

CHARTER



TLL is a beneficiary of Temasek Trust and is an institution with a reputation of integrity and excellence.

- It offers research funding for programmes in line with its strategic focus, and welcomes complementary funding from other sources as a market test of research ideas.
- It values integrity and excellence and expects the new knowledge and its application to contribute to the well-being of mankind.



TLL is a developer of people to deliver breakthrough science and impactful applications.

- It attracts established and young researchers, trains and mentors budding scientists as well as establishes a network of alumni and other scientific and industrial collaborators to achieve breakthrough science and impactful applications.
- It supports, nurtures and challenges our people to be leaders in their fields of science and technology.



TLL is an organisation of people who strive to strengthen it to benefit society and the economy.

- It motivates and incentivises its people to continuously strengthen the organisation as they build up their own credentials.
- It encourages collaborations and partnerships with fellow researchers in basic and applied research to multiply its capabilities in contributing through its research and applications to society and the economy, especially in Asia.

2023

20
years in the
pursuit of
excellence in
the Life Sciences

Looking back at TLL's Phases of Progress

01 Discovery-Driven Phase

Build research and develop competencies in the biosciences

2002 - 2011
Science as the Mission



02 Purpose-Driven Phase

Build innovation to address challenges arising from issues related to planetary boundaries

2012 - 2021
Science as the Means



03 Impact-Driven Phase

Delivering impact through partnerships for the benefit of local, regional and global communities

2022 & Beyond
Science in Partnership with Communities

Science as the Mission

From our incorporation in 2002 to 2011, TLL has sought to build research capacity and to develop competencies in the biosciences. The underlying mission was to address and capture the opportunities brought about by the five major crises that could affect Singapore and the region.

Our aim has been to create new knowledge and enterprises to address the issues brought about by increasing consumption, decreasing land productivity, and escalating demands from the intensification of food production.

Five Major Crises

Population Crisis

9 billion world population expected by 2050

Productivity Crisis

Agriculture intensification affecting future land productivity

Soil & Water Crisis

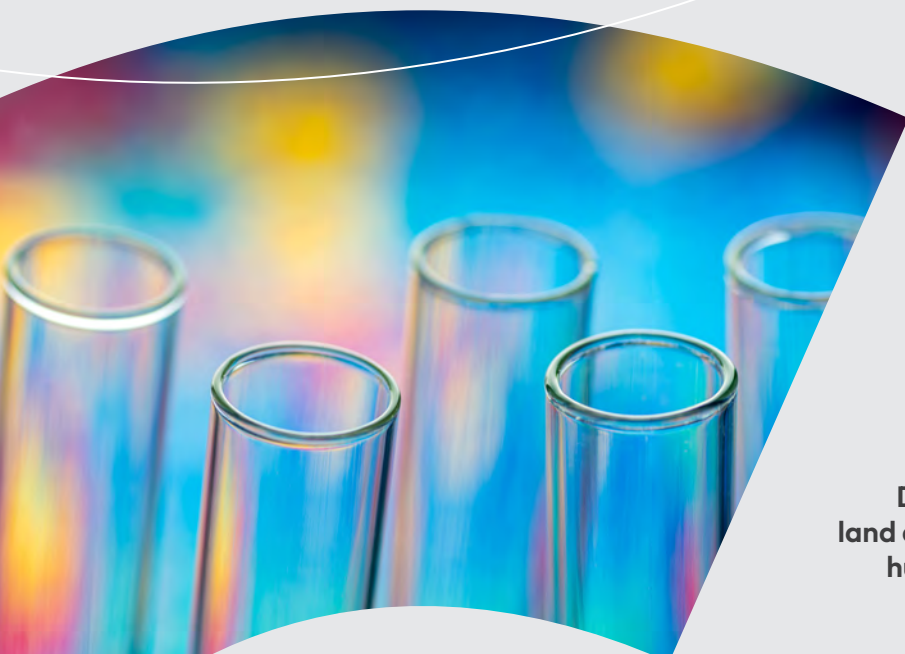
Depletion of arable land and freshwater for human consumption

Environmental Crisis

Pollution and its impact on farming ecosystem

Emerging Diseases Crisis

New and deadly emerging and re-emerging diseases

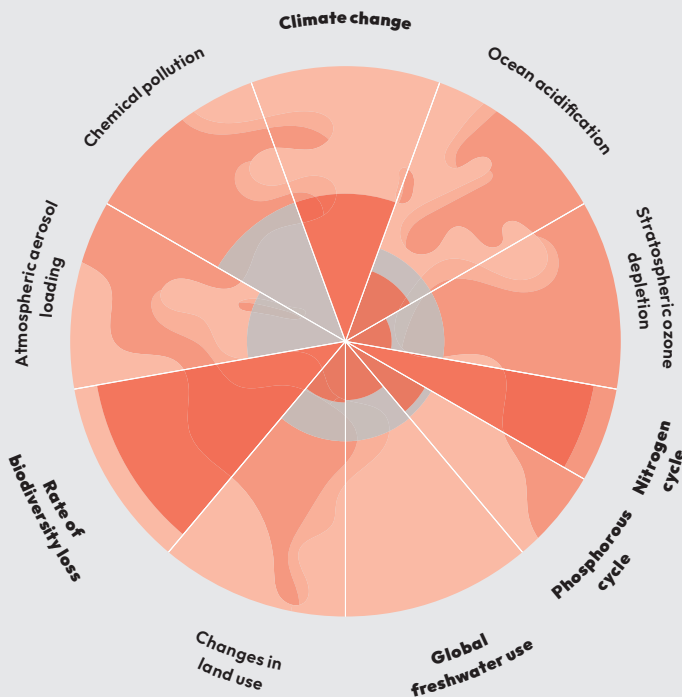


Science as the Means

In 2010, our focus shifted to issues arising from the planetary boundaries. The boundaries can be measured in biophysical terms and help define the operating space in which humanity can safely thrive, although many of these boundaries have already been exceeded.



Planetary Boundaries



TLL principal investigators have directed their basic research to better understand the impact changes in the environment will have on plant and animal development. There have also been instituted applied research programs at TLL that attempt to address some of the pressing breaches to these boundaries, specifically in four chosen areas.

Climate Change Research Programs

- Climate-resilient agriculture – Temasek Rice
- Enhancing tropical aquaculture – St John's Seabass
- Bio-solutions for eradicating mosquitoes

Biodiversity Loss Research Programs

- Sustainable forestry solutions
- Synthetic biology
- Targeted pest bio-control

Global Freshwater Use Research Programs

- Methods for growing rice sustainably
- Saline Tilapia – selective breeding program
- Recirculating Aquaculture System (RAS)

Phosphorus & Nitrogen Cycles Research Programs

- Biological fertilisers
- DiSTAP – Disruptive & Sustainable Technologies for Agricultural Precision
- HiPPA – High Performance Precision Agriculture

PHASE #3 *Impact-Driven Phase (2022 & Beyond)*

Science in Partnership with Communities



Today, TLL research groups use biotechnological tools and techniques to uncover and understand, at the cellular and organismal levels, the workings of viruses, bacteria, yeast, fungi, plants and animals, as well as the interactions between pathogens and their hosts and how these knowledge can be harnessed to help improve lives of communities.

The outcome of these discoveries can be grouped under three broad application areas: Agri-Food Technology, Industrial & Synthetic Biology, and Human & Veterinary Sciences.

This TLL research focus forms the foundation through which three respective global trends can be addressed: Food Security, Sustainability, and Well-Being.

New biotechnology and applications as well as exogenous shocks like COVID-19 are accelerating the convergence of the fields within life sciences. Convergence offers the potential for completely disrupted approaches, and the potential for life sciences to drive greater impact.

Nutrition Security

incorporates some of the aims of food security, but with additional emphasis on the need for consistent and affordable access to foods that promote well-being for populations in urban cities.

Healthspan Extension

is a multidimensional approach to improve human healthspans, as well as to enable communities to achieve their potential in areas linked to neurodegeneration and nutrition.

Sustainability

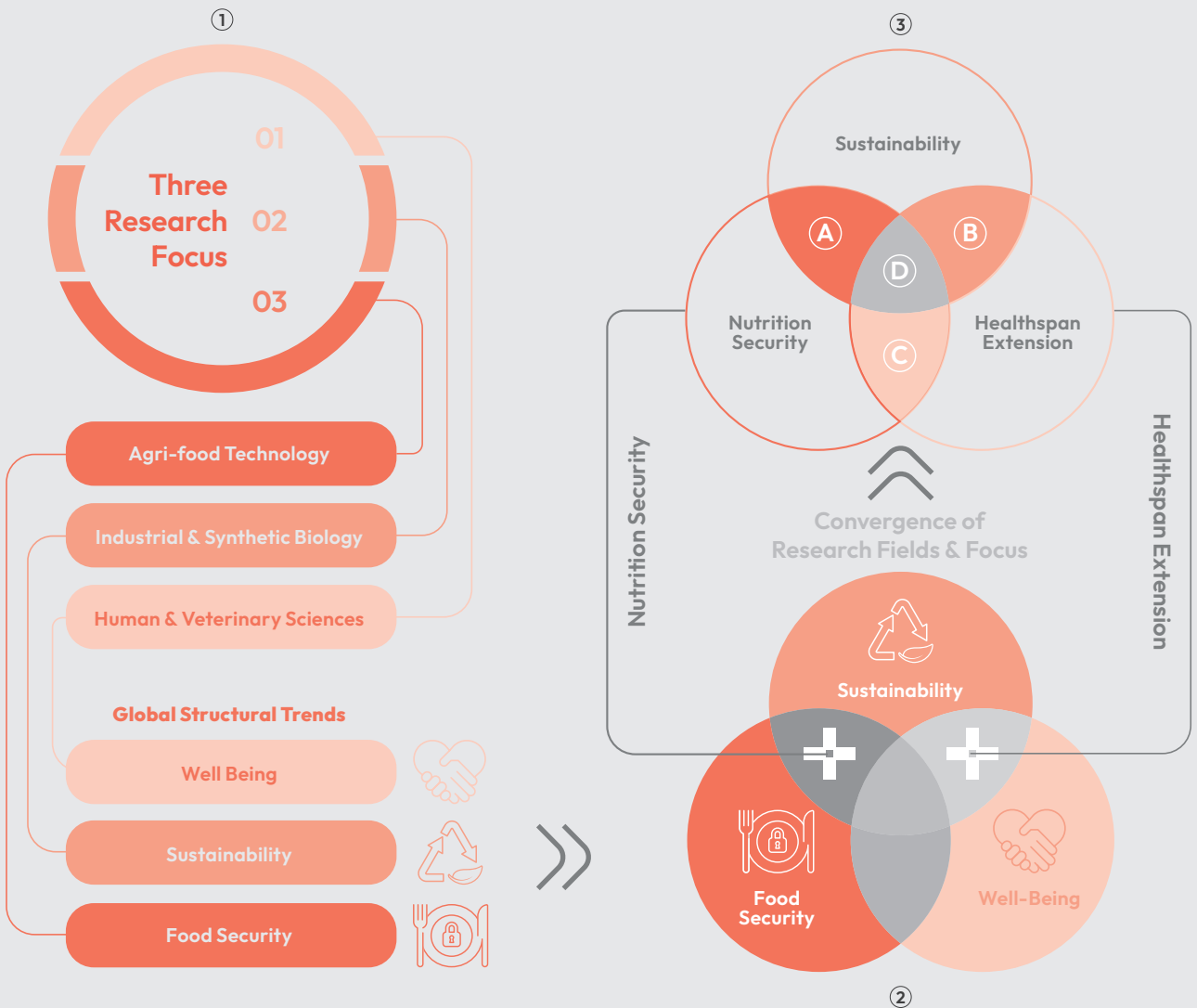
through the use of biotechnology to conserve natural resources and protect the global ecosystem and in so doing, support health and well-being and build thriving communities. Research in these areas include addressing air pollution, biodiversity loss, climate change, resources shortage, zoonotic diseases and over-exploitation of natural resources.



Technological advances have accelerated the convergence of the fields within life sciences and offers the potential for lifesciences to drive greater impact. Convergence across disciplines and trends provides the blueprint for addressing some of the more urgent life science challenges of tomorrow.

Discoveries Within Strategic Areas

- A**
 - Discovering how plants protect and restore our biosphere (e.g. cleaner air, remediate lands, higher nutritional profile)
 - Plant sciences for climate resilient agriculture (e.g. decarbonising rice cultivation)
 - Development of high yielding varieties (e.g. Jatropha as a source of sustainable biofuel)
- B**
 - Studying insects and their relationship to humans, environment and other organisms (e.g. suppressing mosquito population)
- C**
 - Parental health and child metabolic health studies
- D**
 - Plant science programs in support of urban food security (e.g. precision agriculture)
 - Fish nutrition, genetics and disease management (e.g. the AquaPolis programme)



Think Bio Science, for life.

INTRODUCTION

Temasek Life Sciences Laboratory (TLL) was set up in 2002 to undertake cutting-edge research in molecular biology and genetics, focusing primarily on understanding the cellular mechanisms that underlie the development and physiology of plants, fungi and animals.

A beneficiary of Temasek Trust, the research institute is dedicated to the discovery of new knowledge to help provide answers to issues facing humanity today.

In 2022, TLL celebrated 20 years of being on the frontier of scientific research in Singapore, furthering biological discovery and the development of solutions with big societal impact.

**Institution of
Public Character
since 2015**

**Augmented by programme
grants and internally
generated income from
external partnerships**



**Core activities and
research supported
by endowment from
Temasek Trust**

**180 scientists from
20 nationalities**



**Affiliations to the National University
of Singapore (NUS) and the Nanyang
Technological University (NTU)**

**Post-grad to High
School internship
programmes**



**Junior Research
Fellowship, REAP**

KEY HIGHLIGHTS *Since inception*

\$248M
worth of
grants awarded



KEY HIGHLIGHTS

Since inception to March 2023

1,628

interns trained



KEY HIGHLIGHTS FY 2022

247
permanent and
contract staff,
*employed by
the Group*

(As of 31 March 2023)

KEY HIGHLIGHTS *Since inception*

257
PhD students
*trained and
graduated*



KEY HIGHLIGHTS *Since inception*

TLL has contributed

1,325
scientific papers
in international peer-reviewed journals



KEY HIGHLIGHTS *Since inception*

TLL has made

182
discoveries

of which about half have been licensed

KEY HIGHLIGHTS *Since inception*

\$660M
in total funds raised
by companies
incubating in TLL



AREAS OF SCIENTIFIC DISCOVERIES

Temasek Rice & Global Food Security

Featuring the breakthrough Temasek Rice Project that restored Aceh's flood-affected rice fields with climate-ready, toxin-inhibitive varieties.

Read more on Page 28.



AREAS OF SCIENTIFIC DISCOVERIES

Commercialising Jatropha for sustainable biofuel

Featuring our domestication project on wild Jatropha plants for drought regions to remediate soil, offset carbon emissions through carbon sequestration, and produce biodiesel.

Read more on Page 32.



Precision Agriculture System

AREAS OF SCIENTIFIC DISCOVERIES

Featuring the latest HiPPA advancements to maximise crop production, including plant-to-plant communication to enhance plant growth.

Read more on Page 36.



AREAS OF SCIENTIFIC DISCOVERIES

Bio-control of Mosquitoes

Highlighting the testing and culturing of biological agents on different mosquito life stages to better control mosquito populations.

AREAS OF SCIENTIFIC DISCOVERIES

Plant & Animal Genotyping

Showcasing DNA/RNA extraction in animal and plant populations for use in propagation, resulting in enhanced quality and quantity of economically important plant and animal species.



AREAS OF SCIENTIFIC DISCOVERIES

Plants as Environmental Biofilters

Demonstrating the usage of plants to remove pollutants from the air and water.



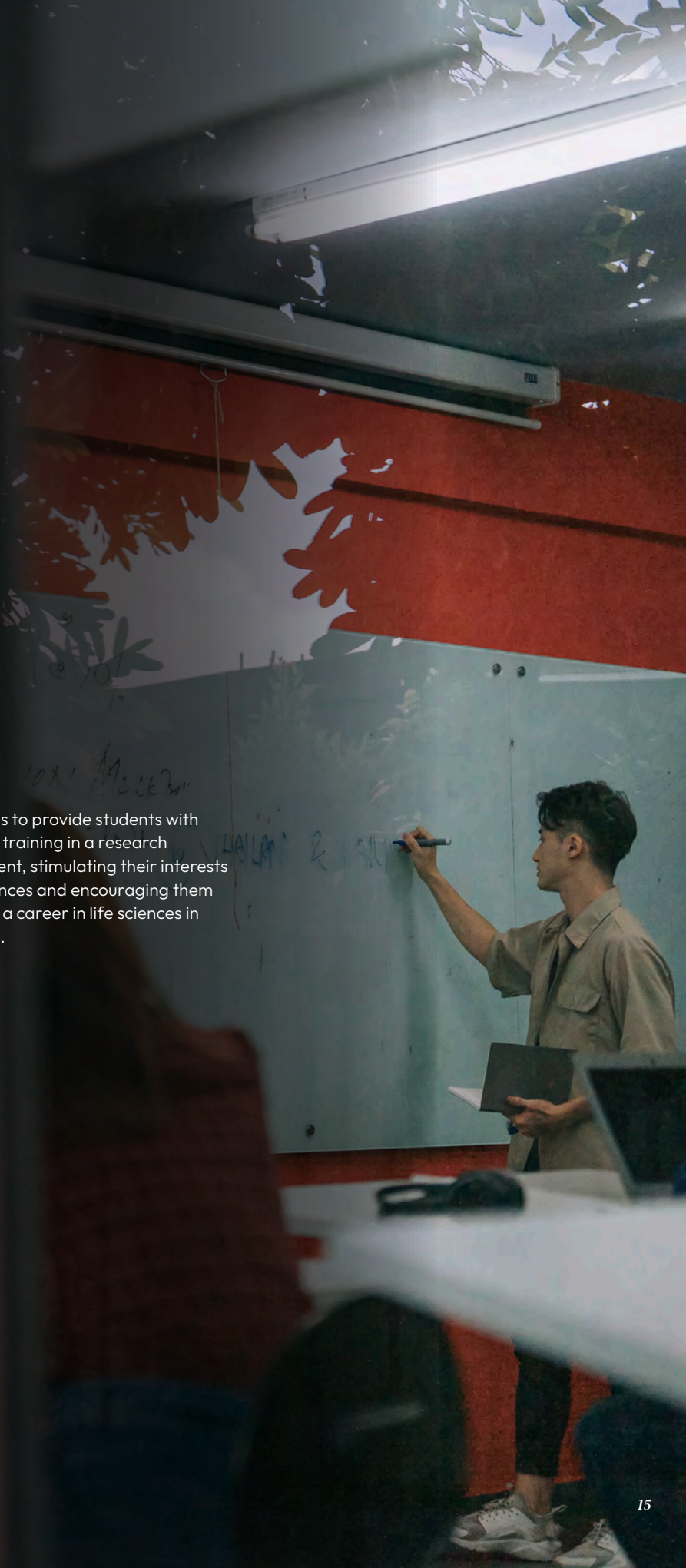
EDUCATION

Research Attachments

The Research Internship @ TLL (RIT) was launched to provide students with opportunities to apply knowledge acquired in the classroom to real-life research laboratories.

The Research Attachment Program (REAP), jointly organised by the Ministry of Education (MOE) and TLL, is specially designed for biology and chemistry students in the first year of junior college, and fifth year of schools offering the Integrated Program (IP).

REAP aims to provide students with hands-on training in a research environment, stimulating their interests in life sciences and encouraging them to choose a career in life sciences in the future.



EDUCATION

Graduate Attachment

This is a program for Singaporeans and Permanent Residents (PRs) who have recently graduated with a good honours degree in Life Sciences. GIT offers the participants a glimpse of research life before they embark on the TLL-PhD program. Each participant is provided a monthly allowance over the 6-month program period.

TLL PhD Training Program

The TLL PhD program provides opportunities for aspiring young scientists to be trained full-time in TLL laboratories under the supervision of TLL faculty. TLL PhD graduates are often able to find placements at top international postdoctoral fellowship programs and/or embark on careers in the life sciences industry.

TLL also contributes to the Singaporean academic ecosystem by coordinating four in-house PhD modules which are accredited by the National University of Singapore (NUS). TLL faculty as well as many well-known local and overseas guest lecturers jointly conduct these lectures that are open to all postgraduate students from NUS, Nanyang Technological University (NTU) and TLL.



Temasek Life Sciences Accelerator (TLA)

Temasek Life Sciences Accelerator (TLA), a joint venture between Temasek Life Sciences Laboratory (TLL) and Vertex Holdings (VH), is Singapore's first agri-bio-sci-tech incubator that aims to incubate, nurture and grow disruptive life science innovations into early-stage companies, with the vision of becoming tomorrow's champions.

With its Incubator Program, TLA aims to become the leading incubator for life sciences in Singapore, dedicated to bringing innovative ideas in the areas of Agri-Food Technology, Industrial & Synthetic Biology, as well as Human & Veterinary Sciences to the market. To achieve our mission, we offer an attractive incubator support program to early-stage companies in Singapore by providing timely and relevant market research, combined with business networking expertise to incubatees.

The Hatchery

Hatchery & Incubation

The Hatchery, fully developed and supported by TLA, is Singapore's leading incubator dedicated to bringing innovative ideas in the areas of Agri-Food Technology, Industrial & Synthetic Biology, as well as Human & Veterinary Sciences to the market.

The aim of TLA is to become the foremost 'go-to' incubator for life sciences in Singapore. To achieve our mission, we offer an attractive incubator support program to early stage companies in Singapore by providing timely and relevant market research, combined with business networking expertise to incubatees.

Agri-Food Technology

Developing innovative solutions to improve overall productivity for food tech, enhanced urban agri- and aquaculture operations.

Industrial & Synthetic Biology

The global market for industrial biotechnology is enormous and innovation is key for economic growth and value creation.

Human & Veterinary Sciences

Bringing together the know-how in vaccine, diagnostics and therapeutics to help Singapore prepare for its ageing population and potential disease outbreak.



Board of
Directors

01



02



03



04



05



06



07



08



TOP TO BOTTOM

- 01 Mr Lim Siang Hoe Benny
- 02 Mr Peter Chia Leong Bin
- 03 Mr Quek See Tiat
- 04 Mr Richard Chu Dee
- 05 Prof Soo Khee Chee
- 06 Mr Tan Suan Swee
- 07 Prof Yu Hao
- 08 Mrs Lee Ai Ming (Long Ai Ming)
- 09 Dr Geh Min
- 10 Prof Lim Kah Leong

09



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Board of Directors

CONTINUED

CHAIRMAN

01 Mr Lim Siang Hoe Benny

- Chairman of National Parks Board
- Chairman of Temasek Foundation CLG
- Special Advisor to Centre for Liveable Cities (MND) and to the National Security Studies Program, RSIS/NTU
- Held Permanent Secretary positions in Home Affairs, National Development, National Security and Intelligence Coordination
- Awarded the Distinguished Service Order in 2021

CHIEF EXECUTIVE OFFICER

02 Mr Peter Chia Leong Bin

- Member of TLL's Executive Committee and Research Strategy Committee
- Chief Executive Officer of Temasek Life Sciences Ventures Pte Ltd and Temasek Lifesciences Accelerator Pte Ltd
- Holds directorship positions in several technology start-ups and organisations, namely, JOil (S) Pte Ltd, Temasek Lifesciences Accelerator Pte Ltd, The Lifesciences Innovation Fund Pte Ltd, Zero2.5 Biotech Pte Ltd, Aqualita Ecotechnology Pte Ltd, Pathnova Laboratories Pte Ltd

DIRECTOR

03 Mr Quek See Tiat

- President, Council for Estate Agencies
- Chairman, Accounting Standards Committee, ACRA
- Director, Singapore Technologies Engineering Ltd
- Director, Temasek Foundation Limited and TF IPC Ltd
- Director, Pavilion Energy Pte Ltd
- Member, Centre for Liveable Cities Advisory Panel
- Public Service Medal, 2009
- Public Service Star, 2014
- Meritorious Service Medal, 2023

DIRECTOR

04 Mr Richard Chu Dee

- Board Director and Senior Vice President, UNILAB, Inc. and Affiliates
- Trustee, Assisi Development Foundation (Philippines)
- Trustee, ASA Philippines Foundation
- Director, Greenfield Development Corporation
- Member, Committee of the Board, Ateneo Professional Schools

DIRECTOR

05 Prof Soo Khee Chee

- Founding Director of National Cancer Centre Singapore, Ex Senior Vice Dean (Clinical, Academic and Faculty Affairs) at Duke-NUS Graduate Medical School Singapore and Ex Deputy Group Chief Executive Office (Research and Education) at Singapore Health Services
- Conferred the 2003 National Day Award Public Administration Medal (Gold), 2008 National Outstanding Clinician Mentor Award by Singapore's Ministry of Health and 2011 President's Science & Technology Medal

DIRECTOR

06 Mr Tan Suan Swee

- Advisory Director, Temasek International
- Retired Managing Director, Investment, Temasek International Pte Ltd
- Previously Assistant Managing Director, Singapore Economic Development Board
- Awarded the 2000 Public Administration Medal (Silver)

DIRECTOR

07 Prof Yu Hao

- Provost's Chair Professor and Head of Department of Biological Sciences, National University of Singapore
- Elected Fellow of the Singapore National Academy of Science
- Previously Vice Dean in Faculty of Science, Deputy Head in Department of Biological Sciences and Chairman of several committees at NUS
- Previously Executive Director in Temasek Life Sciences Laboratory
- Recipient of many awards and accolades such as Provost's Chair in NUS in 2017 and 2020, Singapore National Research Foundation Investigatorship in 2016, the Singapore President's Science Award in 2013, the Singapore Youth Award for Science and Technology in 2007 and the Singapore National Academy of Science Young Scientist Award in 2006

DIRECTOR

08 Mrs Lee Ai Ming (Long Ai Ming)

- Senior Consultant with Dentons Rodyk & Davidson LLP since 2015. Prior to that, she was the Deputy Managing Partner having joined the firm in 1982
- Currently an independent director of Lendlease Global Commercial REIT
- Previously served on the boards of HTL International Holdings Ltd, Keppel Land Limited, Keppel REIT Management Limited (the manager of Keppel REIT) and the Agri-Food and Veterinary Authority and Keppel Telecommunications & Transportation Ltd as an independent director.
- Appointed as a Justice of the Peace in 2015
- Member of the Copyright Tribunal and Board of Visiting Judges constituted by the Ministry of Home Affairs

DIRECTOR

09 Dr Geh Min

- Director of World Wide Fund for Nature (Singapore) and Birdlife International (Asia)
- Management Board Member of the NUS Centre for Nature-based Climate Solutions (CNCS)
- Governing Board Member of Duke-NUS Medical School
- Advisory Committee Member of The Master of Science (Environmental Management) programme (NUS)
- Immediate Past President of Nature Society (Singapore)
- Former Nominated Member of Parliament from 2005 to 2006
- Inaugural President's Award for the Environment (2006)

DIRECTOR

10 Prof Lim Kah Leong

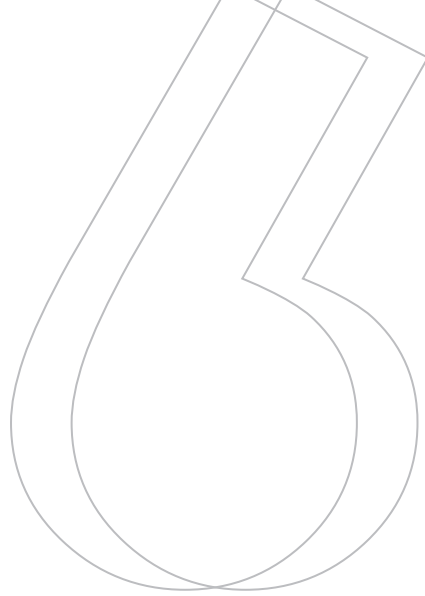
- Professor and Vice Dean (Research), Lee Kong Chian School of Medicine
- President's Chair in Translational Neuroscience
- Associate Vice President (Biomedical and Life Sciences), Nanyang Technological University



Mr Benny Lim

Chairman's *Message*





Through the last two decades, TLL and its people have persevered, overcoming many challenges to stay on course and to stay true to its mission of harnessing the power of life sciences with discoveries that positively impact lives and societies.



TLL began in 2002 and is now 20 years old. Its founding was a reflection of the faith and confidence of those few who were involved at the time, in the critical value and immense potential of life sciences to our lives and to the world we as human beings all have to live in. This was a time before green terms like “sustainability” and “nature-based solutions” became the buzzwords they have become today. Through the last two decades, TLL and its people have persevered, overcoming many challenges to stay on course and to stay true to its mission of harnessing the power of life sciences with discoveries that positively impact lives and societies.

TLL and its people should be proud of having done and for continuing to do good work. Whether it be innovative solutions in nutrition security, advances in knowledge in bio-molecular sciences, or enabling practicable solutions contributing to sustainability, resilience and well-being of our society and beyond, TLL seeks through its work to be always a catalyst for a better world.

It is a world that has become much more complex than ever before, faced with rapidly growing global challenges, critical and urgent. I think the best bet for success in such a world is greater synergistic

collaboration which can bridge and tap holistically the value of diversity of research in different knowledge fields as well as that of the world of operating industry and day-to-day practitioners.

Scientists and researchers including all in TLL have their work cut out for them for much remains to be done and needs to be done. I was reminded recently that someone had once said, “One thing I have learned in a long life: that all our science, measured against reality, is primitive and childlike — and yet it is the most precious thing we have.” That someone was Albert Einstein. Indeed many believe that looking to nature is a good way to go, for it remains the most fertile source for crucial discoveries and inspired sustainable solutions to come.

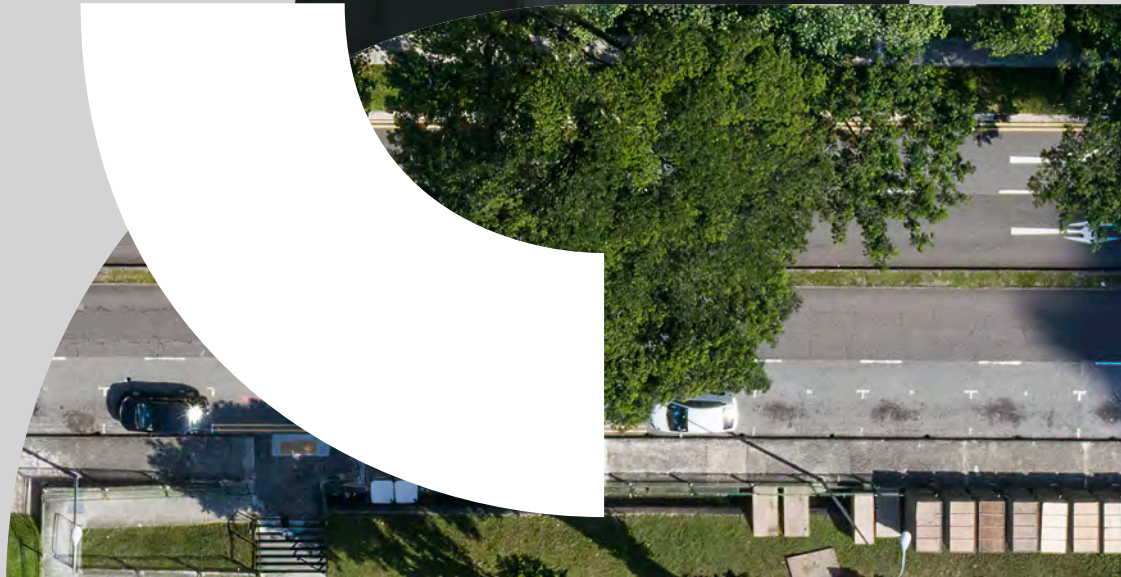
I wish to thank all TLL staff and scientists, past and present, for their dedication and for having faithfully travelled the TLL journey together. I know that I speak for my fellow Board members when I say that we look forward to working with all of you to make TLL a great place to work, to undertake the kind of research that will impact the lives of all for the better.

Benny Lim
Mr Benny Lim
Chairman



Mr Peter Chia

CEO's *Message*



TLL carries out cutting-edge research in important life sciences domains using the methods of genetics, genomics, molecular biology, cell biology, biochemistry, structural biology, and biophysical modelling.

Our research teams hope to understand, at the cellular and organismal levels, the workings of viruses, bacteria, yeast, fungi, plants and animals so as to unravel biological questions that may lead to outcomes that help to improve nutritional security and well-being of people in Singapore and around the world.

Key programs undertaken by TLL are focused on:

- Building up Singapore's life sciences research capabilities in the areas of plant and animal sciences through the training of post-doctorates, graduate students and interns.
- Contributing to the advancement in scientific knowledge through scientific publications in high impact peer reviewed journals and patent applications.
- Collaborating with Singapore's large and medium size enterprises and startup ecosystem to catalyse innovation in deep life sciences technology domains and the commercialisation of Intellectual Property (IP).
- Establishing partnerships with regulatory and development agencies to develop key urban solutions for Singapore and other urban centres.

In FY22, TLL key highlights include the following:

A. Building capabilities in aquaculture

- TLL was appointed as founding member of Aquapolis, together with the Singapore Food Agency (SFA) and National University of Singapore (NUS). A memorandum of understanding (MOU) between the parties and jointly with participating industry enterprises was inked in December 2022.
- Aqualita, a TLL spin-off company, is driving adoption of TLL's scalable urban RAS technologies for fish farming in Singapore and other South-East Asia geographies such as Indonesia. The urban RAS enables sustainable cultivation of fish under controlled conditions thereby eliminating environmental factors such as toxic algae blooms and sea pollution. TLL scientists are also developing microbial processes, nutrient recycling processes and disinfection methods to complement this urban RAS solution.
- **Aquafeed research**
TLL scientists, in collaboration with other institutions, are developing a platform to convert food waste into microbial protein which can then be used for aqua-feed production in a sustainable and cost-effective manner.
- **Disease detection in aquaculture**
TLL scientists are developing a platform that will enable early detection of disease in aquaculture enterprises. The platform will be built on DNA-based assays, integrated with environmental parameters, to measure the level of pathogens or parasites in fish farms. As the aquaculture sector continues to expand space, such a platform will allow aqua-farmers to better manage disease risks and minimise the risk of economic loss.
- **Vaccines against fish-borne viruses**
TLL scientists aim to develop vaccines against major fish-borne viral diseases. The vaccines are particularly important for Singapore's aquaculture sector which deploys high intensity fish farming practices. Such successful vaccine development strategies could bring about long term economic and societal benefits for Singapore, by increasing the sustainability of the country's fish farming industries.

B. Building capabilities in precision agriculture and urban farming

• **Disruptive, Sustainable Technologies for Agricultural Precision (DiSTAP)**

TLL successfully secured \$20 million in funding for the second phase of the DiSTAP programme this year. The programme brings together Massachusetts Institute of Technology MIT's expertise in nanosensor development, optical sensor fabrication, microbial engineering and biosynthesis with the TLL's expertise in plant engineering and gene discovery, Nanyang Technological University (NTU)'s expertise in polymer synthesis, and NUS's expertise in protein engineering and microbial engineering.

• **High Performance Precision Agriculture (HiPPA) System**

In collaboration with Singapore's Agency for Science, Technology and Research (A*STAR) and NUS, TLL is developing capabilities that will enable full automation of farm operations for high-throughput and comprehensive plants-to-agronomics screening platforms to maximise crop production. These capabilities would include robotic manipulation of growing plants and the feedback environmental control with crop diagnosis systems. The use of robotics, optical sensors and artificial intelligence (AI) will present a feasible means towards a sustainable food-production system with minimum human workforce.

• **Optimisation of lighting recipes for vegetable production**

In support of efforts to increase local production of leafy vegetables through vertical farming and hydroponics cultivation, TLL scientists are developing guidelines for light quality and quantity to facilitate optimal growth of leafy vegetables with high nutritional values. The scientists received the Innovative Project/Policy Bronze Award from the Singapore Ministry of Trade & Industry in April 2022.

• **Reducing methane emissions from rice production**

TLL secured funding from Temasek Foundation to develop options to mitigate methane emissions from rice production. TLL is partnering with Rivulis, a global leader in agricultural irrigation, to improve rice yields and reduce water usage while at the same time, reduce emission of this harmful greenhouse gas in the cultivation of this staple food.

C. Bio-based platforms for mosquito vector control

- TLL scientists have been developing alternative bio-safe compounds for use as mosquito repellents. These plant-derived natural compounds are expected to be safer and more effective than commercially available chemical or synthetic repellents in the market today. As the technology has significant commercial potential, TLL is exploring spinning it off as a separate commercial entity.
- TLL scientists also work with Environmental Health Institute (EHI)/National Environment Agency (NEA) to generate Wolbachia-infected *Aedes aegypti* (Singapore) strains for the on-going "Project Wolbachia - Singapore". This will help to reduce the local *Aedes aegypti* mosquito population as well as the incidence of mosquito-borne diseases, such as dengue fever.

D. Rapid response to and research capabilities for infectious zoonotic diseases

- With its strong capabilities in emerging infectious zoonotic diseases, bio-risk management and BSL-3 facilities, TLL is leading the development of needed capabilities for fast and reliable diagnosis and treatment of pathogenic or infectious diseases such as COVID-19. As part of Singapore's efforts to ensure pandemic-readiness, TLL's BSL-3 laboratories will serve as standby testing facilities for the National Environment Agency.



**We aim to continue
inventing, innovating
and investing
to improve lives
through science –
for planet, people,
peace and progress.**

Financial performance

During the year, TLL received \$25 million in donations from the philanthropic endowment of Temasek Trust, aimed at the advancement of science, technology, engineering and mathematics (STEM).

For specific research programmes, TLL relies on grants from public and private sector entities including the National Research Foundation (NRF), the Singapore MIT Alliance for Research and Technology (SMART), SFA and the NEA. Total grants secured during the year amounted to \$22 million, to be deployed over the next one to five years.

In efforts to mitigate rising costs of operations, TLL has been developing new sources of funding, such as licensing of our intellectual property (IP) as well as offering research and support services to the life sciences ecosystem in Singapore.

In the current financial year, TLL received more than \$2.8 million in revenue and other income. In addition to monetising our IP and capabilities, these efforts will enable us to build on our current understanding of the ecosystem and guide our decisions going forward.

TLL ended the year with an operating surplus of \$1.6 million reflecting the fiscal prudence exercised in the management of TLL's activities and operations. We continue to exercise prudence in our spending, in an effort to preserve and strengthen TLL's financial position.

Peter Chia

Mr Peter Chia
Chief Executive Officer

Think Big Case Studies



CASE STUDY #1

Rice *for Life*

A strong, high-yielding, and more resilient strain of rice aims to answer long-term food security for the world's consumers and address climate change at the same time. Rice is the most widely consumed staple food for more than half the world's population. Yet its very cultivation is threatened by disease as well as environmental stressors that have become increasingly problematic with climate change.

TLL's rice research programme is focused on finding innovative solutions to combat these threats to global rice production and food security. At the heart of our research is a study of how rice plants deal with stressors at the molecular level, and how we can develop better rice strains by boosting their natural defence mechanisms.

Challenges on Rice Production



Rice Bacterial
Blight



Rice Blast



Heavy metal
contamination

Threats due to Climate Change



Drought



Heat wave



Flooding impact

Development of Temasek Rice

The use of genomic and marker-assisted breeding technologies have sped up development of new and improved rice varieties. TLL has created Temasek Rice, an elite rice grain, which is a culmination of two decades of research by a team of researchers, bringing together molecular genetics, molecular biology, plant pathology, marker-assisted breeding, and innovations. Temasek Rice is high-yielding rice variety that is resistant to bacterial and fungal diseases and has high tolerance to environmental stressors. This can help ensure more consistent rice yields, contributing to longer-term nutritional security for the region. What's more, the rice is more fragrant and boasts high dietary fibre which provides added health benefits for its consumers.



Gaps



Rice production is one of the largest sources of methane emissions. Methane is a potent greenhouse gas with an estimated 80 times the warming power of carbon dioxide over the first 20 years of its release to the atmosphere. Methane is released when rice fields and terraces are flooded to suppress weed growth. Unfortunately, this waterlogging also prevents oxygen from penetrating the soil, creating ideal conditions for the growth of methanogenic bacteria that emits methane gas.

Furthermore, the rice plant has a tendency to accumulate heavy metals compared to other cereal crops. Arsenic and cadmium are two toxic metals that have a relatively high propensity of transfer from paddy soil to rice grains. Long-term exposure to these metals can pose non-carcinogenic and carcinogenic health risks to the human population.



Social Objective

Betterment and empowerment of rural, small-scale farmers' livelihoods



Climate impact

Reduced methane emissions and conservation of water resources

As part of its climate management efforts, TLL scientists have also been working with regional partners, such as Rivulis, a global leader in the irrigation industry. Through this partnership, TLL has been developing an integrated drip irrigation solution to mitigate methane emissions from rice production by restricting methane producing bacteria (methanogens) growth and promoting methane oxidising bacteria (methanotrophs) growth using chemicals and microbes and water management technologies, leading to more sustainable rice production.

Intervention

Despite the promise of new farming techniques, there are many practical challenges, lack of knowledge transfer, insufficient financial support, and limited incentives to encourage farmers to pivot toward more sustainable practices and low-carbon technologies.

Desirable agronomic traits from TLL's research to combat threats brought about by global environmental changes:



- Fragrance ✓
- Submerge tolerance ✓
- Drought tolerance ✓

- Semi-Dwarf ✓
- Bacterial blight resistance ✓
- Fungal blast resistance ✓



TLL's Bio-based Solutions

- Agronomy- and chemical-based means to reduce methane emission
- Reduce/inhibit methanogens and promote methanotrophs growth
- Improve rice lines to increase yield and withstand stresses

Rivulis's Drip Irrigation System

- Reduce labour, water and fertiliser use
- Develop technology to grow rice in different terrains
- Improve irrigation decisions via Rivulis' Manna system through satellite monitoring and AI models
- TLL is also developing new rice cultivars which aims to limit the accumulation of arsenic and cadmium in the rice grain. Scientists achieved this by introducing specific genes into the rice plant, which helped to enhance the sequestration of toxic elements in vegetative tissues and therefore reduce arsenic and cadmium allocation to the grain, providing healthy and safe rice for consumers.

Outcomes & Impact



Temasek Rice is an elite, high-yielding aromatic rice variety that is high in dietary fibre, resistant to bacterial and fungal diseases, more resilient to environmental stressors and healthier for consumers.

Given the importance of the staple food crop, efforts are underway at TLL to develop low carbon rice production principles as well as rice cultivars that minimise the accumulation of heavy metals in the rice grain. Such efforts will lead to more sustainable rice production, healthier consumers as well as improvements in livelihoods of rice farmers.

CASE STUDY #2

Jatropha

Wild *Jatropha* plants could soon revolutionise the bio-energy market, while being wholly aligned with several key UN Sustainable Development Goals, potentially making them the crop of the future.



The hardy plant, able to survive in semi-arid conditions, can be cultivated at scale to produce novel bioproducts including bio-diesel, bio-glue and bio-plastics. Because of continuing recognition of its value, impoverished farming communities that cultivate it as a crop are also experiencing a rise in their socio-economic status.

TLL-led research and development efforts to domesticate wild *Jatropha* plants are accelerating their advancement as an industrial crop. Traditional breeding methods have yielded new hybrids with enhanced traits — higher seed yield, increased oil-content potential, and improved stress tolerance — to name a few.

What's more, large swathes of plantations of this crop can serve as natural carbon sinks, becoming a key enabler in reforestation efforts. That's because every plant naturally removes carbon dioxide from the atmosphere and stores it — a process of carbon sequestration — which can help mitigate the effects of global warming.

Biodiesel derived from *Jatropha* is known for its environmentally friendly characteristics. Being biodegradable and renewable has made it a preferable alternative to petro-diesel.

JOil (S) Pte Ltd was established in 2008 by TLL with its partners to scale up the industrial farming of *Jatropha*.

Its potential extends to cultivation in marginal, less fertile lands, because its resilient nature makes it an ideal crop even in areas that are hostile to agriculture. A nascent plantation has been established in Ghana, Africa, where it is farmed for biodiesel, among other things.

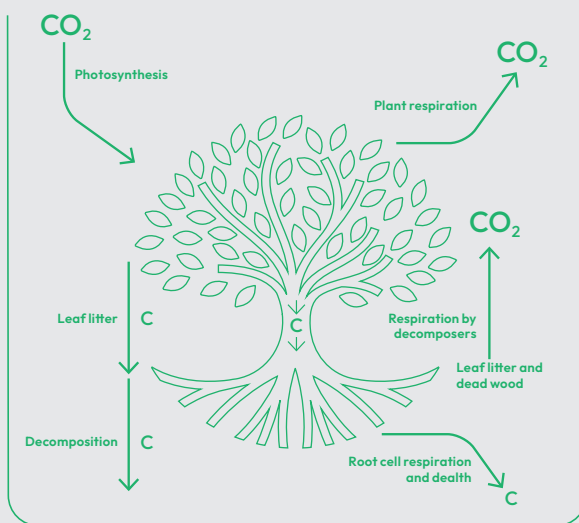


Gaps

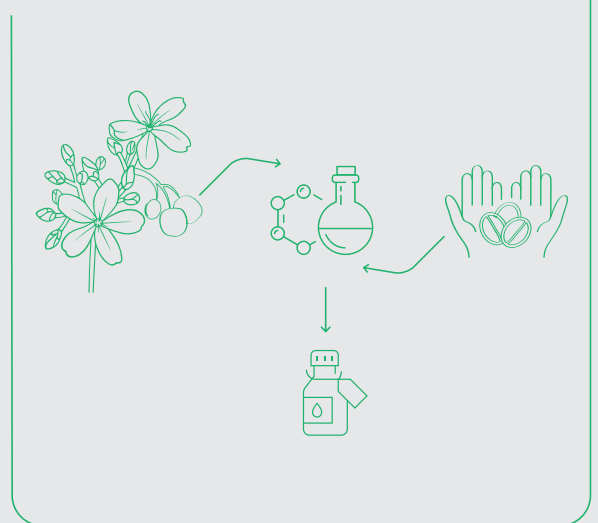
Currently, over 35% of the world's land surface is considered to be arid or semi-arid, receiving precipitation that is inadequate for most agricultural uses.

But JOil's *Jatropha* plants are drought-tolerant, and well adapted to arid and semi-arid climate conditions. The *Jatropha* plant has strong control over transpirational water loss by reducing both stomatal conductance and biomass from its aerial parts. This helps the plant to resist drought conditions.

Carbon Sequestration Process



Jatropha Oil Extraction



Jatropha can augment renewable energy sources. The bio-diesel produced from *Jatropha* is eco-friendly fuel, bio-degradable, renewable and non-toxic in nature compared to petro-diesel. In addition, bio-resin can be produced from crude *Jatropha* oil.



Intervention



With Jatropha plantations forming a natural carbon sink, JOil can further monetise the crop’s ability for carbon sequestration through carbon credit markets.

Nucleus plantations planted until 2018 amount to a total of 1,300 Ha, of which 1,000 Ha have been assessed for carbon sequestration by the South Pole under the Afforestation, Reforestation, and Revegetation (“ARR”) project.

In fact, this crop’s industrialisation is a fully sustainable solution directly aligned with several UN Sustainable Development Goals including climate action, responsible production and consumption, as well as reduced inequalities.

Additionally, JOil has successfully developed a genetically modified (GM) variety of Jatropha with a high oleic acid content, which enhances the cold flow properties of the biodiesel. Extensive trials of this GM variety have been conducted in Singapore, and have received approval for commercial release.

Furthermore, Jatropha has been utilised in the production of innovative bioproducts such as bioglue and bioplastics, diversifying its potential applications beyond biodiesel.

Ultimately, carbon offset helps balance greenhouse gas emissions among parties, with a financial reward for the landowner storing the carbon. Banking on the prospect of getting more communities to farm Jatropha in order to augment renewable energy sources, JOil was incorporated in 2008 to maximise the development of the Jatropha value chain.

AENOR (a body for environmental certificates, validations, and verifications) completed the verification and validation in November 2021. Project design documents have been submitted to Gold Standard (GS) and Verified Emission Reduction (VER) credits of 18,752 tCO₂e were issued in February 2022.

Demand for carbon dioxide removal (CDR) credits have increased, with prices expected to pick up.



Nucleus plantations planted in 2018 and the proposed planting area in FY 22/23 (totalling ~1,000 Ha and ~3,400 Ha respectively), have been assessed for carbon removal by South Pole as an Afforestation, Reforestation, and Revegetation (“ARR”) project.



AENOR has completed the verification and validation in November 2021. Project design document has been submitted to Gold Standard for review.



Verified emission reduction (VER) credits expected for 2019 & 2020 at 12,000 tCO₂e in January 2022.



Demand for carbon dioxide removal (CDR) credits has picked up and expected prices are attractive.



Outcomes & Impact

From the energy perspective, JOil has received interest from Oil & Gas Companies & Bio-Refiners. Advanced biofuels, such as those from Jatropha, now trade at significantly higher prices, meeting high European standards for sustainability.

Manufacturers are also interested in Jatropha bio-resin, which can replace harmful urea formaldehyde, and reduce the overall volume of materials used in the resin. A number of large European companies have been conducting industrial trials for these resins.

What's more, work with Jatropha plants has led to land remediation. Crops have been used to provide green cover to marginal/arid lands, yield fruits/seeds that can be used to produce high quality plant-based fuel and proteins for bio-resins, and at the same time, remediate degraded soil and provide employment to local communities to alleviate poverty.



Potential Interest from the Industry for the Jatropha Products

Interest from Oil & Gas Companies and Bio-Refiners

Advanced biofuels such as those from Jatropha trade at significantly higher prices and are more sustainable.

Interest from Manufacturers

Jatropha bio-resin replaces harmful urea-formaldehyde and reduces overall volume of materials used in the resin.

Continuing Efforts To Scale Impact

As an added benefit, JOil discovered that after a few seasons, the marginal lands, on which the Jatropha plants were cultivated, became more arable after several seasons.

This has allowed intercropping (i.e. growing of two or more crops in proximity) of Jatropha with groundnut, cowpea, soybean, sesame, and sunflower plants, yielding good production results. The farmers as well as the larger community have benefited through higher incomes as well as growing availability of food crops.

JOil is seeking to raise new funds and work with partners to expand its plantation activities, going further downstream to further industrialise this incredible crop.

CASE STUDY #3

Building capabilities in precision *agriculture* and *urban farming*

TLL has several programmes that are aligned with the '30 by 30' goal. In 2019, Singapore set the '30 by 30' goal to expand, in a sustainable way, the nation's agri-food capabilities and capacity to produce 30% of our nutritional needs, by 2030. On the agriculture and urban farming front, TLL has two projects working towards this goal: the Disruptive, Sustainable Technologies for Agricultural Precision (DiSTAP) and the High Performance Precision Agriculture (HiPPA) projects.

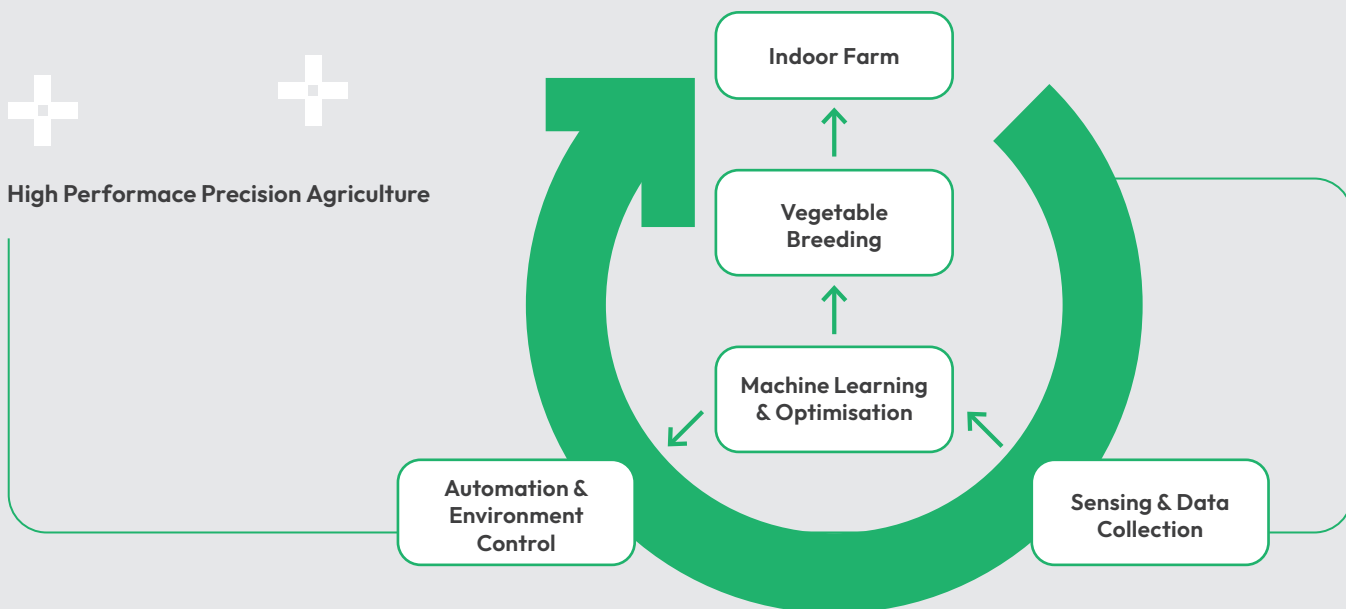
Over the last 20 years, TLL has built a strong position in the field of plant and agricultural sciences. DiSTAP and HiPPA places TLL at the forefront of Singapore's efforts to build expertise in the fields of precision agriculture and urban farming. These projects are multidisciplinary and involves the Singapore-MIT Alliance for Research and Technology ("SMART"), National University of Singapore (NUS), and various institutions from the Agency for Science, Technology and Research (A*STAR). Many companies have either contributed or expressed interest in these projects. The high level of industry engagement is a testament to the relevance of these projects.

The DiSTAP project aims to gather real-time information about plant health and resource efficiency through non-destructive monitoring of endogenous signalling molecules and plant hormones, the program explores the development of next generation real-time, field deployable analytical tools and approaches. DiSTAP is a joint project between TLL and one of the of five Interdisciplinary Research Groups in SMART.

The HiPPA project aims to develop a comprehensive solution to maximise value-to-cost for high-tech indoor farming by integrating molecular breeding, new non-invasive sensors, rapid optimisation of environmental parameters and artificial intelligence. It is conducted in partnership with Singapore's Agency for Science, Technology and Research (A*STAR) and NUS.



High Performace Precision Agriculture



Gaps

The world population continues to grow, so we need to increase global food production, in an environment that is threatened by climate change. Thus, increases in farm productivity must be both climate-resilient and environmentally sustainable. To do so, we need to develop new technologies to increase crop yields while simultaneously lowering input costs (e.g. land footprint, water and energy usage, types and amounts of fertiliser, herbicides, insecticides, labour optimisation).

It is often too late for the farmer to intervene when their crops start to show visible signs of stress. Thus, it is vital to develop non-invasive diagnostic tools that can tell farmers if their crops are experiencing stress (e.g. disease) before symptoms are visible. This gives farmers an opportunity to act before irreversible plant damage occurs. It also allows them to use their resources more surgically – intervening only for the affected plants and at the precise time they need to. More importantly, these new technologies must be translated while keeping the farmer in mind, so that we may see widespread adoption across farms, in Singapore and the rest of the world.

Intervention

The HiPPA facility has been set up on TLL's premises. It is equipped with a highly comprehensive precision agriculture monitoring and management system, which forms a high-throughput and competent plants-to-agronomics research and screening platform. We are working closely with multiple A*STAR research institutes, NUS, and industry partners, to bring advanced technologies in plant biology, robotics, sensors, and artificial intelligence, into this platform. The HiPPA facility will serve as a testbed for the non-destructive approaches developed through the DiSTAP project, creating a synergy between them. In concert with MIT (through SMART), new computational tools will be developed, linking the analytical methods to the newly developed instruments.

Outcomes & Impact

The DiSTAP and HiPPA projects will develop important technologies to enable farmers to be more productive in both traditional field settings and the urban/vertical farms of the future. It takes into consideration that farmers will have to operate in environments that are threatened by climate change, which necessitate methods that optimise land usage, while minimising energy and water input. It will help farmers make farming-related decisions more precisely, allowing them to intervene only when and where they need to. This will have significant impact for urban farming in Singapore, which can also be adopted by other farmers globally.

Continuing Efforts

HiPPA and DiSTAP are both on-going projects. HiPPA has established many collaborative projects with industry and DiSTAP has successfully embarked on a follow-up Phase 2 in 2023, lasting an additional 5 years.