



SYNTHETIC BIOLOGY OPPORTUNITIES IN FASHION AND FOOD

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Executive Summary

In this report, we look into Synthetic Biology, a new discipline within modern biotechnology. It aims to precisely **design and redesign new and existing biological systems**, allowing the creation of products with specific, customized functions. Just like the emergence of the Internet, it is seen as **a disruptive technology**, paving the way for endless new innovations in the coming decades.

Environmental issues brought about by climate change is driving both fashion and food industries to search for innovative solutions. With the help of synbio, both industries are starting to adopt **new sustainable material alternatives**, e.g. bio-synthetics and cell-based meat. Though promising, many synbio innovations are in early stages of commercialization.

With reference to case studies and examples of **successful corporate-startup partnerships**, we believe corporates and synbio startups should join forces to help accelerate the adoption and development of synbio innovations.

Executive Summary

The Emergence of Synbio

We explain how synbio works, and the underlying technologies that enable its growth. Three key drivers are identified, contributing to the synbio boom – this includes lowered gene sequencing cost, gene editing tools like CRISPR & machine learning to digitize biology.

Innovation Trends in Fashion & Food

We deep dive into synbio applications in the fashion & food industry, discussing how sustainability issues are addressed in the following categories:

- Fashion: New materials, textile processing
- Food: Agriculture, food additives & ingredients, alternative proteins

Building Impactful Collaborations

We discuss the synergies and value created by corporate-startup collaborations. We also look into the key steps involved in forming an impactful partnership, highlighting tips and successful examples.

The Emergence of Synbio

From past to future

Technology wave

The Emergence of Synbio

Innovations have always come in waves, enabled by new underlying technology platforms; Synbio will be key tech enabler for the coming decade.

1940s
Petrochemicals
Enables wider range of manufacturing production



Fabrics & dyes Detergents





Plastics Tyres

ExxonMobil
Chemical

DUPONT

BASF
We create chemistry

1990s
Internet
Enables faster and cheaper telecommunications



Web browser Cloud computing





Wireless network E-commerce

amazon



Google

Microsoft

Future
Synbio
Enables creation of products with enhanced performance & personalization



Removal of allergens Vaccines



Lab-grown meat Sustainable biofuels & materials

IMPOSSIBLE

TWIST
BIOSCIENCE

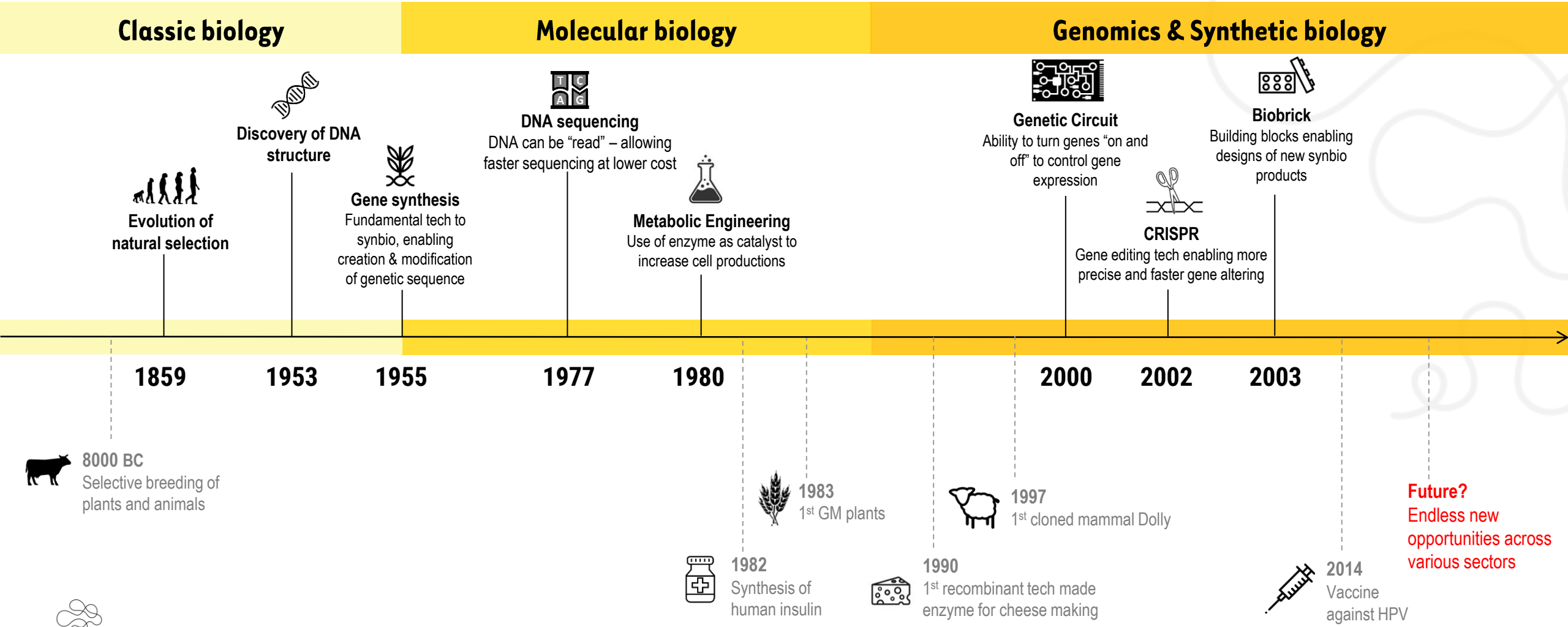
CRISPR
THERAPEUTICS

Origin of synbio

The Emergence of Synbio

Biotech has evolved from discovery & synthesis initially to the ability to engineer biology.

—— Biotech discovery
----- Biotech usage



Synbio explained

The Emergence of Synbio

Similar to computer technology, synthetic biology is about programming and engineering living cells to achieve target outputs.

How Computer Technology works



Programming language is written in sequences of **1s and 0s**



Computer programmers write codes with numbers to create specific computer software



Written computer codes are **run in a computer** to perform specified tasks/ functions

How Synthetic Biology works

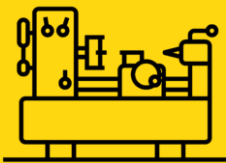


Genes and genomes are made of DNA, which contains 4 basic building blocks (Represented by **letters A, T, G, C**)

The sequence of these letters forms unique genetic traits.



Scientists can copy/ alter DNA sequence from an existing organism in nature, or create a **novel one** to obtain desirable traits



Machine: DNA synthesizer

Synthetic DNA is created using the written sequences



DNA program is put into and **run in a cell** or organism – ranging from a bacteria to an animal/ plant

Synbio overview

The Emergence of Synbio

Synbio as a subset of wider technologies underlying biotechnology.

Synbio enablers

Traditional biotech

Use of **natural** living organisms to create or modify products for better human use

- Breeding of animals & crops
- Cheese & wine fermentation

Genetic engineering

Foundation to biotech that involves **direct manipulation** of genetic information in cells to **alter traits** of living organisms

Process

- New DNA isolated/ copied from genetic material of interest
- Isolated DNA inserted into host organism to produce an improved/ novel organism



Modern biotechnology

Manipulation of genes and cells to produce organisms with desirable new traits

Synthetic biology

Unlike genetic engineering which introduces only small changes to a system, synbio aims to **precisely design and redesign new/ existing biological system** at a bigger scale, to create products with specific functions

Fermentation

A chemical process where organic substances, usually sugar, are broken down by a microbe, producing target ingredients

Traditional fermentation - Typically used in food for pasteurization and sterilization purposes, e.g. cheese making, pickled food

Precision fermentation - Advanced tech that combines gene editing & fermentation

- Enables making of more specific, customized molecules from engineered microbes



Acellular production

Cells/ Microbes (e.g. yeast, bacteria) are used as a “factory” to produce ingredients/ proteins

Precision fermentation

Use gene-edited microbes to produce desired molecules



End products: Wide range of molecules, e.g. proteins, enzymes, fats, to be used as ingredients for food, textiles & more



Others

Use stem cells to express target products

End product: Cultured milk



Cellular Agriculture




The use of microbes/ cells to culture a biological replica of animal-based products in lab

- 2 production methods: Acellular, cellular

Cellular production

Grow proteins, muscles or fats directly from cells (typically stem cells) in lab. The cells will then be used to form the basis of the products themselves

End products: Cultured meat, lab-grown leather, lab-grown cellulose, artificial organs



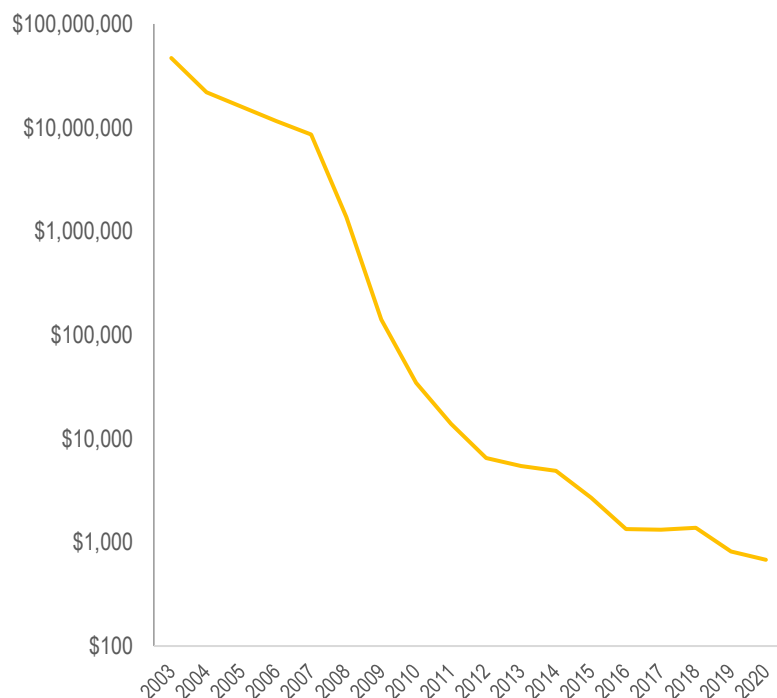
Synbio, a new discipline within modern biotech, combines math, computing, biology & chemistry

The Emergence of Synbio

The boom in synbio is enabled by decreasing sequencing costs, CRISPR & computational bio.

1

Lowered DNA/ gene sequencing costs



2

CRISPR as a fast, cheap & accurate genome editing tool

CRISPR/Cas9, short for CRISPR, is a gene-editing technology that enables precise gene traits to be modified or removed in any animals and plants

- Undesirable and desirable traits can now be added and deleted, increasing the potential to create many more value-added products

Key process in CRISPR tech

- Guide RNA** is used to identify the targeted gene
- CRISPR/Cas9** acts as a scissor to cut out the undesired DNA located
- Desired DNA** piece is inserted to replace the clipped section

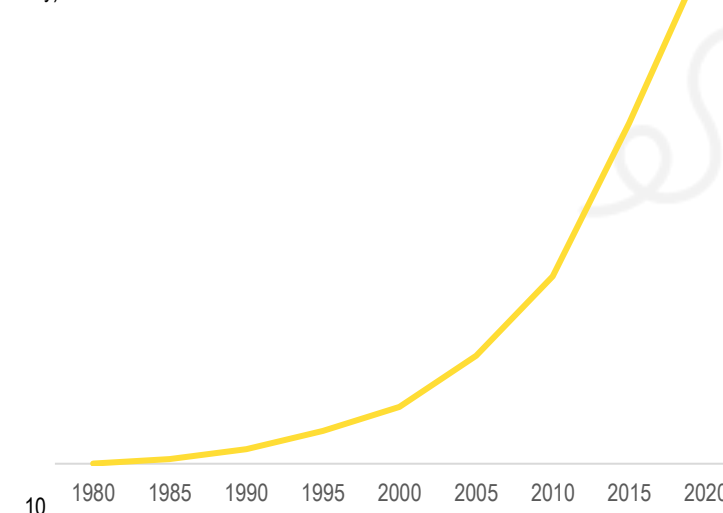
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Advances in machine learning enable faster gene sequencing & data analysis

Machine learning enables large sets of DNA sequence data to be analysed, allowing valuable biological information to be generated accurately & quickly

Speed of sequencing

100 billion
(Kb/ day)



Synbio market

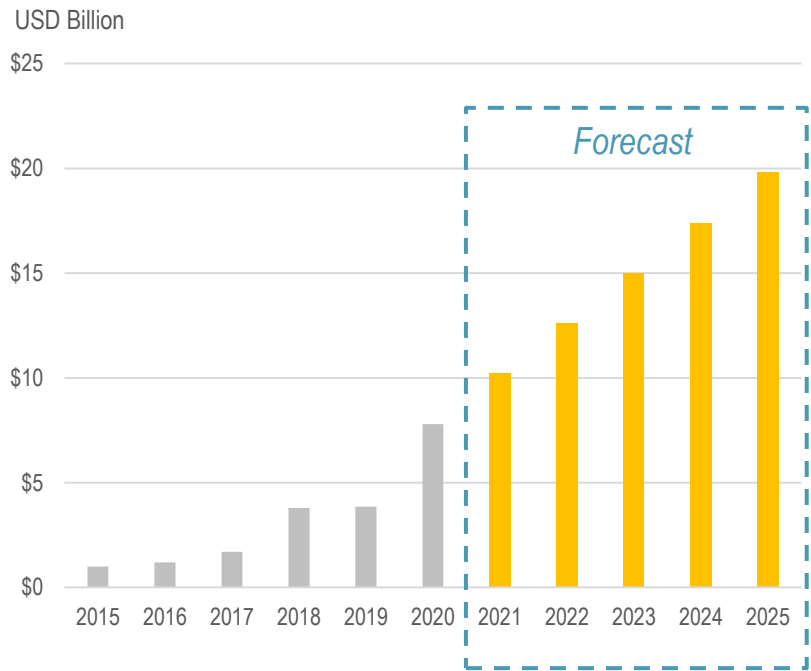
The Emergence of Synbio

High potential growth with prominent development across ag & food sectors.

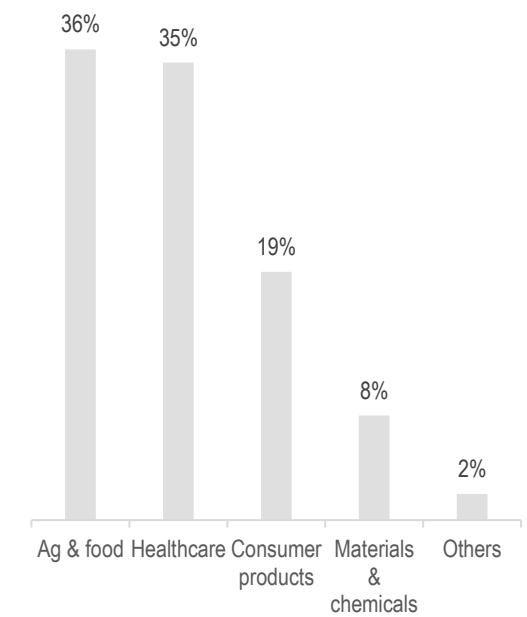
Synbio funding reaching a new record of ~ \$8B USD in 2020; Projected to grow at ~24% CAGR to 2025

Synbio breakthroughs have led to a proliferation of synbio startups across various sectors

Global Synthetic Biology Market



Estimated potential economic impact on various sectors



Food & Beverages



Agriculture



Biofuel & Industrial



Apparel & Fashion



GM Platforms, DNA & RNA Synthesis & Software



Healthcare



Innovation Trends in Fashion & Food

From materials to consumables

Synbio in fashion

Innovation Trends in Fashion & Food

NEW MATERIALS

Precursor materials	Bio-synthetics	Protein-based materials	Cell-based materials
<div>LanzaTech</div> <div>ZYMOCHEM</div>	<div> <div>MYCO WORKS</div> <div>genomatica</div> <div>Modern Meadow</div> <div>MANGO MATERIALS</div> <div>AlgiKnit</div> <div>Algaeing</div> <div>ECOVATIVE DESIGN</div> <div>modern synthesis</div> </div>	<div> <div>AMSilk</div> <div>Spiber</div> <div>Kraig Biocraft Laboratories</div> <div>The Future is Made in the Laboratory</div> <div>BOLT THREADS</div> <div>Spintex</div> </div>	<div> <div>VitroLabs Inc</div> <div>PROVENANCE</div> <div>Gali</div> </div>

TEXTILE PROCESSING

Pre-treatment agents	Dyes & pigments	Finishing coatings
<div>AVCO CHEMICALS</div> <div>novozymes</div>	<div> <div>Pili</div> <div>LIVING COLOUR</div> <div>Algaeing</div> <div>huue</div> <div>ColoriFix</div> </div>	<div>CHECKERSPOT</div>

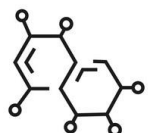
Innovation Trends in Fashion & Food

Reducing fossil fuel dependency through the development of novel precursors and biomaterials. Bio-synthetics, in particular has shown promising potentials & is already used in wide range of textile products.

PROBLEMS

- 60% of textile fibers are **synthetics** (polyester, nylon & acrylic) made from fossil fuels
 - Production is energy-intensive with high GHG emission
 - Non-biodegradable
 - Introduces plastics into the ocean as they release microfibers into the water when being washed
- **Biodegradable materials from renewable sources** present great potentials to reduce fossil fuel reliance and greenhouse gas emission

INNOVATIONS



Precursor materials

Commodity chemicals (typically ethanol) are used as building blocks to manufacture range of products, e.g. biofuels, textile materials

These chemicals can be produced sustainably using renewable feedstock such as:

- Waste gases, e.g. carbon dioxide, carbon monoxide
- Carbon & biomass-derived substrates

Textile materials

Bio-synthetics

e.g. Bio-polyesters, bio-nylon, mycelium leather

Polymers made wholly or partially from biological sources, e.g.

- **1st gen:** Crops (e.g. corn, sugar cane, wheat)
- **2nd gen:** Agricultural waste
- **3rd gen:** Microorganisms (from algae, fungi, bacteria, yeast)

These feedstocks usually undergo fermentation/ chemical process that break them down into polymers. The polymers are then spun & woven into fabric.

Protein-based

Synthetic spider silk

Editing and transferring silk-producing genes to host organisms, e.g. bacteria/ fungi, to mass produce spider silk proteins

Cell-based

Lab-grown leather, lab-grown cellulose

Using tissue engineering technology to grow materials from cells in lab

Innovation Trends in Fashion & Food

Synbio opens up more options for chemical-free dyes and agents with similar or even advanced properties. Below are 3 key synbio applications in textile processing.

PROBLEMS

- 20% of global industrial water pollution is attributable to the toxic chemicals & heavy metals from **dyeing and treatment of textile**
- The cost of filtering waste water is high. As a result, over three-quarters of water consumed by dye mills end up as undrinkable waste
- Replacing use of hazardous chemicals with **bio-synthesized dye/ finishing agents** can effectively reduce water pollution issues

INNOVATIONS



Pre-treatment

Starch-degrading enzymes

Enzymes are used to *replace conventional chemical de-sizing agents*, e.g. acid, alkali, oxidizing agents

- De-sizing is a pre-treatment process before bleaching/ dyeing
- Enzymes offer advantages of better quality control with less water usage



Dyeing

Bio-synthesized dyes

Production typically involves fermentation using 2 main categories of feedstocks

Engineered microorganisms (e.g. algae, bacteria, fungi) – Using cells to produce & deposit pigments into fiber

- Significantly lowers water & energy usage

Molecules converted from renewable sources – Biological enzymes are used to convert carbon into molecules that produce dyes

- Effectively reduces waste & by-products



Finishing





Bio-based hydrophobic coating

Engineering micro-algae to produce bio-based oils



- Finishing in athletic wear with hydrophobic (water-repellent) properties
- Replacement for toxic fluorinated coating

Innovation Trends in Fashion & Food



AGRICULTURE

Plant breeding	Biopesticides & biofertilizers	Biosensors	Post-harvest treatments
			

FOOD ADDITIVES & INGREDIENTS

Colorants & sweeteners	Hypoallergenic ingredients
	

ALTERNATIVE PROTEINS

Recombinant proteins	Cultured meat
	

Innovation Trends in Fashion & Food

Key focuses on solving food security and supply issues without harming the environment; while synbio helps solve agricultural issues in 3 key areas as shown below.

PROBLEMS

- Agriculture brings massive harm to the environment
 - High greenhouse gas emission, e.g. methane from cattle & rice farms, nitrous oxide from fertilized fields
 - High water usage & pollutants
 - Accelerates biodiversity loss as forests are cleared for farms
- With the growing population and changing diets, current food production system is unable to satisfy the demand
- More **sustainable farming practices** are needed to **increase productivity** while ensuring **efficient resource usage**

INNOVATIONS



Plant breeding

Breeding of crops/ seeds with **improved traits** via synthesized genes & CRISPR gene editing

- Produce **new fruit & vegetable variants** with possibly better taste, higher yield, longer shelf life, simpler harvesting and more



Crop cultivation

Improve crop performances without chemical usage:

- **Biopesticides** are engineered to target specific pathogens without harming other species
- **Biofertilizers** contains engineered microbes which convert nitrogen into nutrients for crops
- **Biosensors** for soil & crop monitoring (detection of pathogens & contaminants)



Post-harvest

Treatments to **prolong shelf life** after harvesting

- **Biodegradable coatings**
- **Ethylene** (natural plant-ripening hormones) inhibitors, e.g. 1-MCP

Innovation Trends in Fashion & Food

Synbio helps minimize chemical usage & genetic modification in food products as synbio companies are actively exploring new options to develop better ingredients.

PROBLEMS

- Issues associated with current food products:
 - 70% of products contain **synthetic petroleum-based food dyes**, which are linked to allergies, hyperactivity, & even cancer
 - Sugar is associated with higher risks of diabetes, obesity & heart diseases
 - Conventional sugar substitutes, e.g. xylitol, are also harmful to health and have a bitter aftertaste
- With the **increase in consumer awareness** of health issues, there is a rising demand towards novel nature-based food additives & ingredients

INNOVATIONS



Bio-colorants

Replaces traditional chemical synthesis & natural plant extraction (where color molecules tend to be temperature and pH unstable):

- **High-performance, natural colorants** - using gene-editing technology, e.g. CRISPR, to engineer microbes that have the ability to secrete colors



Sugar substitutes

Develops better tasting, calorie-free sweeteners:

- Engineer Stevia (a natural sweetener) with no bitter aftertaste
- E.g. **Pure Reb-M** can be produced using yeast culture & sugar via fermentation
 - Reb-M is a super-sweet steviol glucosides in the stevia plant that is very rare & difficult to isolate



Hypoallergenic ingredients

Design food ingredients to eliminate allergenicity or to prevent triggering the immune system

- Allergen identification** - identify elements of proteins that trigger allergic responses with the help of AI
- Allergen removal** - Once recognized, these elements are altered or removed while maintaining the structure & overall traits of the proteins

Innovation Trends in Fashion & Food

Innovations are predicted to move mainstream mainly driven by health & sustainability. Below are 2 key tech in alternative protein production include precision fermentation & cell cultivation.

PROBLEMS

- Present livestock agricultural system is unsustainable due to resource demand and environmental impact
 - Livestock farming alone generates **18% total green house gas emissions**
 - To produce 1kg of beef requires **25kg of grain & 15,000L of water**
- Increased consumers' concerns about health and food safety
 - Intake of antibiotics through meat consumption
 - Food-borne illnesses, e.g. E. coli, salmonella, are often transmitted via meat contaminations
- Development of alternative proteins could satisfy consumer needs and take pressure off the environment from traditional livestock

INNOVATIONS



Recombinant proteins

Precision fermentation

- Recombinant DNA tech: Making of GM microbes
- Precision fermentation: GM microbes (e.g. bacteria, yeasts, fungi) produces desired proteins through fermentation
- End products: Protein isolates, e.g. dairy/ egg-white proteins, collagen



Cultured meat/ animal products

Cell cultivation

- Deriving starting cells: Isolate stem/ embryonic cells from sample animals
- Cell proliferation: Cells are put into culture media where they multiply
- Tissue perfusion: Cells differentiate into muscle, fat & connective tissues, and then scaffold into a desired structure
- End products: Whole piece of meat

Fashion vs Food

Innovation Trends in Fashion & Food

Synbio application in food industry is wider than that of fashion, with more active investment activities.

Sector	Selected synbio companies valued 100M+ USD
Fashion	<div> <div>LanzaTech</div> <div>Kraig Biocraft Laboratories The Future is Made in the Laboratory</div> <div> <div>genomatica</div> <div>BOLT THREADS</div> <div>PRECISION BIOSCIENCES</div> </div> <div> <div>Modern Meadow</div> <div>CHECKERSPOT</div> <div>Spiber</div> <div>MYCO</div> </div> </div>
Food	<div> <div>GINKGO BIOWORKS THE ORGANISM COMPANY</div> <div>MYCO TECHNOLOGY</div> </div> <div> <div>IMPOSSIBLE</div> <div>EVOLVA</div> <div>Fynd</div> </div> <div> <div>Apeel Sciences</div> <div>IMPOSSIBLE</div> <div>PIVOT BIO</div> </div> <div> <div>JUST</div> <div>amyris</div> <div>CALYSTA</div> </div> <div> <div>Perfect Day</div> <div>Geltor</div> <div>UPSIDE Foods</div> </div>

Comparison across sectors – 2 vital pillars within the lifestyle industry		
	Fashion	Food
Raw material source	Production of fiber, crops & livestock rely heavily on conventional farming industry → Competition for land & energy usage	
Sustainability challenge	Consumers often turn away from sustainable brands due to higher price points	
Environmental threats	Fast fashion trend increases disposal rate of clothing items, adding burden to the environment	Livestock farming requires extensive land for pasturing, leading to forestation
Future trends	In need of innovations to shift towards sustainable practices	
Regulatory restrictions	Lower	Higher
Margin/ cost	Higher margins, esp luxury products	Lower margins; more cost competitive
Go-to-market	Mostly self-contained	Can leverage 3 rd party distribution/ retailer
Nature of sector	More consolidated corporates	More fragmented market
Technology development	Relatively limited in terms of scope – clothing industry is dominated by 2 types of materials, cotton & polyester	Broader range of food & beverages, e.g. dairy, egg, meat

Building Impactful Collaborations

About synbio partnerships

Working with innovators

Building Impactful Collaborations

Collaborations bring synergies & value-add beyond what corporates & startups can achieve individually.

Rising number of pilots between corporates and innovators in recent years

New partnerships formed in 2021

Stella McCartney Debuts World's First 'Mylo' Bustier & Trousers With Bolt Threads's Mushroom Leather

H&M X Desserto: Fashion Giant Uses Mexican Startup's Cactus Leather In New Sustainable Collection

Business
BlueNalu Signs MOUs with Mitsubishi Corporation and Thai Union to Accelerate Market Development Strategy for Cell-Cultured

April 29, 2021, 4:30 AM GMT+8

Burger King's nationwide rollout of the Impossible Whopper starts next week

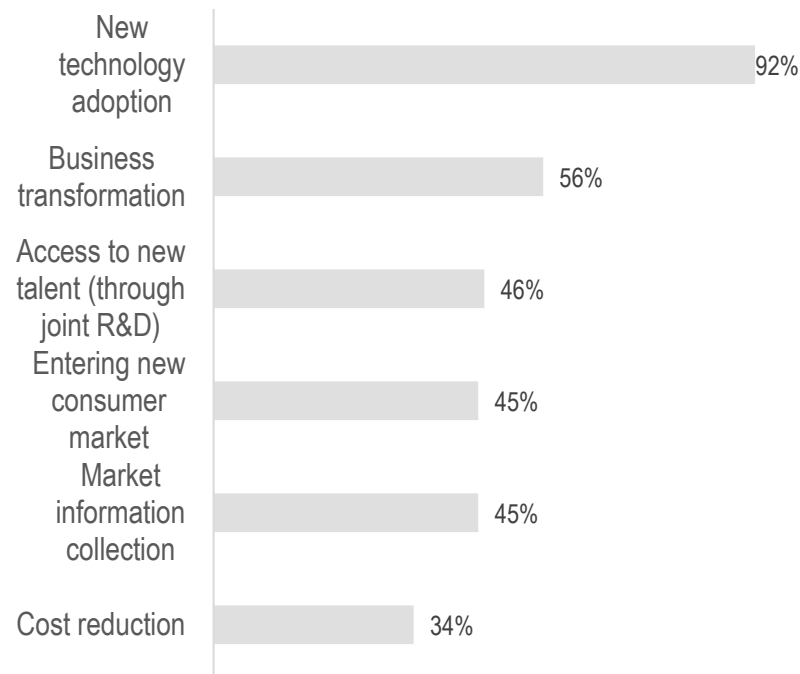
To more than 7,000 locations

By Ashley Carman | @ashleyrcarman | Aug 1, 2019, 5:08pm EDT

Clara Foods Launches World's First Animal-Free Pepsin With Global Giant Ingredient

Most corporates form pilots with startups to adopt/test new tech innovations

Reasons driving corporates to engage with startups



Pilots can be done in 2 general forms

i. Pilot launches: Working directly with an innovator to launch a product, where the corporate brings in their own supply chain partners to support production

An Exclusive Collaboration by Hermès and MycoWorks

HERMÈS
PARIS

X

MYCOWORKS

ii. Industry collaborations: Working with a consortium of brands or supply chain partners

MYLO™ TO BE INTRODUCED BY CONSORTIUM OF BIG NAME BRANDS

STELLA
McCartNEY

KERING

lululemon

adidas

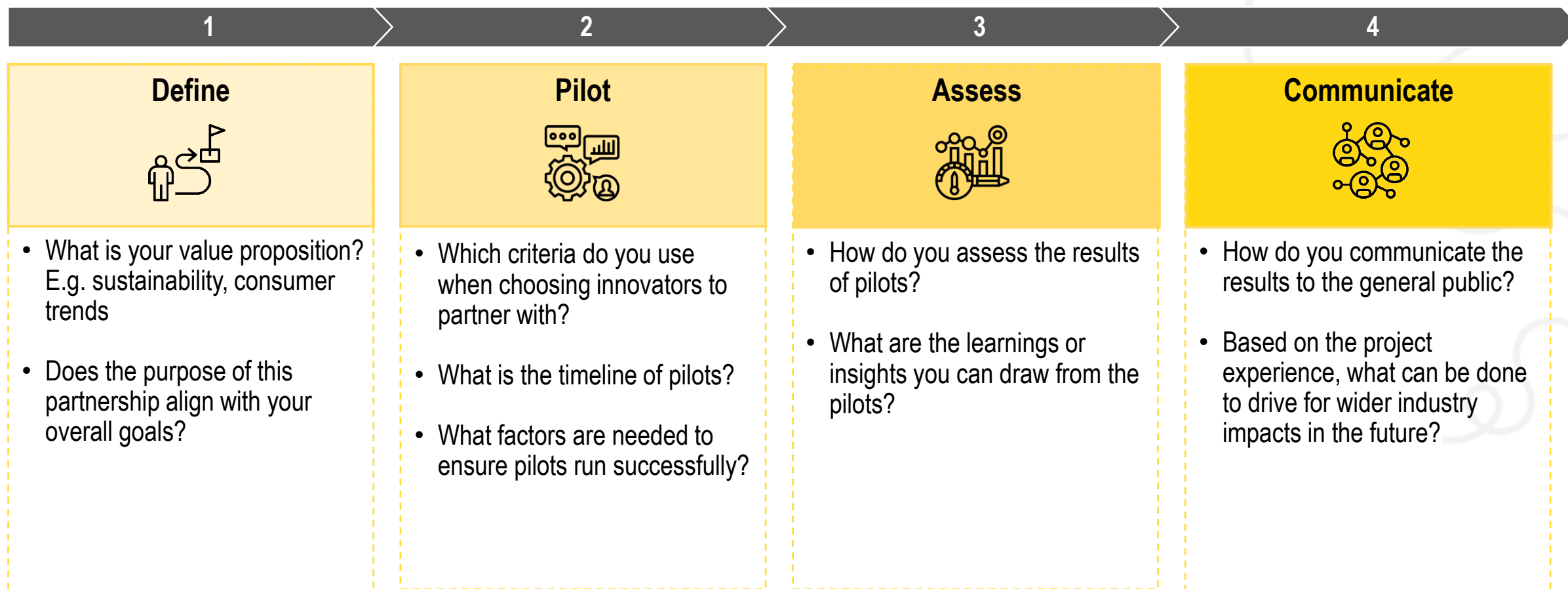
X

BOLT
THREADS

Steps to forming a synbio partnership

Building Impactful Collaborations

Brands should start with a purpose followed by a series of pilots and assessments.



Synbio partnerships

Building Impactful Collaborations

Proper milestone settings are crucial in getting the project moving, though adjustments are expected along the way.

1. Define

Aligning pilot goals with like-minded startups

Potential sustainability goals



Animal-free

Graeter's Ice Cream partners with innovator Perfect Day to launch a line of frozen desserts using Perfect Day's animal-free dairy proteins



Carbon reduction

Hermès partners with innovator MycoWorks to create a bag using mycelium leather, a biodegradable material with lower carbon footprint



Waste management

H&M is launching a collection made with vegan leather from wine waste supplied by innovator Vegea



Plastic-free

Renowned vegetable grower, Houweling's Group, has partnered with innovator Apeel Sciences to launch plastic-free cucumbers



fabrica
南豐作坊

Private & confidential

Source: Vegea, Apeel, Mycoworks, Food navigator, 500 Startups, Fabrica Analysis

2. Pilot

Typical process

i. Innovator selection

- Select "hero product" that best showcases innovation features while having enough margin buffer to cover higher initial costs
- Validate technology of startups based on proven case studies, and ensure that its production is feasible at larger scale



ii. Product design & development

- Offer industry expertise to innovators to help accelerate development, e.g. information on performance requirements



iii. Supply chain production

- Provide support & resources to innovators, e.g. supply chain partner introductions, marketing & branding



iv. Product launch

- Brand building & marketing in advance of launch to build consumer awareness and demand in target market
- Discussions on future roll-outs/ scale-ups including potential licensing model with supply chain partners

Ideal timeframe: Within 3-6 months



- A pilot should be a partnership between corporate & innovator, rather than a vendor-supplier relationship
- Setting key deadlines to ensure that all parties are working towards it

Synbio partnerships




Building Impactful Collaborations

Effective consumer communication helps drive greater impacts.

3. Assess






Conducting ongoing assessments to measure the results of pilots

The result of the pilot can be measured based on:

Attributes	Verifiable metrics
 <p>Consumers' response</p>	<ul style="list-style-type: none"> Consumers' feedback Desirability & demand (sales performance) Viability (Consumers' return rate)
 <p>Product performance/feasibility</p>	<ul style="list-style-type: none"> <u>Standard test criteria</u> - e.g. tensile strength & abrasion resistance in leather alternatives <u>Composition of end product</u> - e.g. % of virgin materials in a recycled fabric
 <p>Sustainability impact</p>	<ul style="list-style-type: none"> <u>Life-cycle assessment (LCA)</u> analyzes product's environmental impact (e.g. land & water use) from cradle to grave <u>Carbon footprint (metric tons per CO₂e)</u> measures total greenhouse gas emissions by a product

4. Communicate

Selecting appropriate strategies for storytelling and launch

Strategies	Competitive advantages	Example
Co-branded name	Provides innovators or corporate brands with an opportunity to differentiate among a crowded market	 <p>Burger King launches Impossible Whopper with Impossible Foods</p>
Embedded ingredient brand	Creates awareness, differentiation & preference for final products with specific component/ ingredient	 <p>Intel displays "Intel Inside" logos on computers with Intel CPU inside</p>
Product impact label	Creates transparency while allowing consumers to resonate, and create an impact	 <p>Allbirds labels its products by their carbon footprint (kg per carbon dioxide)</p>
Premium launch	Heightens demand and desirability through offering exclusive or limited product availability	 <p>Nike worked with Off-White to launch "The Ten", limited edition collection</p>
Influencer marketing	Establishes a market among celebrities/ industry experts to build credibility, trust & recognition	 <p>Oatly launches "Barista Edition" oat milk, targeting skilled baristas at cafes</p>

Concluding Thoughts

The Emergence of Synbio

- Synbio is a new discipline within modern biotechnology that aims to precisely design and redesign new/ existing biological system at a bigger scale, to create products with specific functions
- Synbio market has high potential growth particularly across agriculture and food sectors. This boom is driven by 3 factors – lowered gene sequencing cost, gene editing like CRISPR, machine learning enabling faster sequencing/ data analysis

Innovation Trends in Fashion & Food

- 2 key applications in fashion – new materials, textile processing
 - Replacing petroleum-based synthetic fibers with sustainable new materials, e.g. bio-synthetics, protein-based & cell-based materials
 - Use of chemical-free dyes & agents during textile processing
- 3 key applications in food – agriculture, food additives & ingredients, alt. proteins
 - Optimizing plant breeding, crop cultivation & post-harvest crop protection without the use of harmful chemicals
 - Producing clean food additives and alt. proteins sustainably

Building Impactful Collaborations

- Most corporates form pilots with startups for adoption of new technology or business transformation with new marketing/ product launch
- A pilot should be treated as a collaborative partnership rather than a vendor-supplier relationship. It can be done through i) working with innovators directly to launch products or ii) forming an industry consortium
- Setting appropriate timeframes is crucial in getting all parties involved, managing expectations and moving towards implementation

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3. Check out [our website](#) for more information
4. Schedule a site tour at The Mills Fabrica via contact@themillsfabrica.com