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Bridging the Gap Between Academia and Chemical Industry through Entrepreneurship: An Account on the Case of Hydrogen-assisted Catalytic Plastic Waste Valorisation

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Abstract: Herein, we provide an account on the multi-faceted approach to scaling up a low-carbon chemical technology that originates from academia. First, we discuss technical considerations that must be met prior to industrialisation of a process. Then, we discuss the non-technical considerations such as financing, regulatory and IP rights that are required to obtain support for the project. We use our experience in plastic waste hydrocracking to reflect on strategies that can aid to improve go-to-market time in the field.

Keywords: Entrepreneurship · Plastic waste · Scale up · Sustainability

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1. Introduction

The chemical industry (excluding fuels) accounts for about 5% of global carbon emissions.[1] Decarbonising the industry requires the utilisation of low-carbon energy sources and the utilisation of low-carbon feedstock and chemicals for the processes. Synthetic polymers, *i.e.* plastics, are prepared through a carbon intensive process and have been at the centre of a heated debate for several years. It is recognized that plastics can be sustainable packaging materials (compared to *e.g.* glass or cardboard) provided they are not incorrectly disposed of at the end of life (*i.e.* plastic should be reused, recycled and not inappropriately landfilled or incinerated).[2] Currently, the global rate of recycling is less than 15%, a number too low to consider plastics sustainable, especially since mismanagement of the material can lead to aquatic life endangerment.[3] For this reason, governments are strengthening regulatory aspects related to plastic waste management. Scientists worldwide are also developing technologies in the field of mechanical recycling, pyrolysis,[4] gasification,[5] hydrocracking,[6,7] and more.[8] The ultimate goal is to bring circularity to the plastic value chain. In other words, the vision for a circular economy of plastics is that the carbon contained in plastics remains in the molecular structure of the polymer after recycling, without compromising quality of the product (see Fig. 1 for overview).

As described previously,[9,10] our team originates from a chemistry group from the Ecole Polytechnique Fédérale de Lausanne, Switzerland and develops a plastic hydrocracking technology that promises to convert hard to recycle plastic waste into circular feedstocks such as naphtha.[11] The process combines a metal-supported catalyst and hydrogen to afford high quality naphtha from post-consumer plastic waste. The pioneering work consisted in the production of grid-compatible natural gas from plastics and the technology was later modified to produce naphtha using state-of-the-art catalytic methods.[6,7] Since the early work published in 2019, there have been a plethora of reports describing catalysts, mechanisms, and scale-up procedures for plastic waste hydrocracking.[12–19] In this article we zoom out from catalysis and use our own experience to provide a broader overview of what is required to bring a technology from academia to the industry.

Developing a successful process from scratch in the chemical industry can take over a decade, and deploying the process into the market can take at least one more decade. At the same time, many climate pledges targeted 2025 or 2030 to be implemented. Accelerating new process industrialisation is therefore not only a 'nice-to-have' but is urgently becoming a 'must-have'. In the paragraphs below we will discuss some considerations related to the development of new technologies.

2. What Scientific/Technology Considerations Prior to Scale-up?

2.1 *Discovery: Yield, Selectivity, Reaction Conditions and Mechanisms*

The technical parameters that are required to scale-up a catalytic process contain, among others, data about process operations such as process pressure, temperature, residence time, yield, se-

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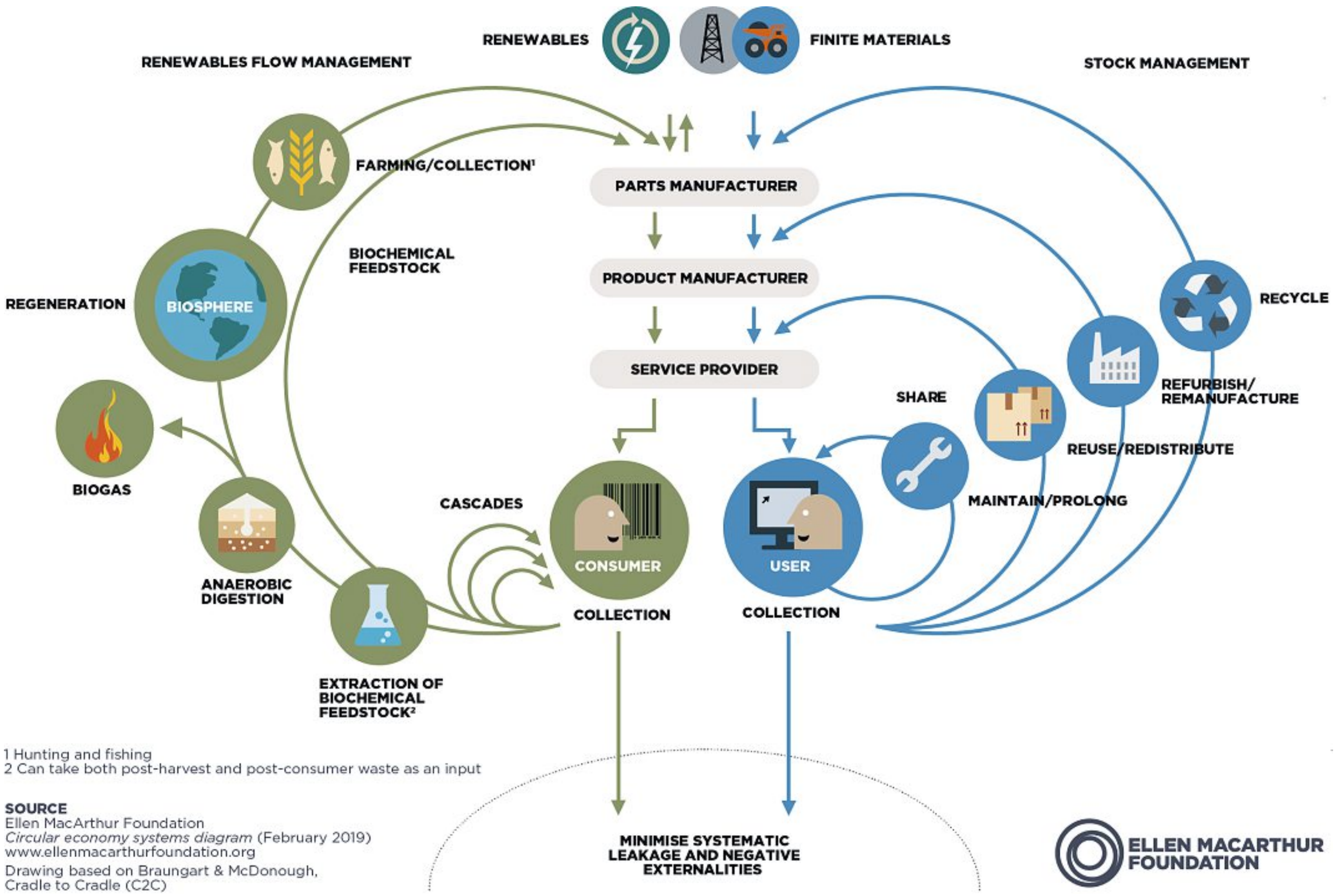

1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input

SOURCE
Ellen MacArthur Foundation
Circular economy systems diagram (February 2019)
www.ellenmacarthurfoundation.org
Drawing based on Braungart & McDonough,
Cradle to Cradle (C2C)

Fig. 1. The butterfly diagram: visualising the circular economy. From the Ellen MacArthur foundation.

lectivity, catalyst-activity relationship, and reaction kinetics. This first bundle of parameters is often studied by chemistry or chemical engineering groups in academia and the published studies contain process parameter information as well as helpful data on mechanisms.

Once the main reaction parameters are known, and if there is an intent to turn the discovery into an industrial process, the results obtained during the discovery period must be used to design a process. At this stage, it is already very reasonable to ask oneself the question of whether the reaction is scalable, and if yes, if it brings value to scale it up. To facilitate answering these questions, considerations about life cycle assessments and economics are required.

2.2 *Industrialisation: Availability of Materials, LCA, Process Design and Scale-up.*

When the decision is made to industrialise a newly discovered process, additional data must be gathered to enable scale up and ensure positive sustainable and economic returns. Additional data can be for example rheology of the reaction media, enthalpy of reaction, catalyst lifetime, which are often not present in pioneering studies but require follow-up investigations. The pioneering work also typically excludes data on life cycle assessments and financial considerations. The latter requires assumptions that can typically only be reasonably provided at a larger scale (*i.e.* when a preliminary process is modelled or designed). Fig. 2 provides an overview of various data parts that make up a Technology.

In our case, as our process deals with bulk chemicals, production cost needs to be driven downwards, and hence a transition towards a continuous process was required. Transitioning from a batch to continuous process represents a very important milestone in the journey to industrialisation, and various studies in adjacent field of biomass pyrolysis reviews indicate that more research data is available for batch systems than for continuous systems.[20–22]

Here, an important learning from our case was about rheology of the reactive mixture. Indeed, our initial results focused on the preparation of the catalyst and on its activity from a yield/selectivity and pressure, temperature standpoint. As the reaction was performed in an 100 mL autoclave with magnetic stirring where mass transfer is typically not an issue, we did not (and could not!) record data related to the viscosity of the system. When we approached stirred tanks suppliers, it became apparent that the data we obtained did not facilitate the conversation towards scale-up, and a pre-requisite was to obtain torque values from mechanically stirred reactor systems.

With the process in hand, there are many tools available to estimate the CAPEX requirements for a project and a first iteration

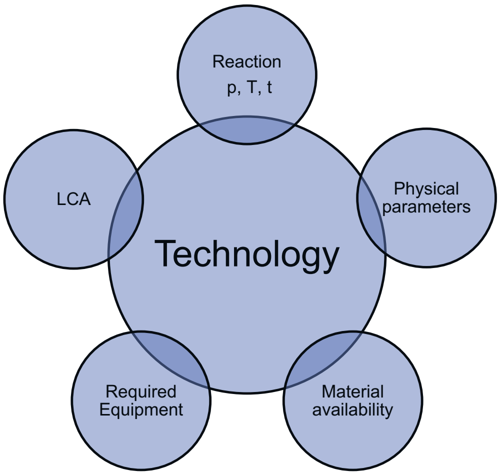

Fig. 2. Main technical requirements before scale-up.

of financial planning can be carried out even when the project is at the discovery stage. For example, the West Virginia University has made available various spreadsheet templates, named 'CapCost', based on Turton's 'analysis, synthesis and design of chemical processes' book that can be used to get a first estimation of the CAPEX required for a process.[23] If the process employs a catalyst, estimating the costs linked to the industrialisation of the catalyst can also be estimated using CatCost templates developed by ChemCatBio, a programme funded by DOE's Bioenergy Technologies Offices.[24]

To build the first financial models for the technology we relied on market values that we could find from suppliers and internet websites to assess whether hydrocracking could result in positive returns. This high-level model is an important sanity check to assess whether the products manufactured by the technology are in fact useful and at what scale.

3. What Non-scientific/Technology Considerations Prior to Scale-up?

In this section, we will focus on the use-case where the scientist who invented the process will lead the industrialisation. In principle, the academic institution's tech transfer office can licence the technology to parties outside of the university who are not the founders of the technology.

The industrialisation journey of a technology first invented in an academic institution requires the creation of a spin-off company, a 'start up', whose goal is to industrialise the technology and commercialise it. This in turn leads to many additional considerations that must be addressed, some of which are not purely technical although tightly linked to the underlying technology. One important comment is that there is no special legislation surrounding 'start ups' and they are, in Switzerland, considered the same as any other company. Consequently, in order to licence the technology, we had all of a sudden to comply with Swiss Code of Obligations and assign a Chairman of the Board of Directors to the newly created company. This role is typically taken on by one of the founders and comes with some additional responsibilities that the first-time entrepreneur is typically not well prepared for, such as organising accounting and setting up mandatory insurances, board meetings and general assemblies. Thankfully, the formal requirements can be quite minimal in the case of a newly created company.

A new process should compare favourably to other technologies from a life-cycle assessment perspective. The intellectual property landscape should not be blocking and freedom to operate should be assessed.[25] The new process should also result in positive financial returns. The team carrying out the 'Project' should have a business strategy to disseminate the technology. To assist in building the start-up, the Swiss government can provide university spin-offs with suitable coaching and consulting on these aspects, for instance through platforms like InnoSuisse.

Scaling-up a process requires building meaningful relationships with various key partners such as suppliers, investors, and customers. Understanding what drives each stakeholder is paramount to the success of the start-up company building a new technology. It is up to the leadership of the project to ensure the priorities of each stakeholder are well understood and addressed. In this respect, linking technical results with projected financial planning demonstrating the financial opportunity should be carried out in the early days of the technology. In the early days of entrepreneurship, contacting potential investors and clients was (retrospectively) done somewhat at random. It took us several months to understand that most actors operate in a very niche area of focus. In fact, representatives of multibillion dollar companies described their products and service as 'niche but used globally'. Similarly, (corporate) venture capitalists will only invest if several criteria beyond the technology are met. These can be for instance geography, type of product (hardware/software), maturity of Project, timing to exit or others. Similarly, when working with potential customers (who can also be investors), it is paramount to understand what guides their decision making. Here, the degree of maturity of the technology can be blocking as a lot of industrial actors want to use the technology only when it is derisked.

Contacting suppliers was also a challenging task for us because of the requirements of our process. Not many suppliers that are specialised in feeding solids/liquids/molten plastics into reactors have equipment that is compatible with a hydrogen atmosphere downstream and we had to interview many different companies before finding good partners for this project.

We also discovered during our pilot phase that the regulatory environment must not be underestimated when developing technology for the field of recycling of plastic waste materials as they can substantially disrupt operations. Indeed, importing waste from abroad requires special, costly permits (cantonal and federal for Switzerland) that can take months to obtain when shipments over 25 kg of plastic waste are considered. Below this threshold value the materials can be used as test material for R&D which is thankfully compatible with our pilot operations.

Another aspect to consider while scaling-up a process is the patent space and freedom to operate. Remarkably, in academic publications most citations refer to other academic publications and the patent literature is not cited even though it contains a wealth of information. Understanding the IP landscape of a particular technology as well as the patenting process is an important aspect to convince investors to support the project. Recently, an excellent overview was published on the basics of patenting that describes the procedure in details and what can be expected during the patent application journey.[26] Understanding the patenting process must come hand in hand with understanding the quality of the patent, which is typically done by analysing the claims and how well the patent blocks others from using the technology.[27] In Switzerland, the Institute of Intellectual property (IPI) offers assistant patent searches wherein a patent expert from the IPI assists the user in searching patents relevant to their field. These patent searches can be very valuable to understand the patent landscape, key players in the field, and if the invention is indeed novel and inventive.[28] In our case, our biggest misconception around patents was that we believed that it 'protected' us and 'allowed' us to use our technology, much like a shield can protect us from arrows. In fact, a patent serves the opposite purpose, it can be used as an 'arrow' to prevent others from copying the protected technology. Fig. 3 summarises the main fields that must be evaluated during the industrialisation journey.

4. Scaling-up: Who Finances Sustainable Technologies?

Bringing a new generation of safe, clean, disruptive technologies to replace mature, well-studied processes is challenging owing to the uncertain nature of the innovation. Pioneering new technologies is common in universities which are typically funded by governments. Institutions such as the EPFL and many others in the world also possess tech transfer offices that have a mission to transfer a technology developed during academic research to the society at large. Various licensing models exist where the goal is to ultimately provide a win-win situation between the academic institution, the entrepreneurs and the future investors and users of the technology.[29] Common terms in licences are equity considerations, royalties on utilisation of patented products, royalties on sub-licenses and maintenance fees of patent applications and patent granting procedure.

The chemical sciences are CAPEX intensive and require substantial financing. Building and operating a pilot unit for a chemical process will require capital of around 1 to 10 Mio CHF and will not yield a positive financial result. Note, the definition of pilot is somewhat arbitrary and industry dependant and budget can vary substantially between projects. It is often required to

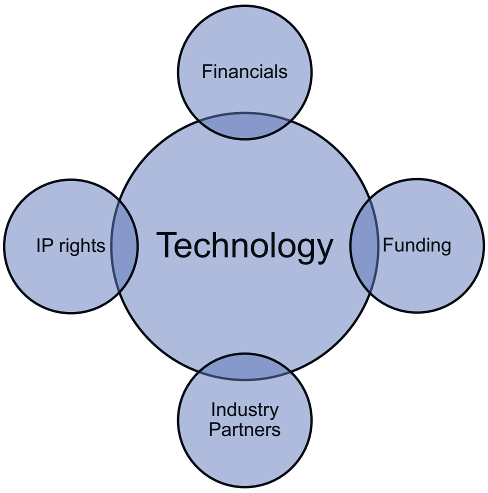

Fig. 3. Main non-technical requirements before scale-up.

link the maturity of a technology with the 'technology readiness level' methodology, as developed by NASA.[30] For the chemical industry, these values are somewhat open to interpretation and this has been addressed in the literature.[31] The pilot studies will reveal numerous process-related data and will further demonstrate the scaling-up and commercial opportunity. Funding pilot projects can be done through grants. Start-up companies can also seek funding through various local instruments. In Switzerland, examples include Venture Kick, Gebert Rüf Stiftung, >>Venture>>, Fondation Innovation Technologique (VD). One challenge associated with these programs is that they will typically fund the salary of a researcher, but CAPEX financing is not feasible.

After the pilot studies, a demonstrator should be built. The goal of the demonstrator is case-dependant and will typically be required to further de-risk critical aspects of the technology at a near industrial scale. Example of milestones to be achieved with a demonstrator are demonstration of year-round operations, demonstration of supply chain, demonstration of commercial traction, demonstration of economics, and more. This step can typically be funded by various stakeholders such as government, venture capitalists and corporations. Here, also, the budget will be technology dependant and can be anywhere between 10 and 50 Mio CHF.

After the demonstration of the technology at a pre-commercial scale the goal is to build plants operating on the process. This will require substantial capital increases that may be financed by corporations, asset managers or venture capitalist.

Overall, scaling a new chemical process from lab to industrial scale will require a decade of continued effort, several upscaling steps, large amounts of capital. Fig. 4 provides a tentative timeline and budgets associated to magnitude of project budgets in the chemical industry.

Finally, when the scale-up strategy is clarified in terms of number of steps and budget estimations, an enterprise financial model can be built. In our case, the founding team started with no formal financial education on board meaning that our financials were not built on professional financial standards. In the initial phases of the project when the goal is to de-risk the technology and estimate its potential, high level financials are sufficient to gain preliminary traction. However, as we progress through the scale-up steps and de-risk the technology, the financial planning becomes more professional and the models now contain robust Profit&Loss statements, Balance Sheet and Cash Flow statements.

5. Rapidly Identifying and Removing Showstoppers

As presented above, building a company developing a new technology is multifaceted and multidisciplinary. It can be difficult to identify and remove risks/showstoppers. In our case, it was apparent that our most important breakthroughs were made when discussing with industry experts directly, as they can provide very valuable insights. Hence, we propose a checklist that can be used to further guide the researchers in the 'right' direction with their scale-ups (Table 1). The checklist provides data on various aspects that must be understood in the early days of the transition from the academic domain to industry. The column 'Tips to answer' mainly consists in interviewing relevant potential stakeholders. Here, it is important to interview industry leaders and receive multiple, ideally consistent feedback from the market. Robust information that can be gathered from industry leaders and reliable sources can be used to build the business plan that will be helpful for obtaining support for the project.

6. Conclusions and Outlook

Herein, we provide a personal account on our journey from academia to industry in the field of plastic waste hydrocracking. The account is not meant to be exhaustive, and many aspects are not covered in depth. Rather, this contribution is meant to provide some insights on the multifaceted and multidisciplinary requirements for process scale-up and entrepreneurship. Reflecting on the timing required between discovery and pilot (current stage), we believe we could have been around 9 months quicker if we had identified key suppliers earlier. Potentially, advisors who understand well the technology and know the supplier/customer/investor landscape could have helped us accelerate the development.

Importantly, it must be reminded that not all scientific research is meant to serve industry, and a lot of research in the field of the chemical sciences is required to push the boundaries of our fundamental conceptual understanding of the world, which is the reason why many of us enter the field of research in the first place.

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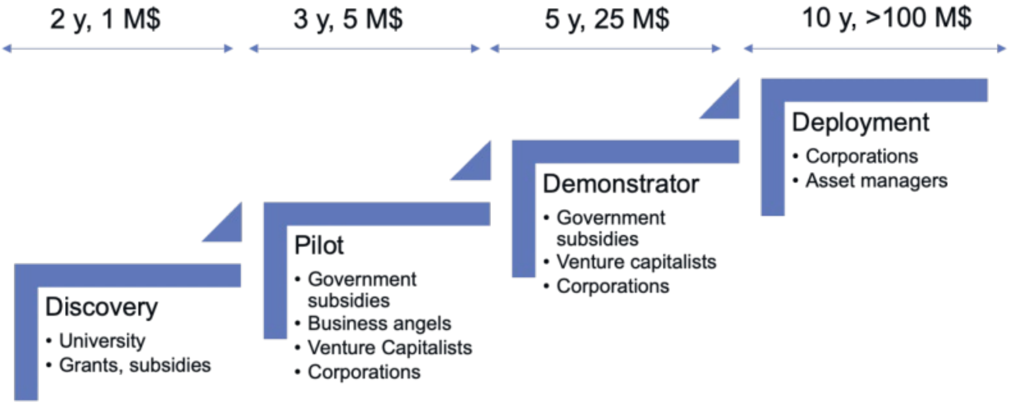

Fig. 4. Stepwise process scale-up and potential financing bodies thereof.

Table 1. Non-exhaustive checklist that a scientist working towards bridging academia with industry should think about.

Field	**Questions to Ask**	**Tips to Answer**
Technology	– Does the invention solve a technical challenge? – Does the collected data support industrialisation (not just proof of concept)?	– Interview industry leaders, understand industrial state of the art. – Interview engineering companies, ask for required data.
Environment, Health and Safety	– Does the invention lead to fewer emissions compared to the state of the art?	– obtain a preliminary LCA
Regulatory	– Are any of the chemicals or materials under strict regulation/banned?	– Interview industry leaders
Intellectual Property	– Is invention patentable? – Is freedom to operate analysed?	– Include patent search on top of academic literature search. – Discuss with patent attorney and/or tech. transfer office
Financials	– Can the invention be profitable? – Where do I obtain information for the price of my chemicals and materials?	– Interview chemical suppliers, request quotations. – Use CAPEX estimation tools.
Financing	– Who will invest in the the technology and for what reason?	– Learn about venture financing from venture capitalists. – Understand who finances what and why.
Team	– Who will carry out the transition from academia to corporate/industry? – How to build the team for scale-up?	– The team leader must be(come) knowledgeable about industrilisation in a broad sense, not necessarily focused on technology.

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