

The development of a fossil-free textile chain: the revival of plant-based dyes

Final wildcard project report

Mark van Hoogdalem, Paulien Harmsen, Marieke Bruins, Luisa Trindade, Anja Dieleman

22 January 2024



This project has been funded by the investment theme Transformative Bioeconomies:
Towards a materials transition that phases out fossil feedstock

Introducing the format

When submitting your Wildcard project you committed to providing several deliverables:

1. A short accessible document for the inter- and transdisciplinary group of people involved in the programme that describes your methodological innovation project / proof of principle project and its rationale;
2. A presentation at a community meeting of the investment theme;
3. A report of the results of your learning journey that describes the key lessons learned about your methodological innovation or proof of principle.
4. Additional deliverables formulated by you as part of the submission, labelled 'Project specific deliverables' in this format.

All Wildcard projects already provided presentations as stipulated under 2. This format then is meant to document deliverables 1, 3 and 4.

In section 2 of the format we ask some additional questions related to possible follow-up.

1. A short accessible document following the headers below (max. 600 words to be published on the website)

Please describe your project in a way that people from completely different disciplines and/or laymen can understand using the below headers and instructions. Note that we will use these descriptions for our website as well.

Innovative idea and objective

Describe the essence of your innovative idea, and what you wanted to study and achieve in this project.

The textile industry heavily relies on fossil resources; not only for their fibers but also for their auxiliaries such as dyes. While there is increasing attention for recycling of fibers and bio-based alternatives, the attention for auxiliaries lags behind. This is rather remarkable, since the environmental impact of these fossil-derived products is substantial.

In this project we selected one dye (indigo) as an example and compared fossil- and bio-based production pathways for this particular dye. The pathways were compared on their economic performance, but also on their environmental impact. By doing this, we aimed to create awareness of the problems associated with fossil-based dye production and show the potential for bio-based dye production in the textile industry.

Relevance to the materials transition in textiles and/or building materials?

Describe how your project is relevant to reducing the use of fossil carbon in the domain of textiles, building materials (housing and interior) or both?

Comparing the fossil-based pathways for the production of indigo with its bio-based alternative(s) on economic and environmental impact will, first of all, provide insight into the importance of the transition from fossil-based to bio-based dye production in the textile industry. Furthermore, it will help identifying potential bottlenecks as well as opportunities for realizing this transition.

What did you do?

Describe briefly what activities you have undertaken to reach your objectives.

First, a brief literature study was conducted to identify promising bio-based production pathways for indigo dye and acquire knowledge on these pathways and the fossil-based (synthetic) pathway. After doing so, a workshop was organized with WUR researchers from different areas of expertise to get a broader understanding of the different indigo production pathways and together identify crucial processes, main bottlenecks, and possibilities for improvement. Using the information collected, the fossil-based (synthetic) indigo production pathway was compared with the bio-based pathway in which indigo is produced in plants. The two pathways were compared based on their economic

performance and environmental impact. In addition, opportunities for reducing the negative impact of the plant-based production pathway were discussed.

Main result, achievement and highlight

Describe the key results of your work. What insights have been generated? What is it you want to highlight?

Three main production pathways for indigo dye were identified:

- 1) Fossil-based synthetic pathway
- 2) Plant-based pathway
- 3) Microbial production pathway

Of the two bio-based pathways, the microbial production pathway is still in a very conceptual stage. Therefore, we decided only to compare the fossil-based synthetic pathway with the plant-based pathway.

The information that was collected during this project was used to describe the pathway basics. However, detailed information on the different steps or data on the economic performance and environmental impact in these pathways was often not available. This made an accurate detailed comparison between the fossil- and plant-based production pathway for indigo dye impossible. However, based on the information that was collected it was estimated that:

- Current fossil-based synthetic production of indigo dye outcompetes the plant-based pathway in terms of economic performance and fresh water use.
- Fossil-based synthetic indigo production of indigo results in higher emission of hazardous chemicals and most likely has a higher energy demand when taking into consideration processes associated with obtaining the starting materials.
- Plant-based indigo dye production may have potentially higher CO₂ capturing potential.

Finally, several potential opportunities for optimizing the plant-based production pathway for indigo dye were identified, including:

- Selecting crops or varieties adapted to specific cultivation conditions and yielding higher amounts of indigo under these conditions.
- Optimizing cultivation conditions for optimal crop growth, indigo yield, and water use.
- Optimizing of harvest and extraction procedures.
- Valorization or recycling of side (waste) streams.

Key message

What is the key message that people working on the materials transition should remember from your project?

Plant-based production of indigo dye has the potential to make the transition towards bio-based indigo dye production for the textile industry possible. However, this would require optimization of this pathway.

Visual abstract

Please place a visual abstract below. Please add a caption of the visual abstract below the image.

		Fossil-based indigo dye production (synthetic)	Plant-based indigo dye production (open-field cultivation)	Opportunities for improvement/reducing negative impact
Economic performance		+	-	optimizing cultivation, harvesting, dye extraction; valorization of waste streams; breeding
Environmental impact	Energy use	-	+	use renewable energy sources; optimizing cultivation strategy
	Fresh water use	+	-	optimizing irrigation strategies; greenhouse cultivation; breeding
	Hazardous chemicals use & emission	-	+	vertical processing
	CO ₂ capturing potential	-	+	

Caption: The table shows results of the comparison between fossil-based and plant-based indigo dye production. “+” indicates that estimated economic performance is higher or environmental impact lower, “-” indicates that estimated economic performance is lower or environmental impact higher. Last column lists per category potential opportunities for improvement for plant-based production.

2. Additional questions about progress and 'readiness' (max 200 word, not for the website)

This section serves the investment theme to understand the development the project has undergone.

Where you started

Explain where the project started. E.g. was there already some foundation, or did you have to start from zero?

In this wildcard project the collaboration established during the 2022 Wildcard project "Dyes for textiles" was continued.

Where are you now

Compared to where you took off, where are you now? What progress has been made? What remains to be done when looking at where you intended to be with this project at the start?

Compared to where we were at the start, we made progress in understanding the different possibilities for (bio-based) production of indigo dye for the textile industry and how the different production pathways compare. What remains to be done is to communicate the findings of this project in order to raise awareness on the topic of dyes for the textile industry.

Potential and next steps

How do you currently assess the potential of your project to contribute to the materials transition? What are logical next steps to take it further?

The lack of available data makes it challenging to show how exactly plant-based indigo production compares to fossil-based indigo production, and how it may be improved. A demonstration project in which plant-based indigo is produced and data is collected would be a logical next step to obtain this data, while at the same time raise awareness on the topic.

Innovation readiness

Where does the project/innovation stand in terms of readiness? Is this something that can be piloted or rolled out in the outside world, or is this something that needs some further development and (lab) testing before it can be piloted in society? Is it possible/meaningful to indicate an 'innovation readiness' level using the below scale? If so, how would you score your project idea?

This project initially focused on comparing existing production systems for indigo production and not on developing a new technology. We did however conclude that plant-based production systems for indigo dye should be improved to make a transition from fossil-based

synthetic indigo towards plant-based indigo possible. This would require setting up a production system, which could be done by combining existing technologies (TRL 9).

Innovation readiness score	Innovation readiness level	Description
0	Idea	Genesis of the innovation. Formulating an idea that an innovation can meet specific goal.
1	Hypothesis	Conceptual validation of the idea that an innovation can meet specific goals and development of a hypothesis about the initial idea.
2	Basic Model (unproven)	Researching the hypothesis that the innovation can meet specific goals using existing basic science evidence.
3	Basic Model (proven)	Validation of principles that the innovation can meet specific goals using existing basic science evidence.
4	Application Model (unproven)	Researching the capacity of the innovation to meet specific goals using existing applied-science-evidence.
5	Application Model (proven)	Validation of the capacity of the innovation to meet specific goals using existing applied science evidence.
6	Application (unproven)	Testing of the capacity of the innovation to meet specific goals within a controlled environment that reflects the specific spatial-temporal context in which the innovation is to contribute to achieving impact.
7	Application (proven)	Validation of the capacity of the innovation to meet specific goals within a controlled environment that reflects the specific spatial-temporal context in which the innovation is to contribute to achieving impact.
8	Incubation	Testing the capacity of the innovation to meet specific goals or impact in natural/real/uncontrolled conditions in the specific spatial-temporal context in which the innovation is to contribute to achieving impact with support from an R&D.
9	Ready	Validation of the capacity of the innovation to meet specific goals or impact in natural/real/uncontrolled conditions in the specific spatial-temporal context in which the innovation is to contribute to achieving impact without support from an R&D.

Table 1: Innovation readiness levels as distinguished by Sartas et al, 2020.

3. Learning Journey (max 300 words)

We would like to understand a bit more about the process you went through, and whether and how being part of the investment theme Transformative Bioeconomies influenced your learning. We ask the project leaders to consult others when answering these questions.

1. Did your Wildcard project involve new collaboration with disciplines or people? If so, briefly explain what was new.

In this wildcard project the collaboration established during the 2022 wildcard project on plant-based dyes was continued. However, during the workshop we organized in May 2023, several researchers from other departments/institutes attended. Furthermore, the wildcard project triggered the interest of a MSc student plant sciences, who is now writing a thesis on the topic of plant-based production systems for indigo dye.

2. If applicable, did the new collaboration alter your original thinking about the topic? Did it change research directions or courses of action? If so, briefly characterize how.

Based on the information gathered during the workshop (the input of the attendees) we decided to focus on plant-based production of indigo during the continuation of the project.

3. Did interactions during community days and/or meetings organized by the investment theme alter your original thinking about the topic? Did such interactions change research directions or courses of action? If so, briefly characterize how.

During the community day on the 5th of December several attendees suggested that indigo-yielding crops may be potentially interesting for nature-inclusive farming or other forms of production systems besides the high-efficiency production systems that we focused on in this project. However, due to lack of time remaining, this did not change the course of action in this project.

4. Did you meet any challenges during implementation of your wildcard project? If so, what kind of challenges were these?

A main challenge was the lack of available data on producing (plant-based) indigo.

5. If applicable, how were these challenges eventually addressed? Did activities organized by the investment theme contribute to overcoming challenges? If so, briefly indicate how.

We focused more on studies in which plant-based and fossil-based production pathways were compared. Furthermore, we decided to focus more on possibilities for improvement of the plant-based production system.

6. Has your involvement in the investment theme resulted in any new initiatives or spin-offs that would probably not have emerged if you had not participated? If so, briefly indicate how these new initiatives came about.

This has not happened yet, but within the project team we are discussing the possibility to continue working on this topic in a follow-up project.

4. Additional project specific deliverables

Copy-paste the deliverables provided in your submission document and explain how you have met these deliverables. If deliverables could not be reached, please explain.

Additional deliverables proposed when submitting the Wildcard project

Copy/paste from proposal

Text from proposal: “Activity 1: Workshop with researchers in the fields of protected cultivation, CO2 reuse, textile value chain, plant breeding, chemistry, processing and science communication. Aim is to develop a cross-disciplinary understanding of the system and to determine the project conceptual approach, work flow and communication strategy. Outcomes will be described in a short document (D1).

Activity 2: Comparison of three pathways (synthetic fossil-based, synthetic biobased, plant-based) for the colourant indigo and possible hybrid alternatives to determine CO2 capture potential and the most sustainable process and value chain. Results will be described in the final report (D2).

Activity 3: Workshop with stakeholders where the results of activity 2 will be shared and discussed, to determine potential future steps. Results will be described in the final report (D2). Furthermore, in this project, we will aim to develop a larger project proposal. We will use this workshop to understand the demands of the textile industry and identify opportunities to make it more sustainable.

Activity 4: Dissemination to the research community by presentations (D3).”

D1: short document on the conceptual approach, work flow and communication strategy

D2: Final report, describing the results of the activities in the project

D3: Presentations to the research community

Status of each project specific deliverable

Please report the status of each deliverable.

D1: Part of the final report (D2; chapter ‘Approach’)

D2: Currently we are finalizing the final report. It will be sent to the Transformative Bioeconomies team before the end of January 2024.

D3: Posters were presented during the community meetings on April 11th and December 5th and send to the Transformative Bioeconomies team or posted on the Teams site.

Links to or copies of deliverables

Please provide links to or copies of deliverables below. You may insert them as Annexes in this document.