FIT-4-AMANDA

Future European Fuel Cell Technology: Fit for Automatic Manufacturing and Assembly

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Publishable Executive Summary

The goal of this deliverable (D1.4: "Optimized strategies for market and production based on customer feedback") is to summarize and classify the collected feedback from interested parties in the research project Fit-4-AMandA and the developed products.
This report links to the submitted report *D1.3 – Report on potential customers and related business cases* (confidential deliverable, the public summary is available here on the project website) and builds on the results presented there by further discussing the optimized strategies for market and production based on the received customer feedback.

The deliverable is structured in the following parts:

- Part 1: report on the selection of stakeholders and possible business case(s)
- Part 2: brief summary of methods used for stakeholder's engagement
- Part 3: analysis of feedback received, and optimised strategies defined

In addition to the numerous other measures for the publication and exploitation of the results achieved (listed in deliverable D7.4), a workshop was held at Fraunhofer IWU as part of the FC^3 Conference in Chemnitz (November 26-27, 2019). Four presentations were given on the project contents and results. The topics were quality assurance in automatic stack production, production of bipolar plates, development and construction of an automated system for fuel cell stack assembly and challenges in the market introduction of fuel cells in terms of quantity and quality.
Based on the resulting customer feedback, existing market and production strategies were considered in this document and adapted accordingly.

1 Stakeholder definition and possible business cases

This deliverable summarizes the identified needs of the potential customers of the project partners in Fit-4-AMandA who are interested in the achieved results of this project. Further, the associated consequences for the Fit-4-AMandA products and the corresponding product adaptations are presented.

Customer feedback and needs was obtained via activities e.g. presentations at international conferences and workshops at Fraunhofer IWU. These activities are further described in the deliverables D1.3, D6.1, D6.2 and D7.4. The evaluation was carried out using the procedure shown in Figure 1-1 to ensure a systematic exploitation of the findings.

Figure 1-1 Determination of customer needs and procedure to ensure a systematic exploitation of the findings

These activities were initiated in order to create a network of potential customers, suppliers, service providers and research institutions. The main motivation lays in the need to investigate existing approaches to create a new market niche and, most important, developing new ones.
In addition, the project strategies and goals have to be compared (and aligned/ adapted in necessary) with the needs and ideas of potential customers and partners.

As detailed reported in D1.3 customers have been identified for different sectors of possible applications:

1. Portable applications;
2. Stationary applications;
3. Transport applications.

One of the outcomes of D1.3 was the definition of a list of potential customers. The customers were divided in two main groups based on the main market interest: i) Potential customers **for MMM for PEMFC-stacks** and PEMFC components – PEMFC Stack Manufacturer and ii) Potential customers for (scalable) **PEMFC stacks in 'high batch sizes'.**

Together with the potential customers possible business cases have been identified and prioritized. Table 1-1 identifies overall uses cases (left column) and the possible business cases prioritized according to their numbering (middle). Furthermore, in the column on the right-hand side, the business areas are divided into global application types.

Table 1-1 Overall uses cases (left) and prioritize business cases (middle) divided by more specific application types (right) [D1.3[1]]

Overall use cases	Prioritised business cases regarding PEMFC stacks	Application type
• Scalable PEMFC stacks • Increased production capacity • Know-how	1. Provider or supplier **PEMFC stacks**	**Portable, Stationary, Transport, Maritime, Rail**
	2. Provider or supplier **PEMFC systems**	
	3. Service provider of **service and maintenance**	
	4. Service provider of **consulting**	
	5. Service provider for **design**	
	6. Service provider of **construction or assembly**	

The business cases **one** and **two** "Provider or supplier **PEMFC stacks** and **systems**" result in the highest prioritized use cases of Proton Motor (PM). The business case **three** "Service provider of service and maintenance" is linked to the previous two and will be expected by customers. Furthermore, a solid service and maintenance concept as use case increases customer confidence in the physical products.

PM is currently focuses on the development, construction and sale of PEMFC stacks for applications with high durability requirements. For this reason, PM currently only uses graphite composite BPPs, as these are superior to metallic BPPs in terms of lifetime. In this way, PM distinguishes itself from the current stacks of metallic BPPs favoured by the automotive industry. This strategic decision brings clear advantages, such as a high corrosion resistance, which results in a long durability. The significantly increased lifetime of graphite-based BPP compared to metallic BPP justifies their use in those applications (e.g. delivery traffic, commercial transport), where a long lifetime is important, despite the significantly higher space requirement compared to metallic plates and other advantages of metallic plates.
Table 1-2 further define the prioritized business case for the defined possible applications.

Table 1-2 Prioritised business cases "Provider or supplier PEMFC stacks and systems" divided by application types based on D1.3

Application type / Characteristics	Portable	Stationary	Transport
Definition	Transportable unit for energy conversion	For energy conversion at a fixed location	Transportable but fixed unit for energy conversion
Typical power range of PEMFC stacks	1 W to 20 kW	0.5 kW to 75 kW (or higher with multi stack systems)	1 kW to 75 kW (or higher with multi stack systems)
Example	• Small or medium sized 'movable' APUs • Military applications • Small portable products • Movable Diesel genset replacement	• EPS, UPS • CHP • Larger 'permanent' APUs • Diesel genset replacement	• Commercial Light and medium duty vehicles • Heavy duty vehicles • Busses • Material handling • Ships (APU or Drive train) • Aviation (APU or Drive train)
		• Engines for automobiles conceivable in combination power supply function	

The following sections discuss how successful these measures were, to what extent the feedback influenced the project results and where the challenges in implementation occurred (project phases, time frame/milestones and actual project status).

[1] D1.3 Report / database on potential customers and related, specific business cases divided by use case (CO), deliverable date 2019-09-20

2 Methods Used

The main objective of Fit-4-AMandA project is to contribute to the further industrialization of PEMFC stack production and to provide affordable FC systems in large quantities to saturate the emerging market / demand. Main products of the Fit-4-AMandA project were concentrated in the following products, presented in Table 2-1:

Table 2-1 Main products of the Fit-4-AMandA project based on D1.3[2]

WP	Fit-4-AMandA consortium	Main Fit-4-AMandA products and benefits
3	Aumann Limbach-Oberfrohna GmbH	• **Automatic assembly machine for PEMFC-stacks** • Establishing networks for better access to potential customers and partners • Knowledge / Know-how
2	IRD Fuel Cells A/S	• **PEMFC components (MEA and BPP)** • Establishing networks for better access to potential customers and partners • Knowledge / Know-how
1	Proton Motor Fuel Cell GmbH	• **Scalable PEMFC stacks in high batch sizes** • Knowledge / Know-how • Establishing networks for better access to potential customers and partners • Knowledge / Know-how
6	UPS Europe SA	• Establishing supplier and partner networks • Knowledge / Know-how → especially in the field of FC system integration
4	Fraunhofer IWU	• Establishing partner networks • Knowledge / Know-how → especially in the field of BPP manufacturing
5	TU Chemnitz / ALF	• Establishing partner networks • Knowledge / Know-how → especially in the field of quality control and assurance

With the focus on the market impact and the potential level of sales figures, the Fit-4-AMandA products and corresponding project partners shown in Figure 2-1 are of increased relevance.

Figure 2-1 Main products which emerge from the development work in Fit-4-AMandA based on D1.3

In the following sub-sections detailed information in the channels and methods used are reported.

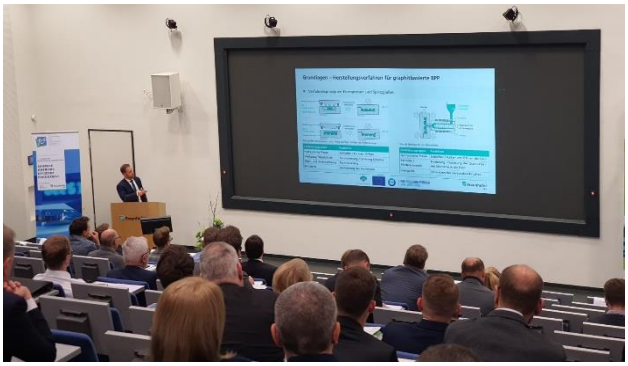
[2] D1.3 Report / database on potential customers and related, specific business cases divided by use case (CO), deliverable date 2019-09-20

2.1 Fit-4-AMandA workshops: *Determination of customer needs*

The motivation for the initiation of workshops was to inform and interest as many industrial partners and research institutions as possible about the Fit-4-AMandA project. The audience feedback was of major relevance to identify the needs of potential partners and customers.

Table 2-2 Fit-4-AMandA workshops

Title	Date	Place
Fit-4-AMandA Workshop no. 1	17/04/2018	Fraunhofer IWU Chemnitz, Germany
 	The audience included • Automotive manufacturers • Components suppliers for automotive application • Materials manufacturer • Representative of the innovation network "Forschungsvereinigung Antriebstechnik"	
Fit-4-AMandA Workshop no. 2 (FC3 Conference)	26-27/11/2019	Fraunhofer IWU Chemnitz, Germany

 	The audience included
	• Automotive manufacturers (OEMs)
	• FC stack and -system suppliers
	• Component suppliers
	  ◦ BPP manufacturers (Tier1, Tier2)
	  ◦ Sealing manufacturers
	  ◦ Machine and Press manufacturers
	  ◦ Tool manufacturers and machine tool manufacturers
	• Funding authorities
	• Research institutes
	• Technical universities 	

The workshop was held, as a part of the FC^3 Conference in Chemnitz, at the Fraunhofer IWU. Besides three full texts, four presentations were given, see Table 2, in which the main results of the Fit-4-AMandA project were presented. As a result, the project consortium was able to receive direct feedback from the participants.

2.2 Workshops information and presentations

In the following Table 2-3 the participations of Fit-4-AMAndA project partners at selected important events and congresses are listed, where concrete requirements were discussed with potential customers.
Contact and discussions with potential customers and stakeholders at these events are an essential input for customer feedback and thus for the development of optimized strategies for market and production based on. In addition, all other opportunities to identify customer requirements were of course also used in detail. This often resulted from bilateral discussions.

Table 2-3 List of important presentations and related publications in the context of Fit-4-AMandA relevant workshops

Title	Date	Place
Fit-4-AMandA Workshop no. 1	**2018/04/17**	**Chemnitz, Germany**
Presentation by Sebastian Porstmann (FhG-IWU)		
INSPIRE Workshop: MEA Workshop / FCH-JU Projects synergies	**2019/03/ 05-06**	**Marseille, France**
Dr. Jiri Hrdlicka (TUC), Dr. Anna Molinari (UNR), Thomas Wannemacher (PM) Sharing technical information and networking within EU projects EU projects VOLUMETRIQ, CRESCENDO, GRASSHOPPER, GAIA, **Fit-4-AMandA**, HYDRAITE and ID-FAST the MAMA-MEA		
Conference "f-cell + HFC"	**2019/03/22-23**	**Vancouver, Canada**
Presentation by Prof. Dr.-Ing. Thomas von Unwerth (TUC)		
10th International Conference Hydrogen Days 2019	**2019/03/27-29**	**Prague, Czech Rep.**
Presentation by Dr. Martin Biák (TUC) Title: Future European Fuel Cell Technology: Fit for Automatic Manufacturing and Assembly		
FCH JU Workshop on regulation codes and standards (RCS)	**2019/06/25**	**Brussels, Belgium**
Presentation by Thomas Wannemacher (PM) Title: Future European Fuel Cell Technology: Fit for Automatic Manufacturing and Assembly - Barriers and challenges within the FCH technologies		
VDMA Fuel Cell Workshop I Quality assurance of repeat parts in membrane fuel cells	**2019/06/03-04**	**Duisburg, Germany**
Co-Organisation and chair of the workshop Thomas Wannemacher (PM) Discussion and group work (Thomas Wannemacher (PM), Dr. Martin Biak (TUC), Alexander Pritzl (PM), Robert Csaky (PM)		
 		
ECFC 2019 – Low-Temperature Fuel Cells, Electrolysers & H2 Processing – Fundamentals & Engineering Design	**2019/07/03-05**	**Lucerne, Switzerland**
Presentation by Dr. Martin Biák (TUC) Title: Future European Fuel Cell Technology: Fit for Automatic Manufacturing and Assembly		

VDMA Fuel Cell Workshop II Automated stack stacking of membrane fuel cells	**2020/01/28-29**	**Duisburg, Germany**
Co-Organisation and chair of the workshop Thomas Wannemacher (PM) Discussion and group work (Thomas Wannemacher (PM), Dr. Martin Biak (TUC), Dr. Thilo Richter (Aumann) **Presentation by Dr. Richter (Aumann)** Title: **Requirements and challenges in stack stacking** Presentation by Thomas Wannemacher (PM) Title: Requirements and challenges in stack stacking from the fuel cell manufacturer's point of view		
 		
8th Electric Vehicle Production Days (EPT)	**2020/10/05-08**	**RWTH Aachen, Germany and online**
Online Discussion and Presentation by Thomas Wannemacher (PM) Title: Industrialisation of the production of NT-PEM stacks - from the hand manufacture to serial production		
Journal on hydrogen and fuel cells	2019/10/01	H2-international 04
Article by Sebastian Porstmann and Dr. Martin Biák Title: FIT-4-AMANDA – STACK ROBOT DELIVERED – Automatic production line for PEM stacks Link: https://www.h2-international.com/wp-content/uploads/2019/11/H2-international-October-2019.pdf		
Open access publication by a peer-reviewed journal	**2019/10/18**	**MDPI machines**
Article by Sebastian Porstmann, Thomas Wannemacher and Thilo Richter Title: **Overcoming the Challenges for a Mass Manufacturing Machine for the Assembly of PEMFC Stacks** Link: https://doi.org/10.3390/machines7040066		
Fit-4-AMandA Workshop no. 2 (FC3 Conference)	**2019/11/26-27**	**Chemnitz, Germany**
Presentation by Dr. Martin Biák (TUC) Title: FIT-4-AMANDA – AUTOMATION OF PEMFC-STACK MANUFACTURE		
Article by Dr. Martin Biák* and Prof. Dr.-Ing. Thomas von Unwerth Title: FIT-4-AMANDA – AUTOMATION OF PEMFC-STACK MANUFACTURE Link: https://monarch.qucosa.de/api/qucosa%3A36264/attachment/ATT-0/		
Presentation by Thomas Wannemacher (PM) Title: CHALLENGES OF AN SME IN THE MARKET RAMP-UP OF FUEL CELLS IN TERMS OF QUANTITY & QUALITY		
Article by Thomas Wannemacher Title: CHALLENGES OF AN SME IN THE MARKET RAMP-UP OF FUEL CELLS IN TERMS OF QUANTITY & QUALITY Link: https://monarch.qucosa.de/api/qucosa%3A36198/attachment/ATT-0/		
Presentation by Sebastian Porstmann (FhG-IWU) ANALYSIS OF MANUFACTURING PROCESSES FOR METALLIC AND COMPOSITE BIPOLAR PLATES		
Article by Sebastian Porstmann*, Allan Christian Petersen and Thomas Wannemacher Title: ANALYSIS OF MANUFACTURING PROCESSES FOR METALLIC AND COMPOSITE BIPOLAR PLATES Link: https://monarch.qucosa.de/api/qucosa%3A36248/attachment/ATT-0/		
Presentation by Dr. Thilo Richter (Aumann GmbH) Title: Automated Fuel Cell Stack Assembly - A Experience Report		

Open access publication by a peer-reviewed journal	2020/11/02	Journal of Manufacturing Processes
Article by Sebastian Porstmann, Thomas Wannemacher and Prof. Dr.-Ing. Welf-Guntram Drossel Title: **A comprehensive comparison of state-of-the-art manufacturing methods for fuel cell bipolar plates including anticipated future industry trends** Link: https://doi.org/10.1016/j.jmapro.2020.10.041		

Summary of the inquiries received during the project period and the questions, suggestions and feedback during the workshops are given in Section 3.1. Further Fit-4-AMandA dissemination activities are listed in the Appendix – List of presentations and publications in the Fit-4-AMandA.
potential customers offers a basis for the optimisation of market and production strategies.

The following Table 2-4 lists project relevant application types or technological fields. The following application types or technological fields were considered:

- Transport applications
- Stationary applications
- Mobile applications
- Materials for BPPs
- Tools and machines
  - BPP production
  - Assembling to a PEMFC stack and clamping
- Quality control and assurance
  - BPP production
  - Assembling to a PEMFC stack and clamping

In addition, selected related industries, customer groups or industry partners are listed. The questions received during project presentations and workshops are assigned to these areas. In order to assign the confirmations to the Fit-4-AMandA products, a separate column, called "Fit-4-AMandA product assignment" (subgroups), has been provided in Table 2-4.

- **aFCSm** = automated FC stack manufacturing
- **QAS** = Quality assurance system
- **FCS&S** = FC stack and system (properties, design, source, cost, manufacturing)
- **FCC** = FC components (properties, design, source, cost, manufacturing)

Table 2-4 contains two columns with the designation "**Subgroup number**" (this refers to the four subgroups) and "**Total number"** of questions (sequential numbering). These have been provided in order to be able to finally assign the number of the questions or feedback received to the Fit-4-AMandA subgroups and to systematically evaluate the feedback.

The questions written in bold in Table 2-4 were asked more frequently (at different events and independently of each other) during the numerous events on the Fit-4-AMandA project and the results achieved. Therefore, these questions are listed several times in Table 2-4. The aim of this approach is to express their relevance and to show from which sector (e.g. manufacturers of different FC application types, different supplier, tool and machine manufacturers, material sector etc.) these questions originate. Insofar as several questions have been asked by one person in context and in a direct sequence, these are evaluated as one question in the table.
Furthermore, some questions concern several of the four subgroups formed. In this case, the questions in question were rated several times according to the number of sub-groups addressed. The reason for this is the evaluation in the diagram in figure 3.
In total, 92 questions were included as a result of the described procedure. The 92 questions represent 100% and are used as denominators to determine the distribution of the percentage of subgroups formed.

Table 2-4 Compilation of the feedback received [questions (Q) and statements (S)], which are classified according to the "Fit-4-AMandA product designations and product allocation". Also included are industry subgroups from which feedback has been received and related applications.

Application type or technological field	Sector, customer group or industry party	Summary of questions (Q) or statements (S)	F4A-Product assignment (subgroups)	Subgroup no.	Total no.
Transport applications	Delivery service	Q: Costs for fuel tank(s) and connection	FCS&S	1	1
		Q: Expenditure and costs for certification and type approval of retrofitted FC vehicles	FCS&S	2	2
		S: Interested in market-ready OEM solutions or products or a statement as to when these will be available.	FCS&S	3	3
	Industrial trucks (e.g. forklift, conveyor vehicle)	**Q: Costs for Tools, general machine and special machine design, construction and plant engineering**	FCC	1	4
			aFCSm	1	5
	Automotive manufacturers	S: Automotive OEMs shows generally a high interest, however without a concrete feedback.	general	-	-
		Q: Costs for Tools, Machine and special machine construction and plant engineering	FCC	2	6
			aFCSm	2	7
		Q: Why does F4A mainly focus on FC stacks with graphite-based BPP?	FCC	3	8
	Cross-sectoral, Components for FCEVs, stationary and mobile applications	Q: Has there been a comparison of the advantages and disadvantages of known clamping and retention systems for FC stacks in relation to automated assembly and regarding to FC stack properties.	FC stack	4	9
		Q: Why does F4A mainly focus on FC stacks with graphite-based BPP?	FCC	5	10
		Q: MEA activation procedures (humidify the membrane portion of the MEA) before stacking	FCC	6	11
		Q: Approaches for the realization of the break in procedure for PEMFC stacks in a high batch size production	FCC	7	12
		Q: MEA activation procedures or "break in procedure fuel cell stack" for high batch sizes	FCC	8	13
		Q: Possible forming processes for BP-HP production (BPP)	FCC	9	14
		Q: Estimation of achievable production rates for BPPs	FCC	10	15
		Q: Estimation of the required investment costs for manufacturing plant and tools (BPP)	FCC	11	16
Stationary applications	Energy supply companies, real estate companies	Q: Possible maximum power of single stack (and stacks in multi stack systems) of machine produced stacks → maximum cell number	FCS&S	4	17
		Q: Lifetime expectations at 24/7 operation and expected down times	FCS&S	5	18
		Q: Safety strategies and approval for residential building	FCS&S	6	19

Mobile applications	No concrete feedback	Q: Expenditure and costs for maritime certification and approval of fuel cell and hydrogen system (IGF codes and Rina rules)	FCS&S	7	**20**
Maritime applications	Ship builders	Q: Special measures necessary for salty (maritime) environment on component side	FCC	12	**21**
		Q: Expenditure and costs for certification and approval of fuel cell and hydrogen system according rail rules (EBA)	FCS&S	8	**22**
Rail applications	Rail vehicles (trains or special rail vehicles)	Q: Why is almost no aluminium used as material for BPPs?	FCC	13	**23**
Materials for BPPs	Material manufacturers or suppliers	Q: What are the requirements for the material for BPPs in terms of processability and application?	FCC	14	**24**
		Q: What dimensional and shape tolerances and surface roughness must be observed in the manufacture of bipolar plates.	FCC	15	**25**
Tools and machines	Tool designers and manufacturers	Q: Can a statement be made about the expected minimum and maximum dimensions of the BPPs?	FCC	16	**26**
		Q: Has a catalogue been developed in F4A or another project, in which the requirements for geometric elements of a flow field are presented?	FCC	17	**27**
	Machine and special machine construction and	Q: Required press capacity and size	FCC	18	**28**
	Plant engineering	Q: Approaches for pre-positioning the cathode and anode directly after forming	FCC	19	**29**
	Companies	S: Interest in future cooperation	*general*	-	-
		Q: What is the material of the sample?	QAS	1	**30**
Quality control and assurance	Machine-vision hardware suppliers	**Q: What is the material of the sample?** Is the sample smooth or are there any structures on the surface?	FCC	20	**31**
			QAS	2	**32**
		Q: Is the sample smooth or are there any structures on the surface? For what types of defect is the detection required?	FCC	21	**33**
			QAS	3	**34**
		Q: For what types of defect is the detection required? What is the typical size of the defect?	FCC	22	**35**
			QAS	4	**36**
		Q: What is the typical size of the defect? What are the dimensions of the tested sample?	FCC	23	**37**
			QAS	5	**38**
		Q: What are the dimensions of the tested sample? Is only pass / fail test required or is the measurement of defect's dimensions also necessary?	FCC	24	**39**
			QAS	6	**40**
		Q: How was the QC performed until now?	QAS	7	**41**
		Q: How was the QC performed until now? Are there any pre-existing cameras or other similar instrument, which can be used?	FCC	25	**42**
			QAS	8	**43**
		Q: What is the available budget?	QAS	9	**44**
		Q: What kind of errors are expected during stack assembly? How often are these errors expected to occur and what effects can they have? How and with what certainty can they be detected?	QAS	10	**45**

	FC stack and -system suppliers	**Q: What kind of errors are expected during stack assembly? How often are these errors expected to occur and what effects can they have? How and with what certainty can they be detected?** What are the challenges in an inline QC in the automated production of components/stacks?	FCC	26	46
			aFCSm	3	47
			QAS	11	48
		Q: What are the challenges in an inline QC in the automated production of components/stacks? What is the planned and max. achievable frequency for the automated stacking process?	FCC	27	49
			aFCSm	4	50
			QAS	12	51
		Q: What is the planned and max. achievable frequency for the automated stacking process? What are the challenges in an inline QC in the automated production of components/stacks?	FCC	28	52
			aFCSm	5	53
			QAS	13	54
		Q: What are the challenges in an inline QC in the automated production of components/stacks? What is the planned and max. achievable frequency?	FCC	29	55
			aFCSm	6	56
			QAS	14	57
		Q: What is the planned and max. achievable frequency? In line control costs for camera system and limits of error detection	aFCSm	7	58
			QAS	15	59
		Q: What are the challenges in measuring half plates and bipolar plates. What are the requirements for optical inspection systems. • **Usual sample size (area and main dimensions)** • **Test parameters** • **Test interval (duration and frequency)**	QAS	**16**	60
	Measurement instruments supplier (such as test stands, fixtures, electronic loads, etc.)	**Q: What are the challenges in measuring half plates and bipolar plates. What are the requirements for optical inspection systems.** • **Usual sample size (area and main dimensions)** • **Test parameters** • **Test interval (duration and frequency)**	FCC	**30**	61
Mass Manufacturing Machine (automated stacking machine)	Throughput and scalability	**Q: What is the target production rate of the developed automated stacking machine?** Can this production rate be further increased and if so, what would be necessary to achieve it?	aFCSm	8	62
		Q: What is the target production rate of the developed automated stacking machine? Are they a bottleneck for the production or stacking rate?	aFCSm	9	63
		Q: Is the machine system modular and scalable? How can I double the throughput?	aFCSm	10	64
		Q: Is there a limitation concerning the number of product types that can be produced on the machine?	aFCSm	11	65
		Q: What if I have to integrate a new type later?	aFCSm	12	66
	Product flexibility and part supply	Q: What stack dimensions can be realized in the MMM. Where are the technical production limits?	aFCSm	13	67
		Q: What are the requirements for the part supply (magazine, stack boxes, ...)? Are there already standard supply systems for the components?	aFCSm	14	68
		Q: How the components have to be separated, when they are supplied as a stack? Can the machine handle intermediate layer? What kind of intermediate layers - one way or reusable?	aFCSm	15	69

		Q: What kind of BPP can be processed in the machine (graphitic, metallic)?	aFCSm	16	70
		Q: What kind of MEAs can be processed in the machine (seal on MEAs, sub-gasket MEAs)	aFCSm	17	71
		Q: Is it possible to preassemble a seal on MEA in the machine?	aFCSm	18	72
		Q: How can the CCM be fed into the machine (sheet, roll)?	aFCSm	19	73
		Q: Can you support us in a suitable to automatic production product design?	aFCSm	20	74
	Layout, footprint, stuff	Q: How big is the footprint of the machine?	aFCSm	21	75
		Q: Is the layout of the machine system adaptable to the specific requirements of the customer?	aFCSm	22	76
		Q: How many operators does it take to run line?	aFCSm	23	77
		Q: What media does the system need (compressed air, cooling media…)?	aFCSm	24	78
	Data tracking	Q: How can I track the product batch, process and machine parameter? Which parameters are collected and stored?	aFCSm	25	79
		Q: Are there preferred methods for the product labelling for single piece tracking barcode, data matrix code)?	aFCSm	26	80
		Q: How can I label my final stack with a unique code for a complete lifetime tracking?	aFCSm	27	81
		Q: It seems to be better to have an air condition area for the CCM handling. Is it possible to climate the working area where the CCM is handled? Are there other possibilities for air conditioning (e.g. entire room)?	aFCSm	28	82
	Air conditioning	Q: Which parameters of the climate need to be regulated?	aFCSm	29	83
		Q: Which types of control are available for the stacking machine systems?	aFCSm	30	84
	Support and maintenance	Q: Can I get the system with our preferred robot type (plant standard)?	aFCSm	31	85
		Q: What support can Aumann give in case of system problems abroad? Is there remote maintenance?	aFCSm	32	86
	Price and delivery time	Q: What is the price for the automatic stack assembling system?	aFCSm	33	87
		Q: What is the absolute minimum price for a low cost start up?	aFCSm	34	88
		Q: What is the delivery time for a new custom made machine system?	aFCSm	35	89
		Q: Are there complete new machine concepts to multiply the throughput?	aFCSm	36	90
	Future concepts	Q: A combustion engine assembly line has an output of 500.000 engines a year has a cycle time of 30 seconds per engine? To substitute one line by fuel cell system we need to stack 10 cells per second? Do you have already solutions therefore?	aFCSm	37	91
		Q: Is it possible to automate also the tensioning - supply and assembly of the pin rods with automatic screwing?	aFCSm	38	92

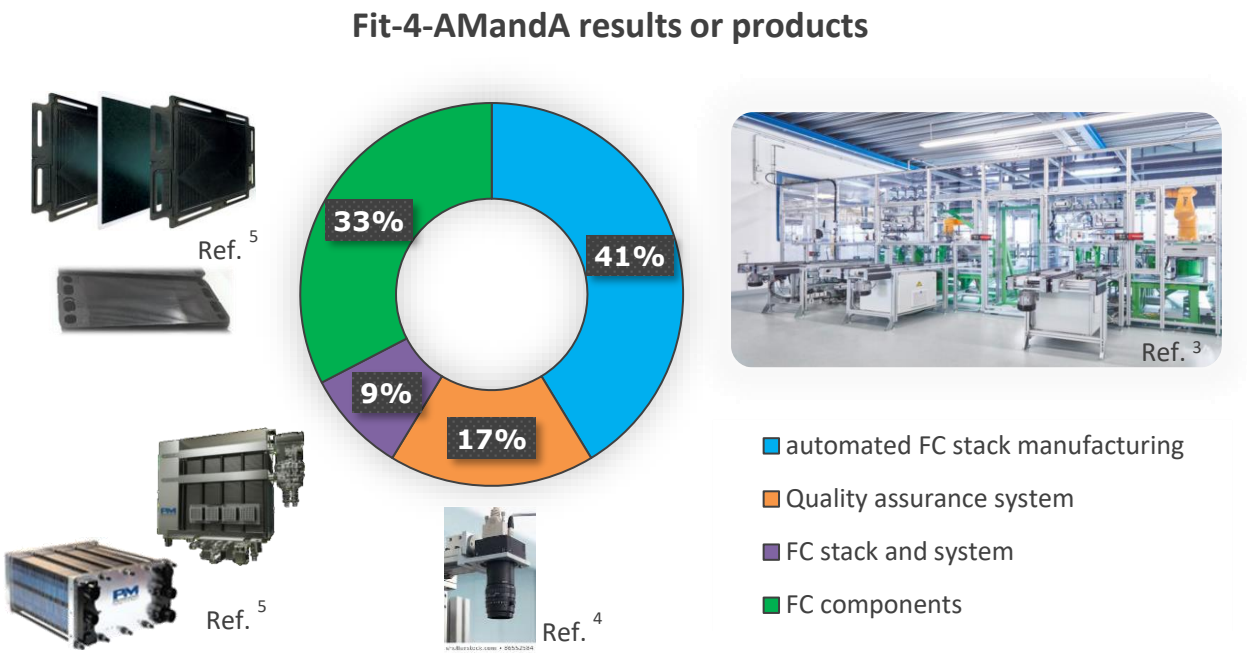


Figure 2-2 Distribution of the feedback received and needs identified (References to the figures shown: automated FC stack manufacturing[3], Quality assurance system – Camera[4], FC stack and system[5] and FC components[5])

The vison and focus of the Fit4AMandA project is mostly oriented in the automated FC manufacturing machine.

The analysis of the received feedback shows the following result:

1. The majority (41 %) of the questions received related to the automated stacking system.
2. Many questions (33 %) were asked about the FC components optimised for automated manufacture.
3. The quality assurance systems under consideration in combination with the automated stacking system were also met with great interest (17 %).
4. The minority (9 %) of the questions received related to the FC stack and system.

At this point it should be noted that there is some overlap, especially in relation to the feedback on the "FC stack and system" and the feedback on the "FC components" and the other two sub-areas. The distribution shown in Figure 3 1 can therefore only give a general overview. This has to be taken in account and may be adjusted depending on the point of view.

[3] Thomas Wannemacher. Title: CHALLENGES OF AN SME IN THE MARKET RAMP-UP OF FUEL CELLS IN TERMS OF QUANTITY & QUALITY. Link: https://monarch.qucosa.de/api/qucosa%3A36198/attachment/ATT-0/

[4] Picture of the camera is only for illustration. Real cameras are confidential.

[5] © Proton Motor - Disclosure or duplication without consent is prohibited

3 Conclusions and Recommendations

The basis of the work package task "optimised strategies for market and production based on customer feedback" is, of course, first of all the collection of the opinions of as many customers and stakeholders in general as possible. As shown in table 2-3, this was also carried out very extensively in many workshops, conferences and other events as well as in concrete discussions of the project partners with their customers.

As a very positive result and outcome of the work on this topic, a generally very strong interest was recorded. In addition, due to the changes in the political and social framework conditions, the general awareness of and interest in hydrogen and fuel cell technology is currently significantly increased, with a continuing strong rising trend.

It should be noted in particular that the automotive industry in particular (although not exclusively) is currently rethinking its approach and is showing great interest in sustainable and renewable forms of propulsion systems and drive trains. This is remarkable in so far as this industry plays a key role in the European economic system.

This trend is also evident in other important sectors such as stationary energy, railways and shipping. Sectoral coupling of important industrial sectors is also playing an increasing role.

This shows that the work within the Fit-4-AMAndA project is an important contribution to the further development of the sectors and technology and came at exactly the right time.

From the feedback received (questions and interest as depicted in table 3-1), it was possible to determine a large agreement with the research questions and objectives already formulated for the Fit-4-AMandA project. From the Fit-4-AMandA perspective, this means that questions and development goals defined for the research project are of significant relevance over the entire project duration and beyond. In particular, this concerns:

1. BPP
2. MEA
3. PEMFC stack
   a. Cost drivers: Identification and assessment of cost drivers in PEMFC stacks
   b. Power classes: Definition and explanation of the PM PEMFC stack performance classes
   c. Plant design: Development of a modular automated assembly line for PEMFC stacks. This line should be modularly expandable. The aim is to enable higher production rates by a slight extension of the assembly line.
   d. Production bottlenecks: Assessment and definition of bottlenecks in the production chain
   e. Assembly: Estimation of the possible production rate (with defined size and number of cells) with the developed automated assembly system in the first stage of expansion

      Guarantee of a high repeatability (min. 99.5 %, i.e. max. one of 200 stacks with 96 cells may be faulty)

      High precision with maximum possible degree of automation

3.1 Optimised strategy for market and production

As an essential component of optimised strategies for market and production, the concrete questions and concerns of the individual stakeholders must first be addressed.

In addition to the previously much stronger concerns about safety in connection with hydrogen, it can be stated that in the meantime the focus is mainly on questions concerning productivity, quality assurance and the parallel growth of demand and supply, i.e. general market issues.

Furthermore, the goal of this report is also to draw preliminary conclusions about the short and medium-term customer needs and the resulting demand quantities based on the results of the analysis (forecast of short and medium-term order sizes for PM PEMFC stacks).

Based on the feedback received, and keeping in mind the main project objectives, different strategies for market application and production have been defined.

With respect to possible market application, the following aspects need to be taken into consideration:

1. User-oriented product design
2. Functional product design
3. Disassembly-friendly product design
    a. Recycling and disposable materials product design
    b. Easy maintenance-oriented product design
4. Ensuring the general boundary conditions

With respect to production steps, the following aspects appear to be the most relevant:

- clarity about key components of the PEMFC stack
- increase of the production rate e.g. by reducing the process time or by process parallelisation
- enhancement of flexibility
- high process reliability
- high performance of the component MEA in combination with the BPPs and sealing / gasket
- determination and assessment of the effects achieved through automated and thus improved stack production (Balance between manufacturability and stack performance)

The products resulting from Fit-4-AMandA research were adapted and developed accordingly the feedback received (from the workshops and customer needs). Table **3-1** lists the customer requirements and the corresponding product properties. In the following Table **3-1**, the common interest are marked (X).

Table 3-1 Finding strategies for market – Needs of the end users

Features / Needs of the end users identified	Reliability (Application-related)	Durability (Application-related)	Usability or handling	Operating costs	Efficiency	Maintenance and service infrastructure	H_2 infrastructure	General manufacturability for mass markets	Recyclability
Matching strategies for market									
User-oriented product design	X	X		X	X			X	
Functional product design			X					X	
Reliable QA system	X	X	X			X		X	
Disassembly-friendly product design • Recycling and disposable materials product design • Easy maintenance-oriented product design						X			X
Ensuring the general boundary conditions					X	X	X	X	
Cost drivers	X	X	X	X	X	X	X	X	X

In addition, Table **3-2** was prepared for the design of future strategies for production, in particular stack assembly and the procurement purchase of FC components. In the following Table 3-2, the common interest are marked (X).

Table 3-2 Finding strategies for production – Stack assembly and purchase of components

Boundary conditions and properties / Requirements for manufacturing	Market availability e.g. by 2nd source	Reparability	Material efficiency	Production rate	Fall-back solutions	Freedom of scalability	Capital costs
Production-oriented product design							
Clarity about key components of the PEMFC stack	X		X	X	X	X	
Increase of the production rate e.g. by reducing the process time or by process parallelisation	X			X		X	X
Enhancement of flexibility						X	
High process reliability				X			X
High performance of the component MEA in combination with the BPPs and sealing / gasket			X	X		X	X
Determination and assessment of the effects achieved through automated and thus improved stack production (Balance between manufacturability and stack performance)		X		X		X	
Integrated construction		X		X		X	
Increasing the degree of material utilisation, e.g. near-net-shape forming			X				
Intelligent purchase of components (e.g. second source)	X						
Product or component design appropriate to the material			X	X		X	
Unification of the production process through standardised series, use of uniform tools and increase in batch sizes		X				X	

In summary, the following is a summary of the objectives achieved in the project and the approach taken:

1) Public discussion - in the form of talks with customers, workshops, conference contributions, presentations, publications (articles) etc. - of the resulting questions and the development needs derived from them
2) Obtaining feedback
3) Exploitation of feedback
   a) Evaluation and classification (relevance, possible effects, feasibility, cost/benefit assessment etc.)
   b) Development of theoretical approaches to solutions
   c) Comparative comparison of the approaches developed
   d) Concretisation of the most promising approaches
   e) Internal and external (public) evaluation of the pre-selected implementation variants
   4) Synchronised product development and marketing strategy (definition of intersection between customer requirements and technological possibilities)

3.2 Résumé and concrete suggestions:

As a guarantor for the success of the fuel cell industry in general and of the involved players and project partners in particular, the elaboration of concrete business cases and a tailor-made solution for specific applications is essential.

In case of fuel cell systems: Particularly in special sectors beyond private individual car traffic, the application case is often more or less precisely predictable and thus the respective energy demand can be well predicted. This is where this technology can play out extreme advantages.

In the case of the component supply industry:
Here, in addition to the reliability and durability requirements of the respective applications, it is certainly very interesting to see how cost savings can be realised through volume effects. A component manufacturer, e.g. a GDL or MEA, can also offer the second-best solution (in terms of performance) as a recommendation if significant cost savings (at the customer's end) can be expected. In the long run, this is the safer way for a success of the technology and the players involved and thus in the interest of both parties (even if not obvious). It turns out that the bilateral discussion with the customer and the mutual understanding of the real needs is essential.

In the case of machine suppliers and QA component manufacturers:
Here, too, it is essential to understand the market and the specific conditions: In addition to the cost situation (particularly relevant for SMEs), the quantities/unit numbers (i.e. frequency and cycle times) are the main issues here. Reliable QA also requires new methods, which are currently being massively developed by manufacturers.

It is also essential that customers understand the technology itself and its opportunities and risks. Therefore, in addition to the global situation, the market strategy should clarify with the customer at the beginning of each concrete project what the real and exact requirements of the respective application (whether fuel cell components,

Although this is generally true, it is given a higher priority due to the special features and novelty of the technology, especially since a basic understanding cannot always be assumed among customers who substitute from another technology.

4 Risk Register

Risk No.	What is the risk	Probability of risk occurrence[6]	Effect of risk[7]	Solutions to overcome the risk
1	considerable investment costs (product development, equipment. and hoist technology, skilled personnel, business analyses) vs. chances of success	M	M-H	Risk analyses • Product innovations • Diversification Benefit from gained experience in budgeting future projects
2	Competitors have a better market position	M	H	• Enhance efforts and offering better products • make more advertising • offer niche solutions
3	Wrong conclusions were drawn from market observation -> wrong strategy	L	M-H	Re-considering and scrutinise the conclusions at a very early stage
4	General and societal framework condition is changing negatively	L	M-H	There a very few possible measures against change in frame conditions → possibly more and better lobbying

[6] Probability risk will occur: 1 = high, 2 = medium, 3 = Low

[7] Effect when risk occurs: 1 = high, 2 = medium, 3 = Low

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Table 5-1 Project partners:

#	Partner	Partner Full Name
1	UNR	Uniresearch BV
2	PM	Proton Motor Fuel Cell GmbH
3	IRD	IRD Fuel Cells A/S
4	Aumann	Aumann Limbach-Oberfrohna GmbH
5	FhG	Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V.
6	TUC	Technische Universität Chemnitz
7	UPS	UPS Europe SA

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6 Appendix – List of presentations and publications in the Fit-4-AMandA

Table 6-1 List of presentations and publications in the Fit-4-AMandA project based on D7.4[8]

Title	Date	Place
HZwo:CONNECT – Network HZwo: Antrieb für Sachsen	01/06/2017	Chemnitz, Germany
6th European PEFC & Electrolyser Forum + One Day Workshop on Monitoring, Diagnostics and Control for Fuel Cells	03/07/2017	Lucerne, Switzerland
7th World Hydrogen Technology Convention together with Czech Hydrogen Days 2017	07/07/2017	Prague, Czech Republic
Hypermotion	22/11/2017	Frankfurt, Germany
E- Monday in Munich // network	20/11/2017	Munich, Germany
Business Day fair of the Ore Mountains	24/10/2017	Chomutov, Czech Republic
eMove360° 2nd International Trade Fair for Mobility 4.0	17/10/2017	Munich, Germany
Industrial workshop: Qualification of materials and components in the fuel cell system organised by ZBT Duisburg in the framework of the project VALIDATE	16.-17/01/2018	Duisburg, Germany
14th International Hydrogen & Fuel Cell Expo	28.02-02/03/2018	Osaka, Japan
Expert Meeting on Autonomous Car Driving System	07/02/2018	Usti nad Labem, Czech Republic
Analytica exhibition 2018	12/04/2018	Munich, Germany
"TUC Hydrogen Day"– international finale of the hydrogen model car race	03/05/2018	Chemnitz, Germany
TRANS³Net.show on "Smart Mobility"	30/05/2018	Decin, Czech Republic
4th Business Forum of the Ústí Region	05/06/2018	Usti nad Labem, Czech Republic
9th International Conference Hydrogen Days 2018	13.-15.06.2018	Prague, Czech Republic
Status seminar organised by ZBT Duisburg in the framework of the project AiF and BiS-Net	26.-27/06/2018	Duisburg, Germany
Canada-Germany Workshop »Fuel Cell Component Quality«	18/09/2018	Freiburg, Germany
World Smart Energy Week 2019 / FC EXPO 2019	27/02-01/03/2019	Tokyo, Japan
10th International Conference Hydrogen Days 2019	27/03-29/03/2019	Prague, Czech Republic
Fraunhofer-Gesellschaft - Veröffentlichungsdatenbank Fraunhofer-Publica	19/09/2018, Chemnitz	Chemnitz, Germany
HZwei	October 2019 edition	Chemnitz, Germany
MDPI Machines: Overcoming the Challenges for a Mass Manufacturing Machine for the Assembly of PEMFC Stacks	18/10/2019	Chemnitz, Germany URL: https://www.mdpi.com/2075-1702/7/4/66
Fit-4-AMandA – Stack robot delivered	December 16, 2019	e-Journal by Hydrogeit URL: https://www.h2-international.com/2019/12/16/fit-4-amanda-stack-robot-delivered/

[8] D7.4 Updated dissemination and exploitation plan (CO), deliverable date 2019-12-20