.g. in Singapore). In (optical) packaging, much is still done manually. In terms of its workforce, ams has thus grown strongly in Asia, but also in America and Europe.

The complexity of manufacturing technology has created many additional research questions in manufacturing in the past decade. Topics and questions - also addressed in collaboration with competitors - are aimed at the fundamental "How do I manufacture?", "What must the machine be able to do?", "What data do I need to control the process? With competitors/cooperation partners, it is primarily about basic approaches and methods.

Long-term topics and ongoing developments (e.g. in automotive, industrial, medical, consumer applications, etc.) are suitable for collaborative research projects before the results of the projects are incorporated into new generations of sensors.

ams entered the first ENIAC project via existing networks of other collaborative R&D projects (EU FP, FFG projects) when taking part in the project IMPROVE (2009 to 2012). For ams, the project IMPROVE was very beneficial for networking and pre-competitive joint learning on similar challenges along the value chain, which the partners mapped.

The ENIAC project EPPL (2013 to 2016) was something like the proper start of the success story of the ENIAC/ECSEL projects for ams. Infineon was the project leader (see also above), but ams led the work package for the 3D sensor integration. Based on the developed process technology, the smallest 3D integrated ambient light sensor could be launched. A product that also built the foundation for ams' world-leading market position for 3D integrated light sensing solutions. The product launch of this sensor was in 2016, with the underlying process technology (especially 3D integration) further developed in the following ECSEL projects. This special technology has also influenced other subsequent developments. ECSEL projects are typically process-technology-oriented, and their sequence allows for increased miniaturisation through new process and manufacturing technology. This strengthens and secures the production site in Austria.

In the following large sensor integration development projects, further process technology developments and thus higher integration levels in combination with other sensors (e.g. colour sensors, proximity sensors) were made possible and miniaturisation was decisively advanced. In the FP7-IA project Multi Sensor Platform (MSP) ams introduced the ambient light sensor, integrated temperature and gas sensor.

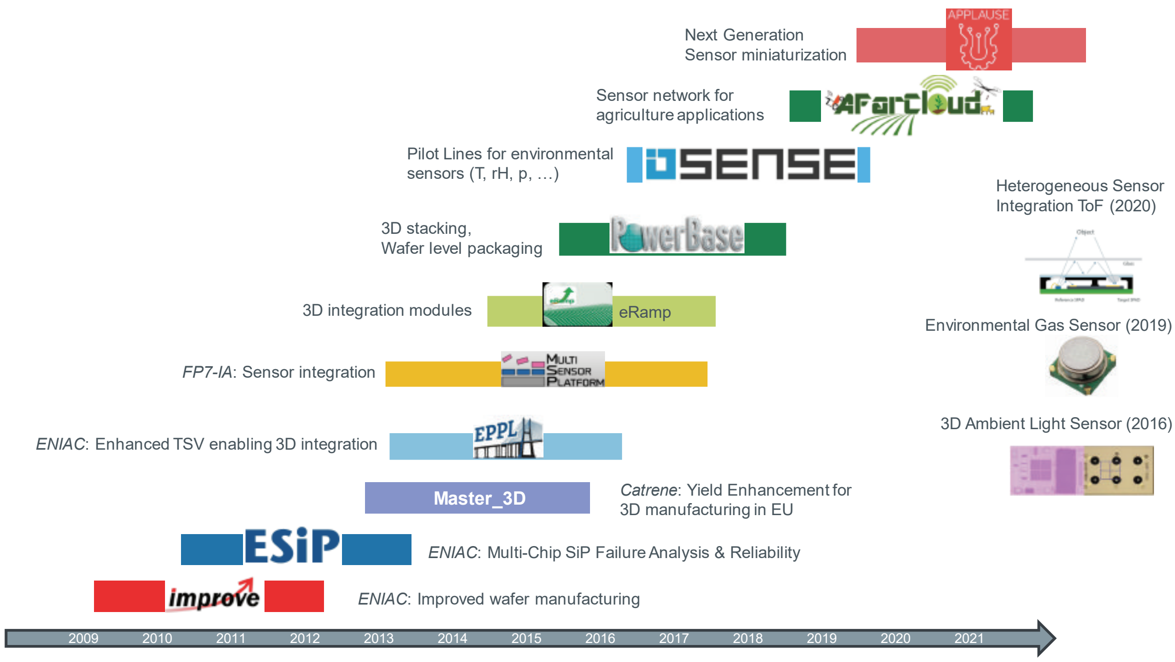
eRamp was the first project for ams in the ECSEL programme dealing with the predictable and fast production launch of new products (ramp up), module improvement for the next sensor generation, integration, improvement and miniaturisation. Further ECSEL projects Power Base and IOsense, the first one enabled proximity function with optical sensors, the second one dealt with integrating pressure sensors, temperature and humidity sensors.

Due to a higher level of sensor integration - which was decisively made possible by ECSEL projects–and increased software-relevant parts of the value chain integrated into ams sensor solutions. This is also reflected in the current ECSEL project AFarCloud, where software development is in the foreground, and increasingly in the development of complete sensor solutions, including end-user application software. The ECSEL projects thus also contribute to a higher depth of added value and forward integration at ams. ams is thus increasingly becoming a system integrator for sensors and a supplier of complete sensor systems, including software solutions.

Later on, AFarCloud dealt with developing sensor network for agriculture applications, a software for sensor interaction. Applause was the most recent project where the next generation of sensor miniaturisation with the goal to make wavers even thinner was developed.

ams has not yet coordinated an ECSEL project. The research work is divided up among the partners in such a way that they do not interfere with each other as potential industrial competitors, i.e. complementarity instead of competition is the primary focus.

Figure 2: Large sensor integration development projects at ams



Source: ams

For ams, ECSEL projects are mainly concerned with manufacturing issues in connection with sensor development. The greatest added value of the ECSEL projects for ams in terms of development content is to work on the topic of 3D integration of micro-sensors and on the development of modules and analysis methods. Together with equipment manufacturers and academic and industrial partners, ams can work on the further development of higher TRLs and the successful production of integrated sensors. ECSEL projects raise the probability of this success, increase the speed towards production transition, and lead to a broadening of the network.

3.3 The role and effects of ENIAC and ECSEL projects

A specific advantage of participating in ECSEL projects seen by ams is that, compared to H2020 projects, larger consortiums are possible. While experimental basic research on rather specific issues is done more in H2020 projects or via projects funded by the National Research Promotion Agency FFG, ECSEL projects range from TRL 4 to TRL 7; readiness levels where many partners are needed because the requirements for the development are becoming more complex and also the research questions are broadening. According to ams, the ECSEL format is very well suited for this purpose, i.e. to map this complexity in the common challenges across a multitude of partners (ranging from 50 to 70 partners). ECSEL project "Power Base" is an example: in such ECSEL projects the entire value chain can be mapped, including device and tool manufacturers and specialists from research to develop the analysis methods in the project. These can then be used as a service after the project or can be purchased, but normally an industrial company would not have the capacity to develop them independently. Methods and devices that are developed in ECSEL projects are used by ams accordingly.

In ECSEL, the implementation perspective "How do I manufacture this?" is more important than in H2020. For ams, not only the proof of concept is important but also the concrete implementation and transfer into mass production. Here ECSEL offers more possibilities. In ECSEL, topics are also addressed that are directly relevant to production technology and thus also strengthen the European production location and provide arguments for manufacturing in Europe.

ams argues also that the probability of success of the application is higher in ECSEL because there is less competition. H2020 projects are comparatively difficult for ams to plan and the success rate is very low (about 5%). In ECSEL, the chances are higher that a project-spanning continuity is achieved. Moreover, further developments and innovations are possible with certain partners and device manufacturers over several projects.

According to a rough estimation by ams, ENIAC/ECSEL projects cover about 10% to 15% of the total product development costs. Often ECSEL projects are about trying out new process chains and production methods in the development laboratory of the equipment manufacturer. Concrete product development then takes place internally. The project start in ECSEL is often not based on basic research, but rather is a starting point for further development with partners in concrete production. Together with the research partners, the (analytical) learning process takes place to discover possibilities and limitations, and how to overcome them. With ECSEL projects, ams can bring ideas and innovations to the production. ECSEL thus serves as an essential bridging function.

In addition, ams participated in the elaboration of the Multi Annual Strategic Research and Innovation Agenda (MASRIA) of ECSEL JU. In the ECSEL JU, research topics can be efficiently brought in by industrial companies respectively. In the ECSEL call, ams chooses what is more important thematically for the company based on its own roadmap. There is also continuity of topics in ECSEL MASRIA. Member companies can directly participate in MASRIA.

ECSEL projects enable the participation of Austrian research institutions and thus contribute to the expansion of the thematic, national innovation ecosystem. Without Austrian industrial companies, research institutions would have difficulty or possible would not participate at all in ECSEL projects. Important partners of ams in ECSEL projects include the Austrian research organisations and universities MCL, FELMI, PCCL, SAL, AIT, TU Vienna and TU Graz.

ECSEL projects are important for gaining understanding of the requirements and considerations of sensor users (e.g. Siemens, Samsung) and exploring the possibilities and limitations together. Set against this background, ECSEL projects contribute decisively to product success from the manufacturing side and enable the development of new business fields.

ECSEL projects must fit into the landscape of the internal technology roadmap. Major topics of ams’ technology roadmap are structured according to individual technological components (sub-roadmaps). ECSEL projects provide insight into different sub-roadmaps, with a focus on 3D integration and process technology.

In H2020, ams tried out comparatively more new approaches, also because of the higher funding rate, sometimes upwards of 80-100%. In ECSEL projects the funding rate is 40%, which means that the thematic focus of the projects (with 60% self-financing from the companies) is comparatively more closely linked to the technology roadmaps of ams and to existing knowledge bases. The more private money from ams that flows into R&D projects, the more it must ensure that the R&D projects produce useful results for ams. ECSEL projects therefore have an "accompanying" character to the technology roadmap with cooperative possibilities that otherwise would not be available for ams.

3.4 Key findings

The first FP6 and ENIAC projects were door openers for further projects and the expansion of the ams’ R&D network. ECSEL projects at ams build on each other and are simultaneously linked to ams’ internal technology roadmap. The success results of one ECSEL project are the basis for the decision for follow-up investments in new ECSEL projects.

ECSEL projects help ams to expand its sensor portfolio and enable sensor integration and continuity of topics. The increased integration of functions and components into miniaturised sensor systems ensures the superiority of ams. The ENIAC project EPPL is considered to be the tangible start of the ams’ success story with ENIAC/ECSEL projects. Based on the developed process technology, the smallest 3D integrated ambient light sensor could be launched. This product built the foundation for ams’ world leading position in the market for 3D integrated light sensing solutions.

Networks are extended by these projects. Learning about and getting to know other high-tech companies and research institutions is made possible, and the reputation and visibility of the company as a potential employer and business partner increases. In addition, ams is introduced to other partners and companies. Such projects are also "used" for M&A of interesting (smaller) companies.

For large consortia with projects TRL 4 to 7, ECSEL is a very suitable track, also regarding the probability of success. ECSEL projects at ams are much more voluminous (30 to 90 million in total) than national or traditional H2020 projects. However, national FFG projects also provide the basis on the European level as a preliminary effort. In ECSEL projects, it is possible to cooperate with European equipment manufacturers along the value chain and develop further in a results-oriented manner.

With ECSEL projects, ams can bring ideas and innovations to production, confirming ECSEL’s essential bridging function. Thus, ECSEL projects contribute to the expansion of the thematic, national innovation ecosystem. Without Austrian industrial companies, research institutions would have difficulty or simply could not participate in ECSEL projects.

4 AVL: On the way to digitizing the vehicle’s development process

4.1 Company at a glance

AVL (Anstalt für Verbrennungskraftmaschinen List) was founded by Prof. Hans List in 1948 with colleagues from the Technical University of Graz. It is often referred to as the first spin-off company of an Austrian university. At first they developed mainly small and medium-sized diesel engines. By the 1960s, the company had become decidedly international with its construction of diesel engines for various applications and customers. At the same time, AVL began developing engine test benches and used the first computers for this purpose as early as 1964.

AVL is divided into three divisions: i) Powertrain Engineering with the development of powertrains including internal combustion engines, hybrid systems, transmissions, batteries, fuel cells, electrics and electronics; ii) Instrumentation and Test Systems encompassing the development of test benches and measurement technology for engines, vehicles, advanced driver assistance systems, automated vehicles and their components; and iii) Advanced Simulation Technology covering the creation of simulation software for engine and vehicle development.

AVL is now known as the world's largest independent company for the development, simulation and testing of powertrain systems (hybrid, combustion engine, transmission, electric drive, batteries, fuel cells and control software and technology) for passenger cars, commercial vehicles, construction, large engines and their vehicle integration.

The expenditures for inhouse R&D account for 10% of the turnover. AVL has over 1,500 granted patents. The company has a long tradition in conducting EC-funded projects and engaging in the development of roadmaps. Since 1992, AVL participated in over 150 EC-funded R&D projects, more than 40 of them as coordinator.

This research-driven company has grown considerably over the last few years, and employs more than 11,500 people worldwide, including 4,300 in Graz. It achieved a turnover of almost 2 billion Euros in 2019.

4.2 The role and effects of ARTEMIS and ECSEL projects

AVL has engaged extensively in ARTEMIS and ECSEL projects since 2009, which contributed significantly to the development of existing business segments and the creation of new ones. AVL recognised that the JU offers the opportunity to engage over a longer period of time and continuously work on consecutive projects in close collaboration with leading international partners to implement a project roadmap. Such a coherent set of projects is defined within AVL as a project cluster and AVL could successfully manage different project clusters for the development of brand new technologies. The technologies developed within these project clusters were further developed and commercialised by additional projects, which resulted in new products or even business fields.

The success story began with engaging in the development of simulation tools that meet new emerging requirements in relation to integration and interoperability, and safety and security. This development path encompasses the project cluster “Systems Engineering, Interoperability and Dependability”. AVL also started to offer technologies and solutions for Automated Driving, for which ECSEL projects played an important role, too. 2015 the first project started opening up the project cluster called “Automated Driving”. In 2013, AVL began to address questions in relation to efficient production, which can be commonly summarised as “Industry 4.0”, the third project cluster. The electrification of the powertrain is another dominant trend within the entire automotive industry. AVL addressed this tope as well within ECSEL projects, staring with the first project in 2015, i.e. project cluster “Electrification”.

The projects in the four project clusters allowed to develop competencies, technologies and solutions for supporting the customers of AVL, mainly OEMs, to develop automated, connected and electrical vehicles. In the presented AVL case study, the first two project clusters are presented to illustrate the role and impact of ECSEL-funded projects for AVL.

Development towards Systems Engineering

Developing simulation tools is one of the key business areas of AVL. While the experience of engineers is important for making design decisions, the new challenge emerging in the beginning of the 2000s was to develop simulations which support the design of new car components such as batteries, engines, transmissions, etc. The rationale was simple, the better the assumption in an early development stage, the better and more efficient the entire development process. A few specific trends triggered the further development of simulation tools: AVL experienced the growing complexity due to the alternative propulsion systems such as hybrid engine and the electrification but was also aware about the trend towards automated driving, which entails new challenges to develop and validate control systems for advanced driver assistant systems and automated vehicles.

Traditionally, when developing a new vehicle, engineers start with the design of powertrain technology, its principal components and the architecture (e.g. combustion engine, gearbox, wheels, axis). However, with the first hybrid cars everything had to be questioned, and it was not clear anymore, for instance, where and how many electric motors are integrated and how they are connected and interact during operation. Given these new challenges and complexities, AVL designed and run simulations to find effective designs and solutions.

ARTEMIS projects offered the opportunity to conduct research in collaboration with other leading organisations across Europe. AVL already coordinated the first project with the acronym CESAR. AVL had already a long tradition in performing and coordinating FP-funded projects beforehand. They addressed questions such as how to assure interoperability and safety in automobiles with more electronic components and continued in the preceding project MBAT. AVL developed and searched for new models and a tool base for designing new cars. This was a challenge due to because the need to use empirical and measurement data to design the new technical systems and components. The entire process was a development and test effort where only some parameters and relationships were known ex-ante and others had to be found and newly established. The basic philosophy was to find the best simulation model which predicts how the system at the end behaves, the final proof of which occurred during final testing.

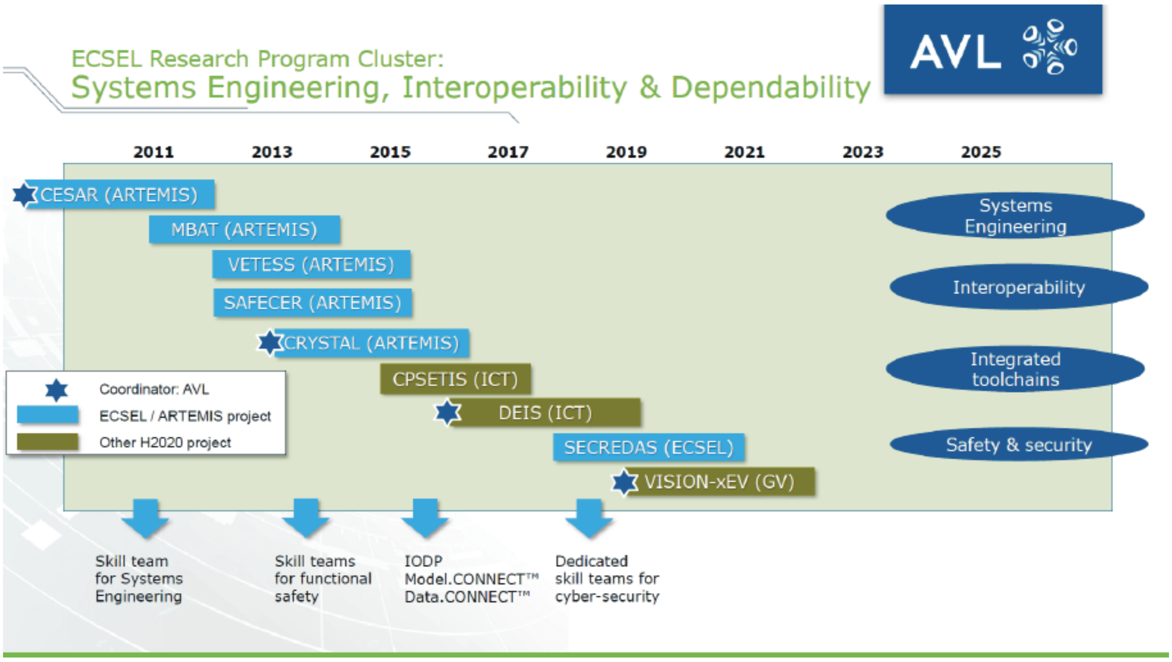
At the same time, SPICE and CMMI emerged in the automotive industry, two process models which had been developed by the German and U-S. automotive industries, respectively. This development was based on Capability Maturity Model (CMM) (invented by the Carnegie Mellon University which was originally developed for the military sector. The automotive industry suddenly had the same challenges as other sectors such as the aircraft industry, which is heavily based on complex software technologies and a high amount of electronics. The question of how to handle such a large software project thus became relevant for the automotive industry, too. One lesson learned from the U.S. development was that proper architecture was a key success factor.

For AVL, CESAR offered to collaborate with IBM and SIEMENS to master this challenge in the automotive domain, which was new for all consortia partners and the entire industry. The aims of CESAR were to find an architecture, structure the development process, and build up an ecosystem open for various partners. For AVL it was obvious, since the beginning, that such an attempt was only possible in collaboration with other larger companies. ARTEMIS offered this space, which compared to FP-funded projects, was larger. In 2000, AVL took part in projects funded by German research promotion agencies in collaboration with the German automobile industry (e.g. STAUMECS project). This was a first step towards the standardisation of CAD development and new architectures for advanced test systems, which later became a standard.

With a total volume of about 70 million Euro, CESAR was the largest project AVL coordinated at that time. The key research question was how to design and develop such complex software systems that meet safety and security expectations. It was difficult to integrate the diverse elements of the project as originally planned, and the entire endeavour was rather a set of loosely coupled projects. However, AVL learned that standardisation is key to engage all partners for true joint development. AVL also experienced the necessity of coordination with standardisation agencies.

CRYSTAL was a preceding project where further progress towards integration of different tools for developing safety-critical embedded systems was achieved. The consortium could successfully establish and push forward and Interoperability Specification (IOS) in collaboration with the standardisation agency OASIS. With this new standard it was, for instance, possible to integrate test systems, exchange data along the entire life-cycle, conduct requirement and scenario management. In CRYSTAL, large players from the aerospace sectors such as Thales and Airbus, which were ahead compared to the automotive industry, were involved too.

Figure 3: ECSEL research project cluster in Systems Engineering



Source: AVL

Parallel to the ECSEL projects, H2020 projects such as CPSETIS and DEIS were successfully acquired, both in the ICT Programme, the latter coordinated by AVL. Compared to ECSEL engagement in these projects, more specific topics in lower TRLs were addressed.

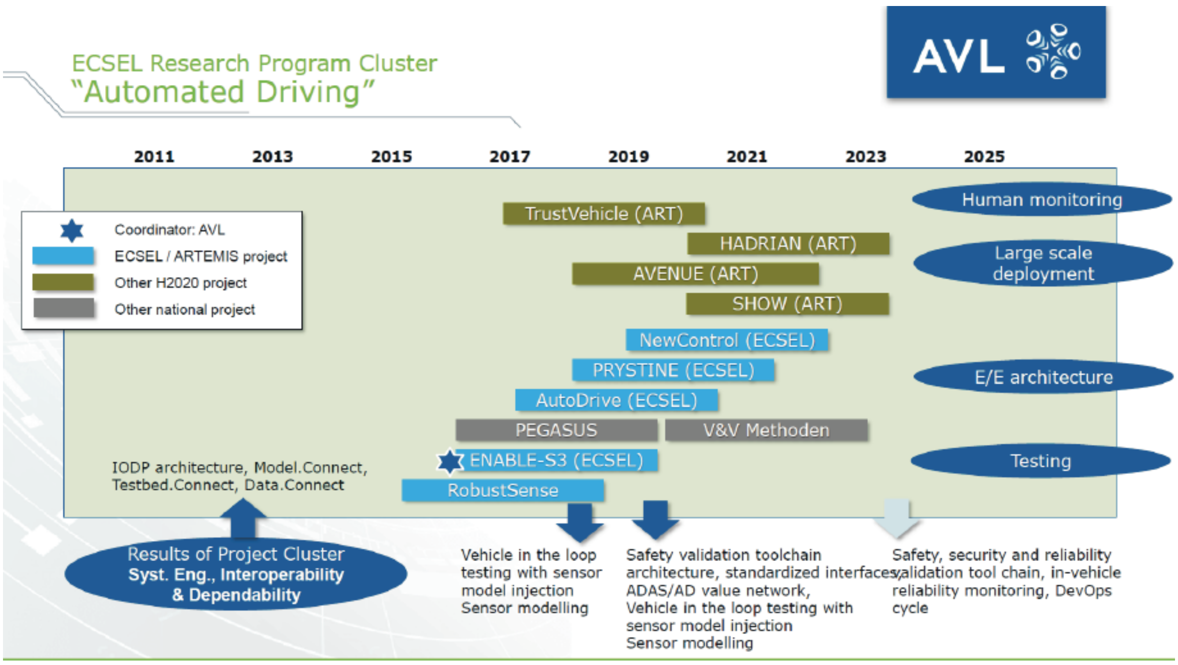
As mentioned, the software was considered a key element for the development and for AVL played a crucial role by developing and providing a modelling language (AML). At this time, IBM served a service provider and developed several software products as open source software. Within AVL there was discussion about a full approach to the open source path, but one experienced that the progress was not rapid enough and thus developed propriety systems.

The collaboration between certain companies was the main characteristics of these projects. For example, a collaboration between a company with a traditional background in the automotive industry (e.g. Daimler) and their strengths, for instance, in thermodynamics and mechanics, and a company with core business in software development and electronics (e.g. IBM and Siemens) was targeted. According to AVL, it took a long time to coordinate the collaborations. This was compounded by the underestimation of the amount of effort needed to, for example, find the common terminology and ontology, about e.g. the meaning of a module. This was laborious but necessary to have a common base for continuous work. Some terms had completely different meanings when, for instance, asking a thermodynamics engineer in comparison to a computer engineer.

Steps towards Automated Driving

In 2015, AVL engaged more deeply with the new demand for tools and simulations in relation to advanced driver-assistance systems (ADAS) and automated driving (AD). This is the second area with a coherent ECSEL Research Programme Cluster (see Figure 4).

Figure 4: ECSEL research project cluster in Automated Driving



Source: AVL

Automated driving creates new challenges especially for the validation and testing of vehicles with new challenges such as that the environment becomes part of the technical system to be modelled, an uncountable number of scenarios, and that sensors can only detect the environment to a certain extent. This implies an increased demand for both virtual and physical testing. These challenges were addressed amongst others in ENABLES-S3, funded within ECSEL JU and coordinated by AVL. The ENABLES-S3 consortium integrated established automotive and aerospace companies such as Daimler and Airbus but also leading IT companies such as IBM and Siemens. The goal of this consortium was to co-develop an industry standard for the architecture and its interfaces.

Acting as somewhat neutral player, AVL took the chance to coordinate this project in which leading global companies participated, who would have been reluctant if one of the leading firms had coordinated and assumingly, dominated the project. In addition, Austria does not host large automotive or aerospace companies, which was considered as an additional factor in promoting AVL as coordinator.

ENABLES-S3 was a first important step towards automated driving for AVL but also for other involved partners with the challenge to develop adequate architectures, tools and sensors. The results of the previously conducted projects were enhanced and transferred for the theme of automated driving. AVL dealt with the architecture and the expanding of the toolchain so that sensors can be integrated and modelled during the design process of a new car. The basic architecture developed within ENABLES-S3 is nowadays used by leading customers of AVL to design and test alternative solutions for automated driving and its multifaced demands within the development process. Later on, a business unit for automated driving was established within AVL.

AutoDrive, PRYSTINE and NewControl are further ECSEL projects with a strong participation of AVL developing validation toolchain architectures, standardised interfaces and sensor modelling techniques.

Commercialisation and economic impact

The research conducted within the ARTEMIS and ECSEL JU has been a key element for the technological development which has then been further progressed within internal projects to develop more specific products and commercialise solutions. When considering the entire R&D cost up to the market launch, these publicly funded projects make up about 5%.

In addition, for the further development in later TRLs, AVL also gained national research projects from the FFG, which, however, were more applied and mostly done alone or with just a few partners. Shaping an innovation ecosystem is not possible with such projects, which is the reason AVL preferred to engage in the international projects which hold particularly for ARTEMIS, ENIAC and ECSEL.

In both areas described here, AVL nowadays offer specific products and solutions which are directly connected with the ECSEL-funded R&D. With the development of the platform technologies and solutions, AVL could gain a leading position in this market segment. ENIAC and ECSEL projects allowed for the accelerated takeover of AVL's "Integrated and open Development Plattform" strategy and the related tools such as Model.CONNECT™ and Data.CONNECT™. The entire business unit at AVL in 2019 employed about 250 people and the turnover in the new business segment Systems Engineering makes about 41 million Euro.

The automated driving business has grown considerably in the recent past, with a turnover of about 20 Mio. Euro achieved in 2019. that should account for about one third of the total revenue of AVL until 2035. The project cluster "Automated Driving" also recruited about 120 new employees.

4.3 Key findings

AVL has digitised the vehicle development process with state-of-the-art and highly scalable IT, software and technology platforms, and creates new customer solutions in the areas of simulation and embedded software development in an agile and integrated environment.

The R&D conducted by AVL is conducted strategically, driven by technology and market trends. An important milestone for building up competencies and technologies in systems engineering was a strategy workshop in 2008. In this workshop, future trends and requirements for the vehicle development process were discussed. The increased importance of digitalisation and new alternative powertrain technologies were anticipated and it became clear that new developments and simulations tools had to be developed. The internal roadmap was updated with a definition of new requirements for the architectures and interfaces which guided the entire development process and a specific search for opportunities emerging within the ARTEMIS and ECSEL JU research projects.

The first ARTEMIS project of AVL, CRYSTAL, addressed the questions and challenges identified at this point of time. AVL recognised that the development of new simulation and testing tools is only possible in collaboration with the big industry players. The possibilities to build up and shape the innovation ecosystem from the company´s point of view was a key argument for engaging in ARTEMIS and later on ECSEL. This is the main characteristics compared to H2020 projects or projects from national research agencies. With H2020 it is more difficult to work over a longer time continuously on a theme with the same consortia. In addition, H2020 projects are smaller, more focused and have a much lower success rate, even though funding rates are higher.

With the enhanced goal to build up new software architectures and platforms, AVL tried to learn from successful international software firms which usually aim to build up an ecosystem around a common platform and network. New architectural innovations require collaboration within a network of partners. The projects funded within ARTEMIS, ENIAC and ECSEL facilitated AVL's entrance into the increasingly digitalised automotive industry. While traditionally the company is strongly driven by expertise and engineers with a strong background in thermodynamics, physics, mechanical engineering, computer science and electronics have become an important competency nowadays enabled in the course of the interdisciplinary European projects.

5 TTTech: Communication technologies for controlling aircrafts, vehicles, and off-high-way-systems

5.1 TTTech at a glance

TTTech is one of the most impactful academic spin-offs in Austria created in the past 25 years. The company was founded in 1998 as TTTech Computertechnik GmbH (TTTech being short for “Time-Triggered Technology”) by a team of visionary entrepreneurs. Their background was in research and first prototypical developments on real-time, time-triggered communication protocols and technologies for safety-critical controls conducted by Prof. Hermann Kopetz at the Institute of Computer Engineering at the Vienna University of Technology (TU Wien) since 1979. TTTech has a long tradition in running European projects and has already conducted underlying research within projects funded in the 5th and 6th Framework Programmes by the European Commission (EC).

Having focused on the development and building of time-triggered data communication protocols and technologies from the start, the Austrian high-tech company TTTech Computertechnik AG has proven itself as technology leader in robust networked safety controls. TTTech‘s products are applied in diverse safety relevant areas in the automotive, space and aerospace, energy production (off-shore wind-power plants), railway systems, and industrial process automation domains, where highest reliability and safety of networked electronic systems are required.

TTTech provides trend setting solutions for the challenges of future vehicle generations. Those challenges include increasing connectivity within the vehicle, the infrastructure, and the growing safety and robustness requirements regarding electronics for highly automated driving. This especially includes safety-relevant areas of vehicle dynamics and advanced driver assistance systems and security. Highly respected partner companies like Honeywell, Hamilton Sundstrand, Alcatel, AUDI, BMW, VW, Delphi, Continental, Infineon, NXP, Airbus, Boeing, General Electric, among others, helped TTTech’s products gain a global reputation in the deployment of leading development and production programmes.

From its development as a small start-up to a SME to a large enterprise with global reach, the TTTech Group of has spun-off several entities: Its automotive branch (TTTech Auto AG) with share-holding partners such as Samsung, Audi and Infineon. It has done the same with its industrial domain (TTTech Industrial Automation AG) with several subsidiaries world-wide and its Off-Highway branch (TTControl GmbH) which became a joint venture with Hydac International. TTTech Computertechnik AG acts as a holding and furthermore houses the TTTech Group's aerospace and space divisions. The TTTech Group companies have become a part in an ecosystem of customers and partners from different industrial domains, research institutions and organizations.

Currently, the company employs more than 2,200 employees in 14 countries, including Austria, Germany, Italy, the Czech Republic, Serbia, Turkey, Romania, the United States, Japan, China and others. With its impressive track record, the company can also be considered as a gazelle, which is defined as a company with strong continuous growth over a long time period. The compound average annual growth rate (CAGR) has remained above 25% since the company's establishment.

5.2 The role and effects of ARTEMIS and ECSEL projects

First ARTEMIS success with INDEXYS

TTTech Computertechnik AG participated in ARTEMIS right from the beginning of the programme and submitted its first proposal at the very first call. TTTech engaged strongly in developing embedded systems. Thus, the ARTEMIS programme seamlessly matched the strategic orientation of the company. The first project TTTech coordinated in the ARTEMIS programme was INDEXYS, which was co-launched by TTTech. It was strongly supported by company co-founders Prof. Hermann Kopetz and Dr. Stefan Polenda, who were both familiar with publicly funded research programmes from their work at the Technical University of Vienna.

The company perceived higher chances of winning projects compared to Framework Programmes due to a lower number of competing proposals. In addition, the company recognized the opportunity to meet new partners and potential customers and thus to expand its network. At that time, it was of paramount importance for a young and comparatively small company like TTTech, to get the opportunity to demonstrate the potential of their newly developed technologies and, in turn, to learn about the demand and requirements for new products from large companies and potential future customers.

Based on the GENESYS project results jointly conducted with the Vienna University of Technology and Prof. Kopetz, INDEXYS was a comparatively small project with 10 partners, the majority of whom had already been involved in preceding projects funded within the EC's 5th Framework Programme. The Vienna University of Technology and the institute of Prof. Kopetz were lead project partners and thus it was easy for TTTech to enter this network. Airbus and EADS were already members of the project consortium as well and later became important partners and customers. INDEXYS focused on developing network architectures and network/system on chip solutions based on the Time-Triggered Protocol TTP/C. TTTech joined as a member from the start of ARTEMIS Austria, an ARTEMIS JU promotion organisation in Austria which was initiated – amongst others – by AVL List GmbH and Infineon Technologies Austria AG. This enabled a long-term R&D project cooperation not only in ARTEMIS/ECSEL but also other EC- and nationally- funded projects.

One year later, the ACROSS project was following-up to industrialize the prototypical developments made in IDEXYS. The Vienna University of Technology led a project consortium which was significantly larger and reached the ambitious goal to provide an FPGA based System on a Chip solution ready for integration on a chip. The technologies and know-how developed in ACROSS were the basis of later hardware designs for the first central driving computers. Its latest versions are now built into the complex ADAS system providing, modern passenger cars.

In same year the automotive domain-oriented project POLLUX was granted as well. Research was further continued to transfer the communication architectures developed to the first vehicles. POLLUX was a project with a similar approach but focusing on application in electrical vehicles initially led by the FIAT research centre and later by SINTEF AF, Norway. TTTech strived to integrate the newly developed architectures, to design safety-relevant TTP/C databus systems incorporated in chips and to commercialize this technology.

The two SafeCer (nSafeCer & pSafeCer) projects conducted consecutively were further important ARTEMIS project milestones. The goal was to analyse the communalities in certification for different industrial domains, investigating if different industrial domains would benefit from cross-certification approaches re-using part of certification artefacts from i.e. the aerospace domain for the same or similar technologies. The rationale behind this approach was that many certification standards were built on the MIL standards. It therefore looked promising to endeavour communalities for re-use to save time and in the elaborative work of certification documentation and conduct of evidence proving testing. The projects investigated aerospace, automotive, railway and “other” domains and detected definitive commonalities. However, it proved to be considerably difficult to capitalize on them as the proof of similarity was challenging. Nevertheless, the experience gained and the knowledge on simplifying procedures were very helpful, even though the simple re-use factor for the one-to-one reuse of documentation for parts of the certification from other domains was limited.

Next, the AVL List GmbH coordinated project CRYSTAL focussed on developing an Interoperability Specification and platform for embedded systems development and tools mainly targeting the automotive industrial domain. TTTech established an integration process and tools interface for their newly developed Time-Triggered Ethernet network technology and a dedicated central driving computer-based demonstrator. Time-Triggered Ethernet also developed with support from different other research projects as a follow-on development from TTP/C widening the bandwidth and taking the next step to larger data rates forming the basis in today’s automotive Ethernet/TSN implementations.

Initiated in 2013, EMC2 was the largest project in ARTEMIS ever with 100 partners coordinated by Infineon Technology AG in Munich, Germany. In this project, about 180 demonstrators were developed in total. Andreas Eckel, responsible for managing publicly funded research projects at TTTech, remembers that at each project review about 60 new demonstrators were presented, impressing also the reviewers of the project. TTTech participated in three subprojects and developed demonstrators in the fields of aerospace, automotive, and industry.

In EMC2, a new path was entered by developing network technologies and systems that could connect to or disconnect from a Cyber Physical System (CPS) anytime to form a larger System of Systems (SoS) i.e. via the internet. In the target developments, TTTech contributed to enable the running of larger systems to autonomously configure in case another system out of a known pool of potential systems wants to connect or leave a connection (I.e. a tablet computer or smartphone as long as the device is in principle supported by the CPS). Thus, this huge and challenging project prepared the way for totally open CPS/SoS, in which the system would react on its own to connection requests from any device as long as it was equipped with the appropriate interface. This was applicable even to safety-relevant systems.

The technologies developed in the aforementioned projects were further advanced and prepared for commercialization into specific products. By setting up demonstrators to provide evidence on the connectivity of wide scale equipment in prototype grade technology readiness level continued the development work up to TRL 6/7. Figure 6 depicts how the different technologies developed within ARTEMIS and ECSEL were exploited due to developments conducted after the R&D projects. After the completion of ARTEMIS/ECSEL projects one of the first early adopters for TTP based data communication systems for safety-critical controls was the Aermacchi M346 Trainer Fighter. It benefitted from a Full Authority Digital Engine Controller (FADEC) codeveloped with Honeywell. Another application could be found in the F16 fighter FADEC. Data communication backbone solutions and network devices based on TTP integrated in the Airbus A380 (cabin pressure control system), the Boeing787 Dreamliner (Power generation/distribution subsystem), the COMAC C919, Bombardier C-Series and the Embraer Aircrafts (primary flight control system data communication for controls), among others.

Compared to competing data communication systems for safety critical controls up to RTCA DO 178B/C (SW) and RTCA DO 254 (HW) level A, TTP/C offers hard real-time, communication schedule-based data communication. Many other systems (I.e. CAN-bus) are event driven and run the risk of data collisions in case of system overload. Such systems are based on a priority setting, for instance, which becomes enormously complex in larger systems or systems of systems. This can, by definition, not happen in time-triggered systems following a detailed communication schedule. In addition, time-triggered systems have defined latency and jitter, which is essential in fast control loops. Another advantage is the incremental certification along the RTCA DO 297 design guidelines for IMA (Integrated, modular avionics). These guidelines only allow for conducting a limited certification restricted to the add-on system in case of upgrades or system enhancements. This is only possible for deterministic systems like TTP/C based systems.

Later developments with Time-triggered Ethernet were based on the same principles but offering direct connectivity to ARINC 664 part 7 (i.e. AFDX) and higher bandwidth. Thus, the experience and developments from the AREMIS-JU Projects and the TTTech TTP/C technology paved the way for the larger back-bone architectures and data communication systems based on Time-Triggered Ethernet and TSN.

The close of the ARTEMIS-JU Programme conducted within the 7th Framework Programme, provided TTTech with the challenges needed to also become successful in the successor programme ECSEL. However, the ARTEMIS-JU projects provided TTTech with an entrance ticket into the new follow-up programme ECSEL in the first place. The programme set up for Horizon 2020 became a lot more challenging due to the larger number of applicants and a significantly widened scope including a significant nano-technology focus. The reason for this change was found in the merging of AENEAS and EPOSS (nano-technology-based) with the ARTEMIS embedded systems focus forming one larger new entity out of formerly three different organizations. Due to the cooperation with large players in the nanotechnology industry as part of the ATEMIS JU programme, TTTech found reasonable conditions for further cooperation with Infineon, NXP, ST and others in the industry to form competitive consortia.

Figure 5: ARTEMIS and ECSEL projects with involvement by TTTech

Source: TTTech

Entering the automotive sector

As mentioned above, in the course of the first ARTEMIS-JU and later ECSEL-JU projects, TTTech started to increasingly transfer proven aerospace network technology know-how into other industries. The automotive sector was an important industrial domain adopter. PRYSTINE carried on EMC2 and ENABLE-S3 developments and TTTech aimed at advancing their technologies based on TTEthernet/TSN for the automotive sector and highly automated/autonomous driving. Here, communication networks were built for the automotive sector with the aim of reducing the number of databus systems towards centralized architectures, a challenge on which colleagues in the aircraft industry already worked on 40 years ago (ARINC 664 part 7 and the AFDX implementation as a switched Ethernet backbone network). The research built upon the previous advanced driver assistance systems (ADAS) successfully developed for Audi, known as zFAS (zentrales Fahrer-
assistenzsystem).

Based on the progress achieved, TTTech could build up competitive advantage over Flex-ray, the competing communication system. Both are time-triggered protocols and offer similar approaches. TTTech had to combat barriers of entry when FlexRay endeavoured to push TTP/C out of the automotive industrial domain. However, FlexRay, despite its dedicated consortium built for developing the technology, never succeeded in entering the safety-relevant area. The market quickly demanded higher bandwidth and so the defeat of TTP/C in the automotive domain was less painful since the area of Ethernet/TSN based systems also ended the potential success of FlexRay.

3CCar was the first successful ECSEL proposal right at the start of the ECSEL programme. TTTech tested the implementation of a new switch design in a novel chip with a close connection to the chip manufacturers NXP and Infineon. It also aimed to drive the number of networks in a vehicle down compared to the cars available on the market and showed the advantages of a back-bone oriented data communication architecture. TTTech integrated various types of equipment with Ethernet interfaces into highly safety relevant applications on the one hand and less critical data traffic on the other hand in one and the same network, proving the freedom of interference and cross influence of the two worlds in a time-triggered environment.

In the AUTODRIVE project, TTTech conducted R&D work concerning their newest approach for seamless integration and abstraction of application with virtualized systems.

The software approach allowed for integration of third-party products such as hypervisors and operating systems for multi-core systems, eliminating the time-consuming software modules supporting such an approach.

Today, the automotive segment is a key business field and the products offered are network architectures, network components, central driving computers for highly automated/autonomous operation, safety and security products and tools enabling autonomous driving system developments. TTTech significantly benefitted from the collaborative R&D work conducted in ARTEMIS-JU and ECSEL-JU projects.

Increased diversification

With the successes in the automotive and the aerospace (aircraft) domains, TTTech widened its scope to other industrial domains such as agricultural machines, other off-highway equipment and in particular space and industrial automation (industry 4.0) and the edge-computing sector. Especially with the latter, TTTech also focused on the "security" domain for safety-critical applications.

The agricultural equipment domain and other off-highway applications

Another market segment for which fundamental developments have been carried out in ECSEL are "off-highway systems". Here, control systems for the entire product chain (display, dashboard, internet connection) for any hydraulic control system used in snow groomers, fire engine vehicles, agricultural machines/equipment etc. were developed and researched up to a prototypical level.

ENABLE-S3 was one of the first agricultural equipment R&D assignments in ECSEL. TTTech contributed to autonomously operating farming equipment prototypes (fleets of harvesters, tractors and a drone for supervision all operating autonomously) and a naval autonomous vessel application for the shore/ship-based bridge approach. The project combined Time-Triggered Ethernet with the new TTTech edge computing devices and software for safe and secure data communication in safety-relevant control applications.

AFarCloud was a further project developing solutions for farming, driving the ENABLE-S3 developments further. Compared to the automotive domain, agricultural machines in the first instance require significantly deviating control devices and sensors. This is due to the harsh environments in which they operate (dust and dirt prohibit the use of cameras also due to front-views not always being available when harvesting crops). We had to completely re-arrange the sensors and sensor fusion. This also required new software and even modified computer and controller hardware.

The industrial automation and edge computing domains

In the industrial automation area, they began with offshore wind power plants and their internal network and control computers. The data communication was performed using Time-Triggered Ethernet-based computing modules. TTTech also started to investigate how to make these networks resistant to unauthorized access. The pre-product prototypes were later used in the VESTAS wind turbine developments and testing.

Productive 4.0 is one of the largest projects, if not the largest within ECSEL, TTTech contributes its edge computing software and modules, which allow to control different manufacturing sites via the internet as well as downloading manufacturing machine control software and control via a protected cloud space.

iDEV is another project aiming to replace Henry Ford’s approach of conveyor belt-controlled manufacturing methods. The long-term vision is to set up a manufacturing eco system capable of retrieving individual (also single lot size) orders via the internet or possibly smart phones. This would trigger a fully autonomous purchase and manufacturing process using different plants and potentially also including suppliers. In the final assembly, manufacturing islands are used to assemble the product and transport it from island to island to receive its different assembly steps. This will be controlled via a plant-unique central computing system engaging edge computing and artificial intelligence measures.

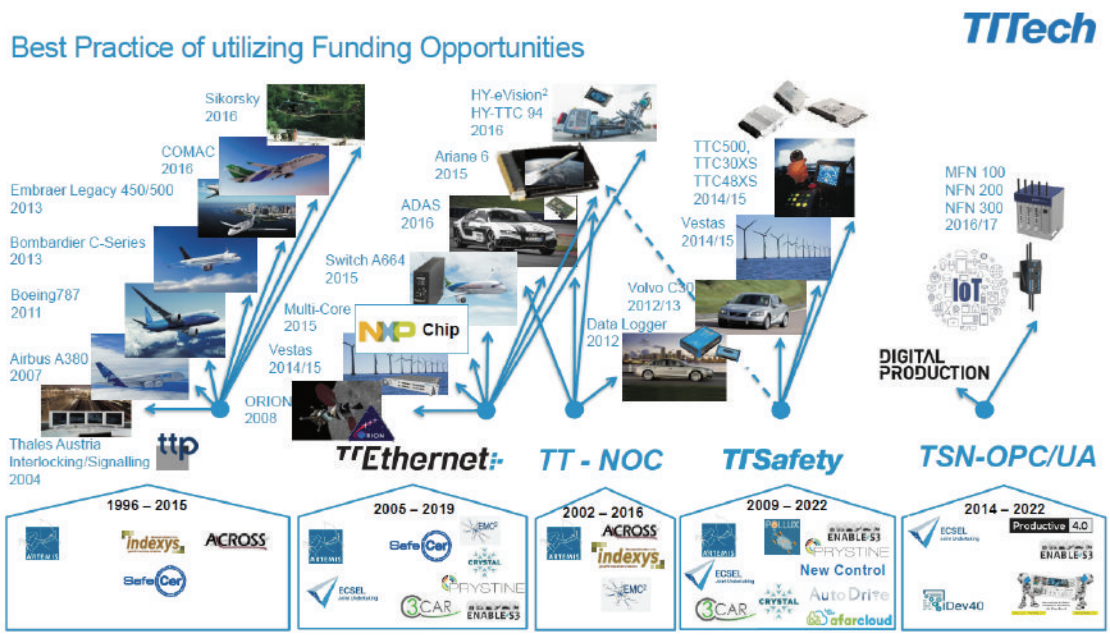
The space domain: The Ariane success

One of the most spectacular successes of an ECSEL-funded project, relaying on the EMC2 project prototypical results, was the development of the Ariane 6 TTEthernet communication backbone & prototypical set-up. The existing technological solutions, such as AFDX, which is Airbus Intellectual Property, were both, hard to beat and to differentiate from. The Austrian FFG-based funding authority for space projects was sceptical about the success of competing with such giants as Thales and Airbus, and even within TTTech the chance of success in this competition was considered low. Yet, the Time-Triggered Ethernet-based approach, including the data communication backbone and the network components on the hardware side and appropriate communication software on the other hand, offered a few significant key advantages: The biggest advantage of Time-Triggered Ethernet is its ability to deal with three traffic classes within one system. Time-Triggered Ethernet can broadcast best effort Ethernet Traffic, (as you will find on any Ethernet connection on every laptop), rate-constrained traffic (ARINC 664 part 7, the most popular implementation is AFDX) and the deterministic, hard-real-time Time-Triggered Ethernet, all three traffic classes in parallel. This supports the transmission of safety-critical (time triggered Ethernet) less safety critical traffic (ARINC part 7) and non-critical traffic (standard Ethernet) over the same network in parallel in a time sliced manner according to an overarching schedule

This success is a further example of how TTTech competed against established organizations, be it in the aerospace or the automotive industries, or others. Although all competitors have tried to develop and manufacture time-triggered systems in recent years, all experienced major difficulties and complexities in handling such a system. Therefore, they stopped its development due to high development costs and too narrowly defined application areas within their own industries. At the same time, TTTech aimed to develop the technology for different application areas and industries and hence was able to exploit synergies between the different fields and gain a leverage effect.

Figure 6 provides an overview of the different technologies and solutions (TTP, TTEthernet, TT-NOC, TTSafety, TSN-OPC) to a large extent developed within ARTEMIS and ECSEL projects. The technologies were researched and prototypes and demonstrators for verification and validation were built. The prototypical results retrieved from the ARTEMIS-JU and ECSEL-JU projects were then subjected to an industrialization and commercialisation phase to distil competitive market-ready products that were marketed successfully in many different industrial domains.

Figure 6: Exploitation and commercialisation of ARTEMIS and ECSEL projects within TTTech



Source: TTTech

5.3 Key findings

Today, TTTech is a research- and development-driven large industrial enterprise led by an entrepreneurial management team following strong technological visions. The company mission is: “With our leading technology solutions, we ensure safety and electronic robustness for a connected, sustainable and automated world”.

The company already had a rich tradition carrying out projects funded within the FP 7 when entering the ARTEMIS JU projects, which matched the strategic orientation of the company very well. In the following years the company submitted several proposals annually winning at least one of them per year and completing it successfully. The projects mainly focused on applications for the aerospace and automotive sectors but were later expanded for industrial and off-highway applications.

TTTech argues that one important benefit of participating in the ARTEMIS-JU and ECSEL-JU projects was to learn about the requirements of large customers in the aerospace and automotive industry. At the beginning, TTTech was unknow to its potential customers and partners but was able to gain trust and build long-term relationships within the ecosystems. Usually, the barriers to entry, particularly in the aerospace industry, are very high, and as a young small company long-term survival is not guaranteed and at high risk. TTTech was able to demonstrate the performance of its time-triggered technology and offered partners in these projects to “try out products at relatively low cost”. Another important motive is risk reduction. Thus, conducting funded projects is not about funding and funds only. It is also related to building a substantial international network for any kind of cooperation and joining the ecosystem. Another important aspect of the participation in the ECSEL project is the possibility to standardize technologies in an ecosystem. As innovator of deterministic Ethernet, it was possible, for instance, for TTTech to become the driving force behind the IEEE TSN standard, the SAE AS6003 TTP/C standard and SAE AS 6802 Time-Triggered Ethernet standard.

From TTTech’s point of view, the network-architectures, control computers, network components as well as safety & security products developed with support of ARTEMIS-JU and ECSEL-JU funded projects not only acted as a considerable source of employment (over 2,200 employees world-wide by 2020) and turnover growth (CAGR >25% over the years). It also contributed to the competitiveness of the entire European industry. The technologies delivered milestones for autonomous driving and for implementing aerospace on-board components and networks for almost all large passenger aircrafts. In addition, digital manufacturing (e.g. by edge computing computers and software) is supported and off-shore wind-power plants are becoming safer and more secure. ARTEMIS-JU and ECSEL-JU, thus also significantly propel employment in organizations making use of their offers in the high-tech job areas of industrial development and R&D. Both JUs therefore contributed to keeping Europe at the leading edge of technology development and competitiveness.

TTTech has clear, future-oriented R&D goals and an internal R&D roadmap for roughly the next five years, driven by the business units and TTTech Group entities. Public funds are important to implement the roadmap with the logic that the company is searching for possible public funding to mitigate risk. TTTech prefers a proactive approach and therefore does not follow a tactic of adapting its bidding strategy in order to meet the requirements of existing projects.

ARTEMIS-JU and ECSEL-JU projects in sum accounted for about 30% of all publicly funded projects within TTTech. Projects funded by the Framework Programme and funds from national research promotion agencies make up the remaining part. The ECSEL-JU projects generally are providing results up to an early technology readiness stage (TRL). Hence the company cannot realise R&D results and ideas up to product level to immediately sell to potential customers. However, R&D funded projects help to cover part of the cost of the risky development path and thus help to mitigate the risk. In addition, it is of high importance to retrieve information ahead of time directly from partners about their needs and requirements, so that they can become customers shortly after project completion.

6 Summary and Conclusions

The case studies revealed the large impact on the development and growth of four high-tech companies, and the specifics of the ARTEMIS/ENIAC/ECSEL JU. All companies were able to enter new scientific and technological fields associated with high risks and challenges. Within these projects, fundamental breakthroughs were achieved in early stages. The competencies, technologies and solutions developed and built an important base for further product development and commercialisation by the companies. To summarize:

- Based on ENIAC/ECSEL projects, Infineon Austria was able to realise the 300mm thin waver technology for the manufacturing of wavers, one of the decisive factors for the continued existence of the Infineon location in Villach. Production is now being expanded.
- The Austrian semiconductor company ams was able to develop technologies for the integration of functions and components into miniaturised sensor systems. ECSEL projects helped ams to decisively expand its sensor portfolio and enable sensor integration and continuity of topics.
- AVL was able to develop platforms, tools and architectures for simulation of testing the development process in the automotive industry. The technologies helped strengthen its position in the global market and pave the way to new business fields.
- TTTech developed technologies and protocols for the communication and control of aircrafts, cars and other devices, and like the other companies was able to grow in terms of sales and employees.

The project outputs overall have been protypes, architectures, process and manufacturing technologies, publications, and to some extent patents. In addition, common platforms, reference architectures, and pilot testing facilities have been developed. The projects also allowed for contribution to standard development.

Apart from the impact on individual firms' development, their technologies, products and solutions even contribute to the development of an entire industry in Europe. Important solutions for automated driving, the control of industry 4.0 devices, or secure and safe passenger aircrafts have been developed. ECSEL demonstrates the strengthening and maintaining of manufacturing sites for the production of high-end semiconductors is possible in Austria and in Europe.

In all projects, the Technology and Manufacturing Readiness Level (TRL) has been substantially increased by about 3-4 levels starting from an TRL of approximately 2-4 and reaching a level of 5-7 by the end of the projects.

The main thematic impacts and specifics of the projects funded within ARTEMIS/ENIAC/ECSEL can be summarised as follows:

1. Funding and risk-sharing

Understandably, financial funds are important. Funds allow R&D to be conducted, including sharing and mitigating the risk of innovation and R&D. However, as mentioned by every organisation, funding is only one reason for participation.

2. Networking and partnerships

ECSEL allowed for the creation and strengthening of international networks for any kind of cooperation, and for meeting potential customers to learn about their requirements. For smaller organisations such as TTTech, ECSEL projects expanded access to larger partners (and later customers) to learn about their skills and competencies. In addition, taking part in the projects helps to remain well informed about other technologies developed in the community. The companies participating in ECSEL projects know that R&D is conducted collaboratively and hence that IP can only be protected to a certain extent.

3. Thematic scope

ECSEL projects have a larger scope and orientation, and almost always encompass multi-industry or cross-industry applications areas. This is important given the fact that technological development in early stages is associated with high uncertainties and possibilities to explore different application fields and markets. Generic technologies often can be applied in different industries and for various applications. AVL and TTTech, for instance, developed technologies that can be used within the automotive, aerospace and manufacturing industries.

4. Building ecosystems and value chains

ECSEL efficiently helped both large and small organisations build an ecosystem and develop platforms and standards cumulating in a dominant design. Such development are also crucial for Europe's global competitiveness. The possibilities to jointly shape such an innovation ecosystem was one of the major benefits the companies experienced.

5. Speed

Participating enable a speedy fulfilment of the development goals in comparison to global competition. The companies might have even completed the projects without funding, however, they would have been slower, had less volume and less likely to achieve market success.

6. Specifics of ECSEL JU projects

R&D is a risky endeavour, and all projects conducted within the ARTEMIS/ENIAC/ECSEL JU were in the early TRL with a given high risk. Evidently, not all results have been exploited and commercialised. However, the indirect effects were important, too. Examples of indirect effects include relationships, a common terminology, interfaces, and standards. The case studies also reveal that ECSEL offers a chance to develop and test different approaches and solutions and to verify technological capabilities.

The case studies Infineon Austria and ams presented here can be allocated to the semiconductor industry. For them, the predecessor ENIAC was more relevant. AVL and TTTech are engaged in embedded software development, and for these companies ARTEMIS was more relevant.

In the semiconductor industry (ENIAC) an important role was to build up value chains, while the industry more closely associated with embedded software (ARTEMIS) was particularly interested to build up ecosystems. These are different industries and it is difficult to compare the outputs of the ECSEL projects by figures such as number of employees, manufactured products, etc.

With this context, the companies also stressed that ECSEL allowed for integrating different industries to jointly conduct interdisciplinary R&D. One example is the increasing importance of software and electronics in the automotive, aircraft and manufacturing industries, where the Austrian and European companies were able to synthesise mechanical engineering and software engineering.

Accordingly, ECSEL funded projects have specific characteristics compared to other publicly funded projects and programmes. ECSEL projects are characterised by size and position in the TRL. The projects allow work in different sectors, domains, and on very specific themes. ECSEL is important in the middle stages of the chain. In the beginning, usually smaller and more explorative projects are done, but later on, more specific and applied projects are conducted. In contrast to ECSEL, H2020 projects are usually much more narrowly focused.

All companies argued that R&D is driven by internal strategic decisions. All companies are performing R&D strategically using an internal roadmap with clear development goals. Within this process, technological and market factors are taken into account to define R&D priorities for the coming years and build a base for specific products launches. Within this background, the companies are searching for opportunities to get certain R&D projects funded by European and national research programmes. All the companies stressed that a project, and specific research, is done only because of the research programme or call availability, and hence, the projects must fit the internal requirements. The ECSEL projects therefore must support the corporate strategy in terms of content and fit in within the company's internal technology roadmap.

List of figures

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