



FRAMEWORK PROGRAMME OF EARLY STAGE RESEARCHER TRAINING¹

1. BASIC DATA

Mentor's name and surname	izr. prof. dr. Julija Volmajer Valh	Mentor's register number at ARIS (SICRIS) :	20238
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Research programme (RP) leader's name and surname:	red. prof. dr. Lidija Fras Zemljič	RP leader's register number at ARIS (SICRIS) :	19753
Title of research programme:	Textile Chemistry and Advanced Textile Materials	RP's Register number at ARIS (SICRIS) :	P2-0118
Research organisation (RO) of University of Maribor, where training shall be conducted:	Faculty of Mechanical Engineering	RO Register number at ARIS (SICRIS) :	0552-0795
Research field according to ARIS classification :	2.14 Textiles and Leather 2.04 Materials	Research field according to EURAXESS classification	Materials engineering

2. DEFINITION OF RESEARCH PROBLEM AND GOALS OF DOCTORAL RESEARCH²

Starting point of research task of the early stage researcher and its position in the research programme, where the mentor is included, work hypothesis, research goals and foreseen result with emphasis on an original contribution to science:

Scientific Background

Polyamide 6,6 (PA6,6), commonly known as nylon 66, is one of the most important thermoplastic polymers in the polyamide family. It is produced by the melt polycondensation of adipic acid and hexamethylenediamine. Due to strong hydrogen bonding between the polymer chains, PA6,6 exhibits excellent mechanical properties, high thermal stability, and good resistance to hydrolysis, enabling its widespread use in the textile industry (synthetic fibres, yarns, technical textiles), automotive and mechanical engineering industries (gears, bushings, component housings), electronics and electrical engineering (connectors, insulating components), as well as in the production of films, pipes, filters, and protective

¹ Term early stage researcher (ESR) is written in male form and used as neutral for women and men.

² Research and study programme of training have to harmonise with contents of the research programme, where the mentor is a member.

materials. Owing to its favourable combination of low weight, strength, and abrasion resistance, PA6,6 is used in woven, knitted, and nonwoven materials, as well as in the form of engineering plastics, which underlines its broad technological and industrial relevance.

PA6,6 exhibits high chemical stability and is poorly degradable in the natural environment, significantly contributing to plastic pollution. Globally, approximately 0.59 million tonnes of PA6,6 waste are generated annually, while the annual production of this material is estimated at around 2.1 million tonnes. This represents a substantial environmental burden and, due to external influences, leads to the formation of microplastics, which may have adverse effects on human health.

The extensive use of PA6,6 also presents challenges for sustainable waste management. The use and disposal of PA6,6 are directly governed by European and Slovenian legislation on plastics, waste, and environmental protection. At the European Union level, Directive (EU) 2019/904 on single-use plastics plays a key role by banning certain single-use plastic products and promoting the use of recycled materials. Slovenia has incorporated this directive into its national legal framework through the Waste Management Act and related secondary legislation, which regulate the collection, treatment, and recycling of plastic waste, as well as restrictions on specific plastic products. These regulatory frameworks are directly relevant to the production and waste streams of PA6,6 and increase the demand for sustainable material management and the reduction of microplastics in the environment.

Traditional approaches to plastic waste management typically involve incineration or landfilling, leading to resource depletion, high emissions, and environmental pollution. The reuse of plastic waste therefore represents a key research direction. Currently, the main recycling methods for end-of-life PA6,6 products are mechanical and chemical recycling. Mechanical recycling involves directly reprocessing PA6,6 products into recycled materials; however, prolonged use often results in reduced molecular weight and deteriorated material properties, limiting the quality and applicability of mechanically recycled products. Conventional chemical recycling relies on depolymerising PA6,6 into monomers through processes such as hydrolysis, ammonolysis, alcoholysis, and hydrogenolysis. The main drawback of this approach is the difficult and inefficient isolation of pure monomeric products.

The development of innovative concepts for transforming waste into high-value materials with tailored functionalities through targeted chemical reactions is therefore crucial for effectively addressing environmental challenges. Unlike conventional recycling methods, which often only reduce waste volumes, upcycling approaches focus on increasing the value of recycled products. Such strategies contribute to sustainable material management and support industrial development and economic growth. Waste materials such as PA6,6 can therefore represent important secondary raw materials with high potential for reuse in advanced applications.

The research conducted in this doctoral dissertation is thematically embedded in the research programme Textile Chemistry and Advanced Textile Materials.

Work Hypothesis

The development of innovative chemical concepts for converting waste into high-value materials enables effective mitigation of environmental challenges associated with improper plastic waste management. In this research, the doctoral candidate will focus on advanced approaches to the chemical recycling and upgrading of waste polyamide PA6,6, with the aim of producing materials with added value.

The first research direction is based on the hypothesis that waste PA6,6 can be chemically recycled into adipic acid, and that this recycled adipic acid can be used directly, without prior isolation, in selective condensation reactions with suitable diols. This approach is expected to enable the synthesis of aliphatic polyesters with controlled chemical structures. Particular emphasis will be placed on investigating the influence of monomer ratios, diol selection, and reaction conditions on molecular weight, polymer chain architecture, and material properties. It is hypothesised that appropriate polymer design will result in materials exhibiting biodegradable behaviour and representing a sustainable alternative to conventional polymers.

The second research direction focuses on the direct functionalisation of waste PA6,6 by incorporating selected monomers or reactive compounds into the polymer matrix. The working hypothesis is that this approach preserves the fundamental mechanical and thermal properties of the polyamide while imparting additional functionalities, such as antibacterial activity or other advanced properties, which significantly

enhance the material's functional and market value. By combining both approaches, the research contributes to developing integrated strategies for the sustainable upgrading of waste polymeric materials.

Research goals

Goals of the First Research Direction

- The primary goal of the research is to develop and evaluate innovative chemical approaches for transforming waste polyamide PA6,6 into high-value, functional polymeric materials, thereby contributing to sustainable plastic waste management.
- To develop and optimise a chemical recycling process for waste PA6,6 that enables the production of adipic acid and its direct use in subsequent synthesis steps without prior isolation or extensive purification.
- To investigate selective condensation reactions between recycled adipic acid and various diols for the synthesis of aliphatic polyesters, and to determine the influence of monomer ratios, diol type, and reaction conditions on molecular weight, chemical structure, and thermomechanical properties.
- To evaluate the biodegradation potential of the synthesised aliphatic polyesters as a function of their chemical composition and polymer architecture, and to identify key structural parameters affecting material degradation.

Goals of the Second Research Direction

- To develop procedures for the direct functionalisation of waste PA6,6 by incorporating selected monomers or reactive compounds that enable the formation of materials with additional functional properties.
- To investigate the impact of functionalisation on the structural, mechanical, and thermal properties of PA6,6, and to identify the balance between maintaining the intrinsic properties of the polymer and introducing new functionalities.
- To evaluate the added value of functionalised materials, particularly regarding antibacterial activity and their potential for advanced applications.
- To establish an integrated strategy for upgrading waste PA6,6 that combines chemical recycling, synthesis of new polymeric materials, and functionalisation, and to assess its contribution to sustainable development and the circular economy.

Foreseen result with emphasis on an original contribution to science

The research is expected to generate new scientific knowledge in sustainable chemical recycling and polymer upcycling. A key anticipated outcome is the development of an innovative chemical recycling process for waste PA6,6, enabling the production of adipic acid and its direct use in condensation reactions without prior isolation. This represents an original contribution towards more energy- and process-efficient recycling methodologies.

The research will also enable the synthesis of aliphatic polyesters from recycled feedstocks and establish clear relationships between chemical structure, monomer ratios, and material properties, including potential biodegradability. Additionally, the development of direct functionalisation strategies for waste PA6,6 is expected to yield materials with added value, such as antibacterial properties, while preserving the essential characteristics of the base polymer.

The original scientific contribution of this research lies in the integrated combination of selective chemical recycling and direct functionalisation of waste polymers within a unified sustainable framework, opening new avenues for the development of high-value materials in the context of a circular economy.

3. STUDY PROGRAMME

Foreseen study programme, to which early stage researcher shall be enrolled in academic year 2026/2027:

Doctoral Study Programme UM FS

4. DESCRIPTION OF WORK AND TASKS

Implementing projects of scientific research.
Taking part in the design of research programmes.
Cooperating with research sponsors.
Drawing up research and other reports.
Monitoring and coordinating research work according to the grant agreement.
Ensuring safety and health at work.
Organising and instructing employees and students on using personal safety equipment and other safety measures.
Performing other tasks at the behest of the superiors.
Participating in ad-hoc and permanent committees of university or faculty bodies.
Acting on behalf of colleagues and superiors during their absence (upon authorisation).
Participating in annual and other inventories.
Performing other related tasks delegated by superiors.

5. REQUESTED LEVEL OF EDUCATION

VII/2. tariff group

6. REQUESTED FIELD OF EDUCATION

technical, natural sciences

7. KLASIUS SRV

Seventh level: second cycle of higher and similar education/second cycle of higher and similar education

8. KLASIUS P

01 – Educational sciences and teacher education
05 – Natural Sciences, Mathematics and Statistics
07 – Technology, production technologies and construction

9. REQUESTED KNOWLEDGE

Computer Skills: MS Windows, Word, Excel, Internet, E-mail, E-commerce

10. REQUESTED SPECIAL REQUIREMENTS

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11. REQUESTED LANGUAGES

Active knowledge of one world language

12. REQUESTED WORK EXPERIENCE

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13. FORESEEN POSTDOCTORAL TRAINING

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Mentor's signature:

**Julija
Volmajer Valh**

Digitally signed by Julija Volmajer Valh
DN: C=SI, S=Slovenija, OU=individuals, G=
Julija + SN=Volmajer Valh +
SERIALNUMBER=2482770242032 + CN=
Julija Volmajer Valh
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Research programme leader's signature:

**Lidija Fras
Zemljč**

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Name and surname of Dean or
authorised person³:
prof. dr. Matej Vesenjāk

Signature of dean or authorised person:



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Date: 2026.01.25 16:14:54 +01'00'

Place and date:

Maribor,

23. 01.
2026

³ The training program is signed by the dean of the member where the ESR's employment and training will take place.

Stamp: