Ny forskningsplan för SLUs strategiska forskningsområde, TC4F

Sedan 2009 har SLU ansvar för det strategiska forskningsområdet (SFO:t) ”Hållbart nyttjande av naturresurser”, inom SLU kallat ”Trees and Crops for the Future” (TC4F). Den årliga tilldelningen till TC4F, samt återrapporteringskrav, anges i SLUs Regleringsbrev. Verksamheten inom TC4F sker i samarbete med Umeå universitet och Skogforsk och är utformad i överensstämmelse med intentionen i den beviljade ansökan 2009 samt i enlighet med den utvärdering som genomfördes av Vetenskapsrådet 2015 av samtliga SFO:n, där TC4F var ett av de SFO:n ansågs som så framgångsrikt att det rekommenderades fortsatt finansiering. Totalt finns ett 20-tal SFO:n vid de svenska universiteten.

Anslagstilldelningen via statsanslaget till SLU är på årsbasis och efter utvärderingen 2015 upplevdes en frustration inom programmet att operationalisera forskningsverksamhet för bara ett år i taget. SLU:s Rektor tog därför 2016 beslut att garantera finansieringen för en fyraårsperiod, 2017-2020. Då denna period närmar sig sitt slut har ett arbete påbörjats att formulera en ny forskningsplan för perioden 2021-2025.

Inom SLU har TC4Fs verksamhet hela tiden varit centrerad till fakulteten för skogsvetenskap (T-delen) och fakulteten för landskapsarkitektur, trädgårdsvetenskap och växtproduktionsvetenskap (C-delen). Fakulteternas respektive delar sköter den dagliga verksamheten fristående från varandra, i enlighet med ett Rektorsbeslut från 2018, men samarbetar med övergripande planering, årlig rapportering samt utvärdering.

Övergripande handlar TC4F om växtproduktionsforskning och produktutveckling inom skogs- och lantbruk. Inom fakulteten för skogsvetenskap är T4F den viktigaste pågående satsningen på institutionsövergripande forskning med disciplinöverskridande samarbeten. T4F är tvärvetenskapligt mellan grund- och tillämpade ämnesområden och har dessutom hela tiden verkat för att skapa interaktioner och samarbeten mellan stora externforskningssatsningar inom fakulteten, som tidigare till exempel Future Forests, Bio4Energy och för närvarande UPSC Competence Centre for Forest Biotechnology och olika pågående KAW-satsningar. Hitintills har programmet möjliggjort avgörande forskningsgenombrott, unika forskningsinfrastrukturer och innovationer som tillämpas inom praktiskt skogsbruk.

Programdelen C4F har satsat på utveckling av växtbaserande produkter från grundläggande forskning hela vägen till den färdiga produkten. Många värdefulla relationer är knutna till biotekniska industrin och jordbruk, till exempel SLU Center för Växtförädling, SweBlood , SweOat, SLU Biobased Materials samt Plant Protein Factory och många fler. Dessa relationer och den ständig växande kompetensen inom mångsidiga delprojekt kommer att vara ett stort stöd i C4Fs mål att bidra till en cirkulär bioekonomi i Sveriges samhälle.

Programmets övergripande målsättningen är en hållbar utveckling som stödjer den gröna omställningen av samhället. Denna kräver tillgång till bioråvaror med önskade egenskaper och hållbara produktionssystem från gen till produkt. TC4Fs forskningsprofil möter ett omfattande kunskapsbehov gällande bioråvarornas potential och produktionssystemens utmaningar. Med TC4Fs nära kopplingar mellan forskning och näringsliv kommer dessa att utforskas och användas!

I det följande presenteras forskningsplaner för T4F (Bilaga 1) och C4F (Bilaga 2) delarna. Detaljerad årlig rapportering från TC4F finns på https://www.slu.se/centrumbildningar-och-projekt/trees-and-crops-for-the-future/

Strategic Research Plan, TC4F Phase 3, 2021-2025

Background

Since 2009, SLU has been responsible for the Strategic Research Area (SRA) "Sustainable use of natural resources", within SLU called "Trees and Crops for the Future" (TC4F). The annual allocation to TC4F, as well as feedback requirements, are stated in SLU's Appropriation Directions. The activities within TC4F take place at SLU across three faculties (S, LTV and NJ), and in accordance with the original application from SLU's Vice-chancellor, in collaboration with Umeå University and Skogforsk. The focus of the activities is generally designed in accordance with the intention in the approved application in 2009 and in accordance with the evaluation carried out by the Swedish Research Council in 2015 of all SRAs, where TC4F was one of the SRAs that was considered so successful that continued funding was recommended. In total, there are about 40 SRAs at the Swedish universities.

In accordance with the call text and the application, TC4F has focused on forest and other crops with a distribution for operations and budget of 75% for the forest part (Trees - T) and 25% for the crop part (Crops - C). The operations were led during Phase I and half of Phase II by a program manager for the whole program (Jan-Erik Hällgren (2009-2011) / Eva Johansson (2011-2017)) and a steering group. Thereafter, SLU's Vice-chancellor decided that the T and C part of the program should be led separately by a program leader (Annika Nordin - T / Eva Johansson - C) with a separate steering group each. This was to increase the strength and quality within the different parts of TC4F. Responsibility for the activities was divided in connection with this to the Faculty of Forest Science (for T) and the Faculty of Landscape Planning, Horticulture and Crop Production Science (for C). Thus, the daily operational activities are managed independently of each other, but cooperation takes place with overall planning, annual reporting, and evaluation.

The work of formulating a research plan for the period 2021-2025 has been led by the respective steering group for the various parts and with the help of a working group (for T) and a management group (for C). The aim was to build on the successful investments made so far of the program in research and research infrastructure, while the plan should also lead to renewal, enable new international research breakthroughs and lead to innovations for the benefit of practical applications.

Overall, TC4F is about sustainable plant production and crop-based product development in forest and agricultural systems with a main focus on a circular and bio-based economy (TC4F strategy 2019-2021). Within SLU, TC4F is one of the most important ongoing investments in interdisciplinary research with cross-disciplinary collaborations. TC4F is interdisciplinary between basic and applied subject areas and has also constantly worked to create interactions and collaborations between major external research initiatives. So far, the program has enabled crucial research breakthroughs, unique research infrastructures and innovations with practical applications. Detailed annual reporting from TC4F is available at https://www.slu.se/centrumbildningar-och-projekt/trees-and-crops-for-the-future/

Strategic Research Agenda – Trees for the Future (T4F)

Bilaga 1

Introducing a strategic research agenda of T4F for the period 2021-2025

Here we propose a plan for the next phase of the TC4F program (2021-2025) that aims to expand the successes of the first decade. The program is designed to generate new knowledge and research connections that are needed to develop knowledge on sustainable plant production and crop-based product development within agricultural and boreal systems with the main objective to support the development of a new circular bioeconomy in Sweden. Our plan will promote a collaborative research environment between many departments within SLU, with Umeå University and Skogforsk as well as other companies within forestry and plant biotechnology. The program will build upon the innovative success of individual research environments across institutions. The new TC4F period will serve as a key vehicle to further connect individual research groups that work at different scales so that a more integrated and holistic knowledge base on sustainable plant production and crop-based product development can develop. Our plan for strengthening research connections includes new investment into new national scale experiments, maintaining and developing analytical platforms that will be widely available to researchers across all participating institutions, and through strategic recruitments of new junior and senior researchers that will connect disciplines, and thereby add value to the wider research communities of each participating institution. We foresee that the continuation of the TC4F program will generate a new wave of forest and crops science innovation that will influence how Swedish forest management and crop-based product development can be adapted for future climates and to meet society's shifting demands. The suggested strategic research agenda for the period 2021-2025 is described below, separately for the Trees and Crops part.

T4F Working Group

Michael Gundale, Stefan Jansson, Vaughan Hurry, Urban Nilsson and Annika Nordin

Strategic Research Agenda – Trees for the Future (T4F)

Background to the proposed research

Anthropogenic greenhouse gas emissions are increasing global temperatures, with global mean temperatures rising by about 0.13°C per decade for the last 75 years. Future warming is predicted to accelerate by about 0.2°C per decade. This warming is not evenly distributed, with the highest degree of warming occurring at the highest latitudes, with some boreal environments predicted to warm by as much as 6°C by 2100 according to the recent ICPP report. The boreal forest, which dominates Sweden's landscape, accounts for 1/3 of the world's forests and global terrestrial carbon stocks. Forestry in the boreal region is also a major source of economic activity, including in Sweden, where it is a major contributor to the national economy. Climate change-induced shifts in the functioning of this ecosystem may therefore have immense consequences for global carbon cycling and storage, as well as on the national economy. **Economics and environmental sustainability can often appear to be competing goals; however, the goal to increase productivity in Sweden's forests can be hugely beneficial for both.** While increasing forest productivity clearly provides economic benefits for forest owners and for the national economy, increased productivity is also beneficial for environmental sustainability because enhanced forest production is likely to promote CO_2 sequestration. In addition, incorporating advanced breeding for increased growth, alternate forest species and species mixes within the national forest landscape may provide the opportunity to set aside more forest for biological conservation without adverse effects on the economy.

In recent years, Sweden has pursued more intensive forest harvesting to fulfil the requirements of the EU renewable energy directive. Concurrently, recent climate change has not uniformly affected boreal forests: tree growth has increased in some regions in Fennoscandinavia and North America but declined in others. For example, warming in Eurasia has increased boreal tree growth at only 17% of sites where growth changes have been evaluated. This variable response suggests that in the boreal zone the strong historical correlation between forest growth and temperature may be breaking down, and that we are entering a period of great uncertainty and challenge. **To accomplish the competing goals of sustainable development and high rates of forest-based renewable energy production, we need to better understand the physical and biological processes that result in changes in forest productivity, and how our forests can be managed to optimally mitigate climate change.** New forest management strategies will be key in preparing for this uncertain and changing future. However, the net effect of management strategies on stand productivity and stand level carbon sequestration remains unclear. Forestry management strategies that are poorly adapted to future climates may increase the frequency of suboptimal growth conditions. Conversely, carefully selected forest management treatments may reduce damage, enhance productivity, and maximize carbon storage in both trees and soils. **To prepare for the future, we must also confront the aspect of the forestry sector that sets it apart from other sectors: its long-term planning horizon.** In practice, a full tree generation is in the order of 60-120 yr in boreal regions, so today's management decisions are likely to have different outcomes in future climates. Our tenuous grasp of future climates, and of the responses of tree populations to novel conditions, creates uncertainty for forest managers and the forest industry that can only be addressed through a carefully targeted research program.

Main challenges targeted by T4F - A new paradigm for forest management

Mitigating the combined threats of climate change and increasing demand for biomass production will require a knowledge-based approach to understand and utilize the interactions between genotypes, species, management, and the environment. Forest owners, managers and breeders need quantitative predictive tools in order to plan today for the future, to complement the experience-based, practical knowledge that often drives management decisions. Such experience-based decision making will be insufficient to meet the challenges posed by future climates, particularly under the long stand rotation age that is common in Swedish forests. These forest management challenges will be targeted in an organisation ensuring an interdisciplinary research environment and a continuous dialogue with stakeholders from the forest sector.

T4F research has, since the start of the program in 2009, addressed a broad range of issues related to this overarching forest management challenge. Over this period researchers within T4F have built new and complementary knowledge bases and it is now natural to engage in a joint effort to combine the disciplines of conifer and broadleaved genomics and molecular biology, ecophysiology, and silviculture in order to directly address the challenges facing the forest sector. In the future T4F research funding framework, the most important research areas to enhance and sustain forest production under a changing climate are:

- **Identifying the best genotypes for the Swedish landscape**. Substantial genetic variation exists within all tree species that occur naturally on the Swedish landscape. For many decades researchers have sought to isolate the most productive individuals from the landscape, and then breed them to create the next generation of trees. Genomics provides new tools for the genetic toolbox, some of which (like Genomic selection) are closer to traditional breeding than others (biotechnology such as CRISPR). When these tools are combined, and also used in combination with cloning methods such as somatic embryogenesis (SE), the next generation of forest trees are expected to be better adapted to different local environments, but also to deliver larger genetic gains in general.
- **Identifying which native and non-native tree species perform optimally in which environments.** Modern forestry practices in Sweden primarily focus on managing Norway spruce and Scots pine. All other tree species have been of minor importance. However, there are indications that this focus leads to problems, for example, in southern Sweden Norway spruce is severely damaged by wind, bark-beetles and root-rot. In the north, young Scots pine trees are damaged by browsing and several different pathogens to a level that makes it difficult to establish new stands. Other species viewed as native, such as birch and Siberian larch, and non-native species may serve as a tool to enhance forest production under increased environmental pressure.
- **Identifying the advantages or disadvantages of mixed species forests on growth.** Swedish forests have traditionally been managed as mono-cultures. However, there is some evidence from the ecological literature that species mixtures can enhance productivity due to complimentary resource use between species and/or complimentary tolerance to disturbance or stress. While it is proposed that species mixtures may serve as an insurance policy for forest growth under changing climates, surprisingly little research has adequately addressed this research frontier, and it remains a major knowledge gap.

- **Understanding the impact of these site level forest composition choices on landscape level production and carbon sequestration.** While new forest management tools such as listed above have great potential to enhance forest productivity, there remains substantial uncertainty over how these types of forest compositional choices will perform in response to variable and changing climates; and further, what the impact of these compositional choices will be on the landscape scale carbon balance. *One key uncertainty is how more intensive forestry may impact soil carbon and nitrogen stocks and turnover.* On the one hand, enhanced forest productivity may lead to greater carbon inputs to soil that may enhance carbon storage. On the other hand, enhanced forest production may change the quality and stability of carbon entering the soil, as well as the composition and functional diversity of the microbial community that drives soil nitrogen and carbon turnover. The net impacts of forestry on soil and ecosystem carbon and nitrogen exchange remains hotly debated, and thus unravelling the direct and indirect effects of new forest management activities on soil carbon turnover, and upscaling both soil and forest carbon balances to the landscape level (via modelling) remains a major frontier in understanding how forests and forest management practices may impact the Earth's climate system into the future.

An organizational framework for the 3rd phase of T4F

We suggest that in the 3rd phase (2021-2025) T4F should continue to broadly address the objectives of the first two phases of the program – ***to build a knowledge base for the sustainable use and management of the Swedish forest landscape***. We propose investing in five specific competencies and infrastructures common to the whole program (described below). Further, the research questions addressed will be subdivided into three overarching topics, with several departments being involved in each of them. The program will continue with the same organizational units that were originally awarded the government grant, including Forest Ecology and Management (FEM), Forest Genetics and Plant Physiology (GenFys), Southern Swedish Forest Research Centre (SSFRC) at SLU, Plant Physiology (FysBot) and Ecology and Environmental Sciences (EMG) at Umeå University, and Skogforsk (SF). We envision that the next phase will provide new collaborative opportunities between these units and also additional units within the faculty of forest sciences that have already been connected to T4F research, i.e. the Department of Forest Mycology and Plant Pathology (MycoPat) and the Heureka team of specialists at the unit for Forest Sustainability Analysis. The more exact organizational outlay of the new T4F, i.e. leadership and allocation of resources and responsibilities, remains to be discussed.

1) <u>Suggested investments into common competencies and infrastructures</u>

In the following is described six areas for investments in either competence or infrastructure. New recruitments of researchers will be allocated to ensure cutting-edge developments within these areas that are all spanning several disciplines and are already well established within T4F. The new long-term field infrastructures will be designed as hubs for investigations by researchers from a wide array of disciplines, also bridging basic to applied science.

A) Bioinformatics

T4F has been crucial for establishing the Tree bioinformatics competences in Umeå, which in turn has been crucial for genetics, genomics, breeding and metagenomics activities. There is now an

established Bioinformatics platform at UPSC, T4F should continue to support that to ensure that the needs of these activities will also be met in the upcoming phase.

B) Tree breeding

Skogforsk will continue as main provider of resources in tree breeding and quantitative genetics. Breeding applications will be developed in relation to developments in forest management and in addition to Norway spruce and Scots pine, also for other species such as birch, larch and lodgepole pine.

C) Microbial Ecology

The focus will be on the analysis of functional aspects of the soil metacommunity, soil metatranscriptomics and soil community sequencing, to provide mechanistic insights into the effects of climate change and altered forest management approaches on soil carbon and nitrogen cycling.

D) Modeling

The modeling will focus on implementing new process-based functionalities in the Heureka forestry decision support system in close cooperation with the team of specialists at the unit for Forest Sustainability Analysis. The new functionalities will be brought in from ecosystem models that use physio-chemical inputs to simulate forest growth, e.g. models like 3PG or BIOMASS and the overarching aim is to allow for Heureka, which is the tool used for forestry planning in Swedish forestry, to better capture the effect of climate change in long-term simulations of stand-, estate- and landscape forest development.

E) **Establishment of a new stand scale genetic improvement experiment.** A new nation-wide experiment will be established consisting of large scale replicated plots (> 0.1 ha) with genetically improved trees (via breeding programs) and appropriate outcrossed controls for both *Pinus sylvestris* and *Picea abies*. The experiment will be designed to complement existing genetic field trial experimental infrastructure, which are maintained primarily by Skogforsk. Much of the existing experimental infrastructure is not set up at a large enough stand scale to allow evaluation of genetic improvements on ecosystem properties, such as stand level carbon exchange or soil carbon dynamics. Further, for existing infrastructure that is set up at an appropriate scale to address ecosystem level impacts, they often lack adequate spatial replication, making it difficult to investigate the impacts of genetic x environment interactions on stand ecosystem dynamics, which is exactly what is needed to understand how genetic breeding programs can be used to adapt forests to climate change. Thus, a new national level experiment will be set up to allow future research within this theme, which is currently limited by available infrastructure.

F) Setting up a new mixed species field site/experiment.

A new nation-wide regeneration experiment will be established that will address questions relating to seedling survival, vigor and subsequent growth as influenced by site preparation and site

conditions. The experiment will be designed so that over time it can develop into a long-term tree-species mixture experiment including long-term performance of SE-seedlings. The experiment will aim at explaining growth and survival at the level of tree-physiology as well as assess the effects of damaging environmental factors such as abiotic and biotic stress factors. The experiment should be replicated on multiple sites from Norrbotten to Skåne, which will enable in-depth studies of seedling establishment in very different climatic and environmental conditions, which will be directly relevant for understanding forest productivity and resilience in response to climate change.

2. Specific research topics

A) Breeding for the future.

The task of this topic is to do research on how to breed most efficiently for production and tree health, i.e. enhance resistance to pests and diseases. Operational tree breeding and academic molecular research has been united by genomics, and the interaction between Skogforsk and the academic environment, in particular at UPSC, is very fruitful. The large KAW-funded projects and the research school(s) in Forest genetics that just have started are capitalizing on this, and the T4F funding within this topic should, like before, be spent on academic research at the interface towards breeding.

Key research questions include:

- Deciphering of the genes behind important tree traits like phenology, productivity, abiotic and biotic stress resistance, wood formation and flowering. This is a very wide field but knowledge about this is important for understanding of the physiology, that could lead to changes in forestry practices, for genetics to understand the genetic architecture of traits and the natural variation in them, and also for breeding with modern tools. The already on-going collaboration between researchers at UPSC and MycoPat ensures world-leading competence of pathogen-tree interactions to be developed in T4F. This will also strengthen the biotic stress aspect of T4F, highly relevant for conifer breeding.
- Tree genome sequencing, resequencing and high throughput genotyping are essential tools for this, and also RNA sequencing and development and management of databases for genomics data.
- Develop and provide tools for breeding of birch and lodgepole pine, in addition to Norway spruce and Scots pine, where this development is already ongoing.
- Develop Genome Wide Association Studies to be used to analyze traits.
- Develop the use of Genomic Selection in breeding programs.

This topic will build on the Bioinformatics common activity, as well as field experiment, including mixed forest species trials that also offer opportunities to study resistance. New clonal tests/field experiments of natural ecotypes, breeding material and transgenics will also be established.

B) Future forest composition.

Tree species for the future

Future climate change demands new forest management tools that fit with the new climate. For this, preparation for the use of exotic tree species and increased use of underused native trees are an obvious path. Fortunately, previous researchers have been thinking along the same lines, and we are relatively well equipped with tree-species experiments that are between 30-60 years old. These experiments that are located at or near to the experimental stations in Vindeln, Siljansfors, Asa and Tönnersjöheden will be used for examining broad ecological and production aspects of various tree species.

Key research questions include:

- What level of total production can be expected from different exotic conifer species and native and exotic broadleaved species (including noble broadleaves) and how do different silvicultural practices impact this?
- How do different introduced species affect the diversity and function of the soil microbiome, and do the different exotic species change soil carbon storage?
- What is the timeframe for large-scale introduction of a specific exotic tree-species including time for finding genetic material, building know-how of forest management and investigating environmental risks?
- How do different tree species respond to spatial and temporal variation in climate, and can this be used as a tool to predict growth under predicted future climates?

Mixed species forests

Depending on how tree-species mixtures are defined, most forest stands in Sweden are mixed. However, most of the silvicultural recommendations and our eco-physiological understanding originates from experiments with monocultures. Of the more than 1700 long-term experiments that are managed by the forest faculty, less than 50 address mixed-species questions (Figure 1, Item 6).

Key research questions include:

- What are the effects of species mixtures on total production and how do different silvicultural measures impact this?
- From these data, can we develop new individual tree empirical and hybrid growth functions for trees in monocultures and in mixed species stands, and can we use these data to describe historical area- and volume-development of mixed species stands since 1983 using NFI-data?
- How should stands be managed in terms of regeneration, pre-commercial thinning, and thinning used to retain tree-species mixture throughout the rotation?
- How do different species mixtures affect the diversity and function of the soil microbiome and are there flow-on effects of tree species mixtures on soil carbon storage and nitrogen cycling?

- How do species mixtures versus monocultures respond to spatial and temporal variation in climate, and can this be used as a tool to predict growth under predicted future climates?

In addition to utilizing existing mixed species experimental infrastructure, we will establish a new nation-wide mixed species field-experiment to provide short term data and provide long term opportunities for future generations of forest production and ecology researchers. The tree-species component will be a full combination of monocultures and mixtures of Norway spruce, Scots pine and birch.

C) Plant-soil interactions and soil carbon stocks.

Boreal forests have more than twice as much carbon stored in the soil than is found in the living tree biomass. Soil carbon represents the balance between carbon inputs from forest vegetation, which can vary in quantity and quality; and carbon outputs, which are driven by the action of the soil microbiome and that can vary in biomass, composition and function. The soil microbiome not only controls soil carbon losses but also influences plant growth, as a recycler and supplier of nutrients to trees. Forest management has a strong potential to influence soil carbon stocks by altering both the quantity and quality of carbon inputs, and by impacting the microbiome that controls carbon outputs and nutrient cycling. A critical knowledge gap therefore is to understand how a wide range of forestry activities influence soil carbon stocks through influencing carbon inputs from vegetation and the soil microbiome composition and activity.

Key research questions include:

- How will changes in climate (e.g. seasonality, soil temperature and soil water status) affect plant-microbial interactions and carbon cycling?
- How do changes in species composition and mixtures in the forest, the type of N used for fertilization at different growth stages and shifts in the genetic makeup of planted material, influence the microbial community and related ecosystem services such as carbon storage, nitrogen cycling and water availability and use?
- Genomic selection and the deployment of somatic embryogenesis will potentially cause rapid shifts in the gene pool at the landscape scale as well as corresponding changes in tree-level traits – how will this influence the composition and functioning of the microbial community and the outcome of plant and forest exposure to abiotic stress?
- What are the multi-level interactions between fungi, bacteria, archaea and viruses within the soil communities? Altering interactions with the microbial community could have unexpected and important effects of invasion and infection of pathogenic microbial and herbivorous species, which will be exacerbated if climate change also alters the lifecycle and range of those species.

Bilaga 2:

Strategic Research Agenda – Crops for the Future (C4F)

C4F Management Group

Eva Johansson, Li-Hua Zhu, Roger Andersson, Per Hofvander and Ramune Kuktaite

Introducing a strategic research agenda of C4F for the period 2021-2025

Here we propose a plan for the next phase of the TC4F program (2021-2025) that aims to expand the successes of the first decade. The program is designed to generate new knowledge and research connections that are needed to develop knowledge on sustainable plant production and crop-based product development within agricultural and boreal systems with the main objective to support the development of a new circular bioeconomy in Sweden. Our plan will promote a collaborative research environment between many departments within SLU, with Umeå University and Skogforsk as well as other companies within forestry and plant biotechnology. The program will build upon the innovative success of individual research environments across institutions. The new TC4F period will serve as a key vehicle to further connect individual research groups that work at different scales so that a more integrated and holistic knowledge base on sustainable plant production and crop-based product development can develop. Our plan for strengthening research connections includes new investment into new national scale experiments, maintaining and developing analytical platforms that will be widely available to researchers across all participating institutions, and through strategic recruitments of new junior and senior researchers that will connect disciplines, and thereby add value to the wider research communities of each participating institution. We foresee that the continuation of the TC4F program will generate a new wave of forest and crops science innovation that will influence how Swedish forest management and crop-based product development can be adapted for future climates and to meet society's shifting demands. The suggested strategic research agenda for the period 2021-2025 is described below, separately for the Trees and Crops part.

Strategic Research Agenda – Crops for the Future (C4F)

Background to the proposed research

The **major aim of C4F**, according to the strategy for 2019-2021, is to develop sustainable new crop-based products through the use of modern technologies to contribute to the development of a circular bioeconomy in Sweden. This aim corresponds largely to the objectives of the original call text for the crops part and also to the aim of this part of the program over its first phase. The exception is that the program with its present aim includes all types of products for both non-food and food purposes, while at the start of the program, only non-food applications were included. This is highly relevant as crops need to be used for several different products for economical, societal, and environmental sustainability. Often, similar components are important for both areas and one crop can be used for several purposes.

The target of the research topics within C4F has become even more important over the decade of its existence, as crop-based products have become increasingly popular due to health, ethical and environmental concerns. To understand the increasing importance of crop related products in the modern society, one can enter a local food store or listen to the debate about a future sustainable world. By entering a food shop and comparing the diversity of products in a current one with that of a similar shop 10-15 years ago, the large number of novel products is obvious. A major shift is the availability of more crop-based products such as meat without meat, milk without milk, egg-based products without eggs, flour- based products without wheat etc. This product shift has been largely consumer-driven and is the result of allergic/intolerant reactions, interest in sustainability and health issues, and ethical concerns, where the novel products contribute a significant positive effect. A significant amount of the debates are related to climate/sustainability issues, drawing the attentions to carbon foot-prints, CO_2 equivalents and hazardous elements, and in addressing these questions, solutions are often searched for that are related to products based on crops or biological solutions and bioeconomy. Crop-based products are not always but mostly a more climate friendly solution than the current alternatives. Thus, crop-based products have never been as central as at present and are therefore more relevant than ever as a target for C4F.

For a sustainable future, crop production needs to target and address a combination of different challenges including; development of environmentally friendly crops, resource effective crop production systems, sufficient food production to an increasing world population (expected to be 9.8 billion in 2050) in a changing climate and the need for bio-based products (to e.g. replace petroleum based ones). For success, programs and project targeting various parts within the crop production and crop-based product development chain need to be connected and suitable collaborations need to be established. Therefore, C4F should strategically be inter-linked to other large, medium and small programs at SLU, focusing on research and development in other areas of the chain.

Main challenges targeted by C4F - The paradigm for crop-based products

The focus of the research within C4F is clearly in line with societal needs and the strategy of SLU. The C4F research goes also well in hand with the political desire of the development of a circular bioeconomy. The research carried out within C4F aims at replacing fossil oil and fossil-based industrial products without hampering crop-based food production and the sustainability of crop production in general. Furthermore, research at C4F should contribute to novel food products and innovations linked to both food and non-food applications. Since, C4F is targeting a broad aspect of

globally highly important topics related to sustainable food products and consumption for the growing world population, and sustainable and low-climate affecting products to reduce negative climate impact, the research tasks of the program are rather demanding and challenging. The paradigm to succeed with such a high amount and wide array of crop-based products has to rely on close collaboration and inter-linking with other small, medium sized and large projects and programs within SLU. C4F should act as a research hub, driving the science in important research areas forward.

C4F has had and is going to have close collaborations with **i)** the SLU Center for Plant Breeding where the future crops for Sweden are developed with modern plant breeding tools, **ii)** the SLU Platforms for crop production, plant breeding and plant protection where knowledges are gathered in topics of relevance for crop production, **iii)** the SSF funded projects OCF (Oil Crops for the Future), SweBlood and ScanOat where products based on oil, hemoglobin and oat proteins are developed, **iv)** the SLU Biobased Materials Initiative where knowledge on 8 biobased materials are collected into joint activities, **v)** the SLU industrial food-based PhD program where novel knowledge in food primary production is gathered, **vi)** the Mistra and SLU funded projects Mistra Biotech and Mistra Future Food, where biotechnology for food production and food production systems are evaluated, **vii)** The Linnean Center for Plant Biology in Uppsala and Umeå Plant Science Center where joint technologies are used and developed, **viii)** PlantLink where research networks are connected nationally and internationally, and **ix)** Plant Protein Factory where protein fractionation and use from green crops side-streams are developed. A close cooperation with similar and/or complementing national and international research environments is a matter of course for C4F. Of specific value for C4F are the ongoing opportunities that MAX IV, and future ESS offers.

An organizational framework for the 3rd phase of C4F

The organizational framework of C4F was changed recently, during Phase II (mid 2017), shifting C4F to become an own organizational unit under the Faculty of Landscape Planning, Horticulture and Crop Production Sciences (LTV), with its own Program leader, Vice Program leader, Steering Committee and Management group. At the same time, a strategy for the period 2019-2021 was developed. Currently, two SLU-faculties are participating in C4F (LTV- and NJ-). At present, it is proposed for C4F to continue as the organizational unit in accordance to the relatively recent decisions on the current program strategy, made by the Vice Chancellor of SLU and the Dean of the LTV-faculty, as well as with the development of a new strategy for 2022-2026 during the year 2021.

Specific research topics

Specific research topics for the beginning of Phase III of C4F follows the pace of the strategy developed for 2019-2021, as described below. However, it is envisaged an update of the strategy within C4F during 2021. What is clear already is a wish within C4F to develop a clear and safe strategy on how to terminate ongoing/finalize sub-projects within the program and to develop strategies on how to catch and start interesting novel projects from novel ideas and participants. There is a need of more dynamics in the program simultaneously as stringency and long-term security have to be taken into account. Generally, the program should continue to gather a network of strong PIs, although funding should primarily go to

younger researchers/ post-docs/ PhD-students. Furthermore, funding from C4F should also continue to contribute to on-going activities of relevance and to start-up activities that can be developed into novel larger projects and programs in a near future. C4Fs connections and collaborations with the biotechnological industry in general and specific companies in particular will be strengthened and developed further.

Specific research areas (according to current strategy);

- Improvement of quantities and qualities of oils, starches, proteins, minerals and bioactive compounds and other metabolites in crops for various end-uses. Here, C4F intends to use various methods including environment, genetic and processing conditions to tailor qualities of specific compounds in crops for certain properties.
- Development of processing and analysis tools in order to determine and characterize properties of the above mentioned components Here, C4F intends to apply and develop the most modern technologies, including those available at the national research platforms to describe and understand the characters and opportunities to fine-tune properties of the compounds of interest.
- Development of novel crops- and bio-based products close to market. Here, C4F will collaborate with other projects and with relevant partners and SLU Holding to develop products out of the research carried out within C4F.
- Development of novel production tools of the above mentioned components, including microbial and tissue culture based systems Here, C4F intends to develop novel plant or microbial systems for production of specific and pure components of interest to evaluate specific characteristics and long-term production of certain components of interest in higher quantities for pharmaceutical or other industrial applications.
- Evaluation of structure-function relationships of certain biobased materials for various applications Here, structure of components after certain production treatments will be evaluated and related to functional performance of the components.