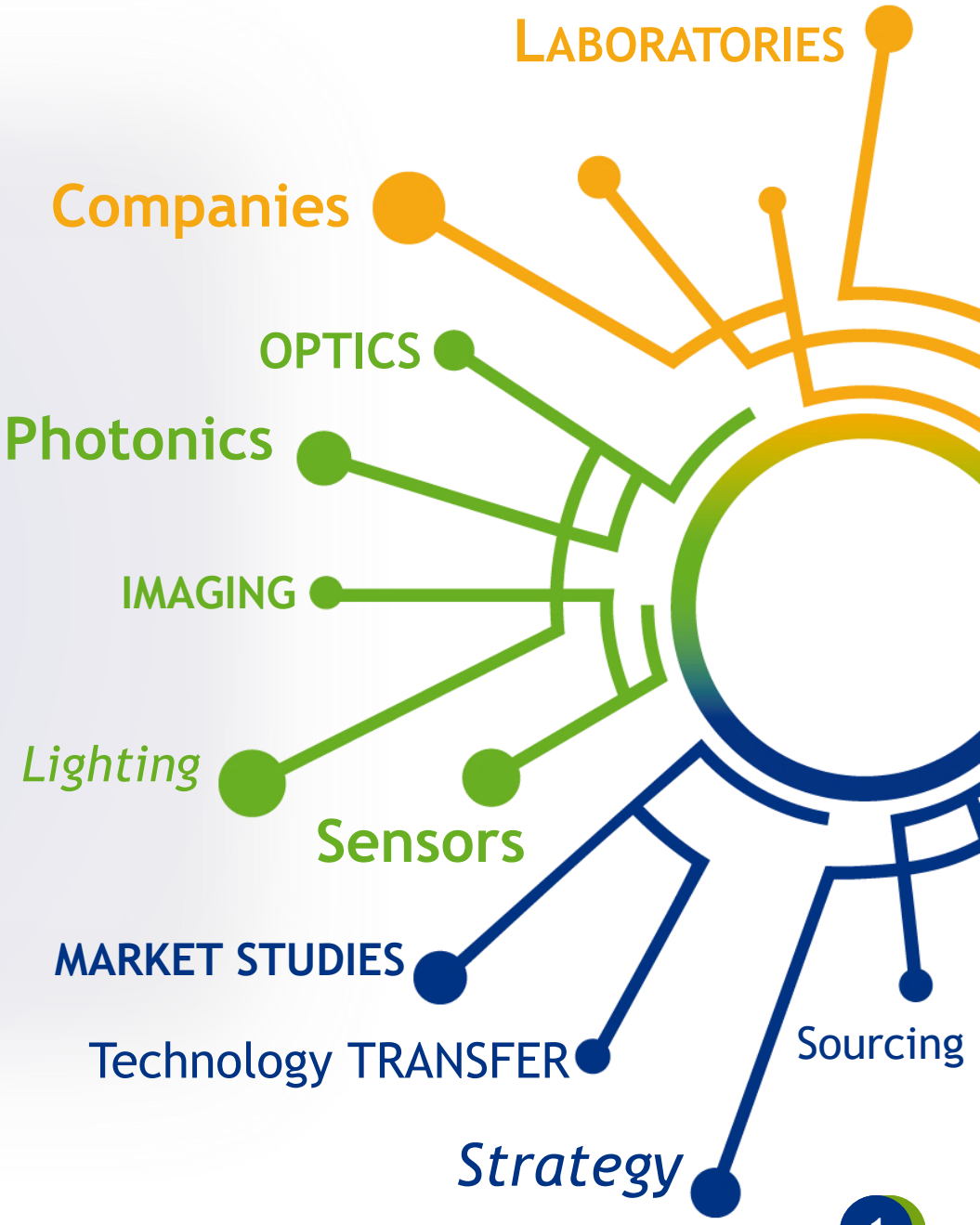
Tematys

Exploration of photonics markets



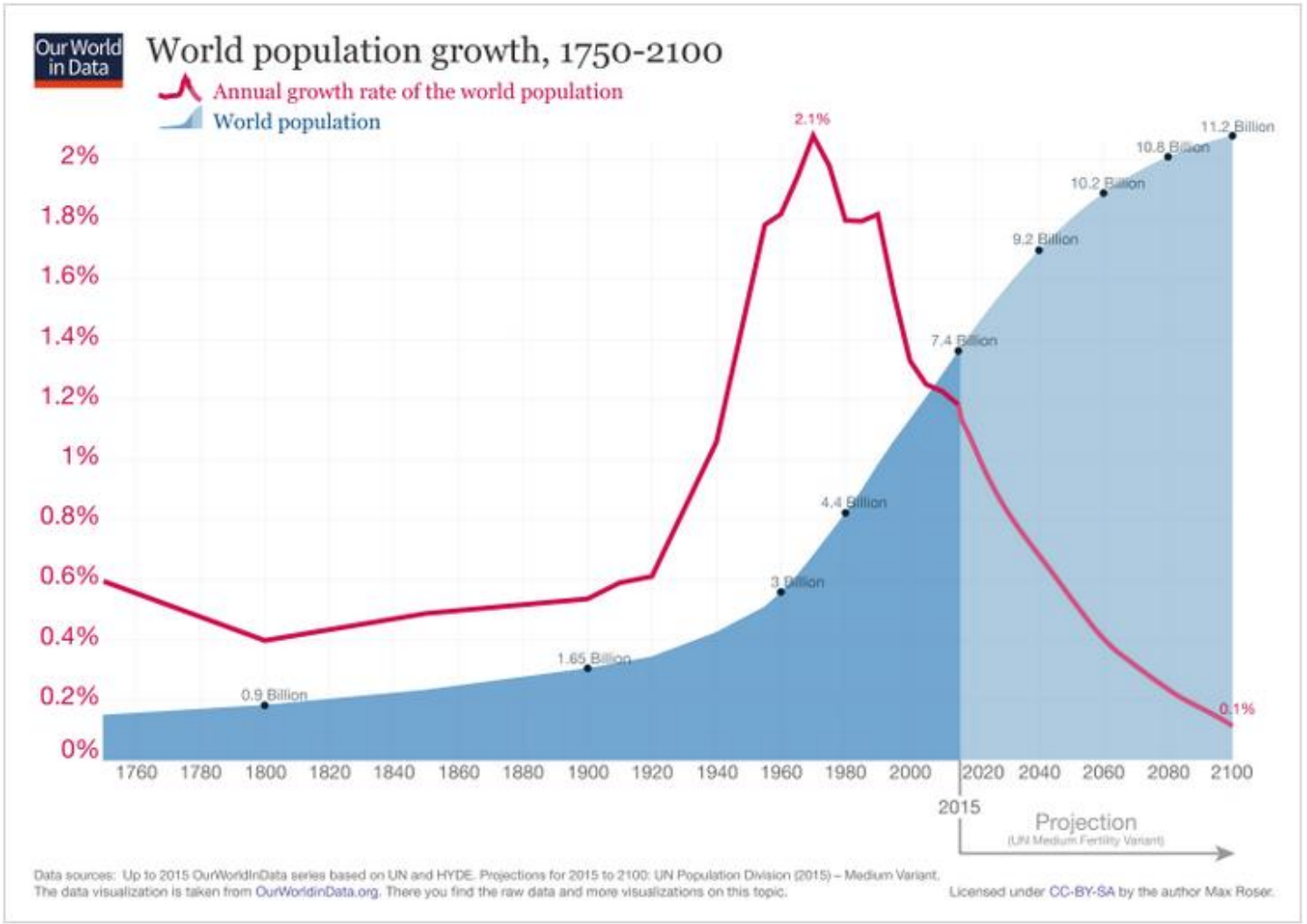
Tech4Food Workshop

Paris, 17th October 2019

Photonics : an enabler for Precision Agriculture

Good news : The worst is behind us

- Continuous growth of world population along the century – (9,8B in 2050, 11,2B in 2100)
- 70M inhabitants more per year – a new France to feed each year
- Slower rate since the 70's



Source : United Narions, OurWorld in data, USDA

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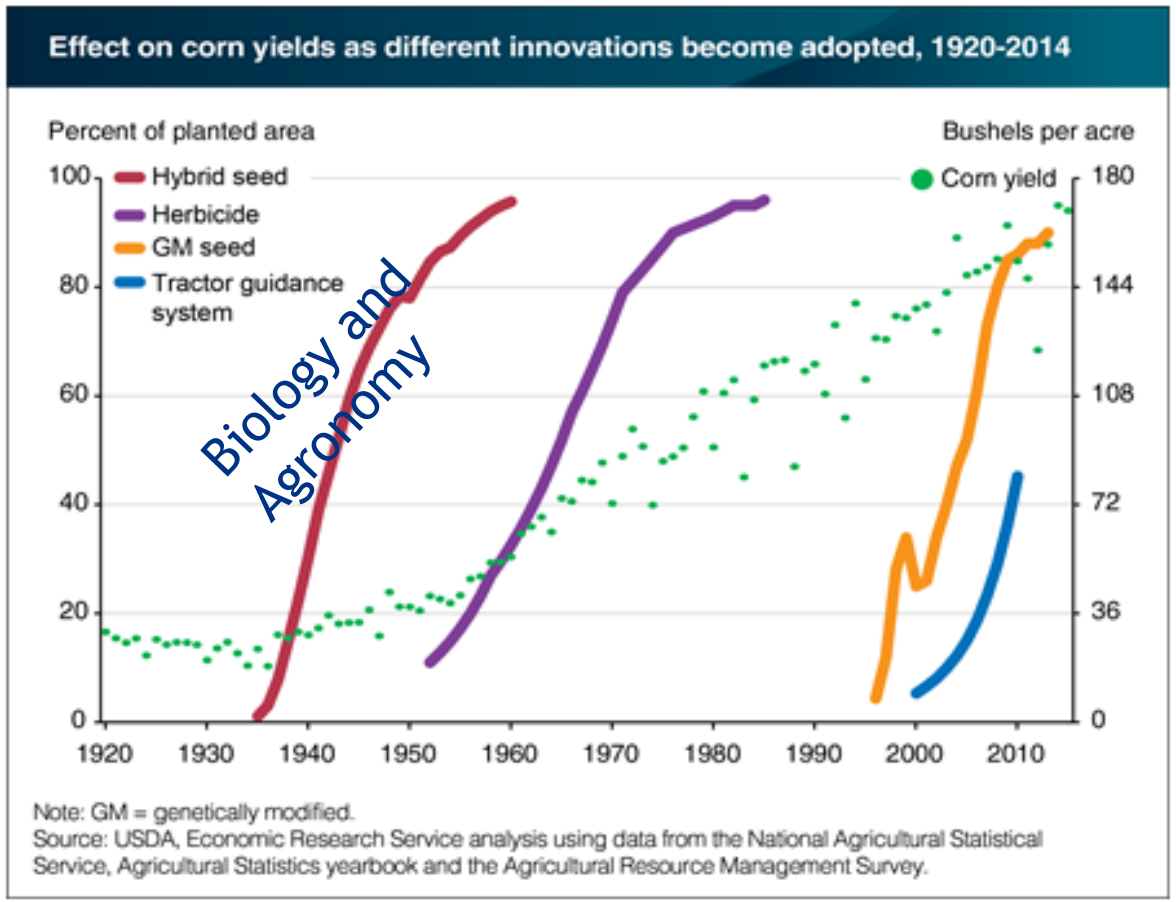
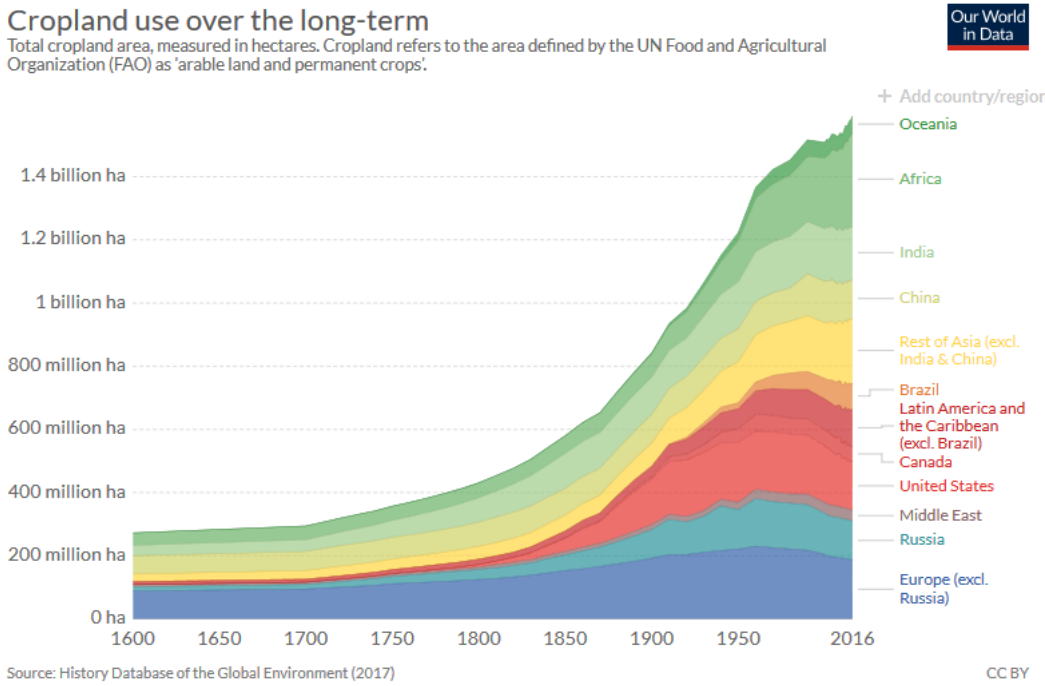
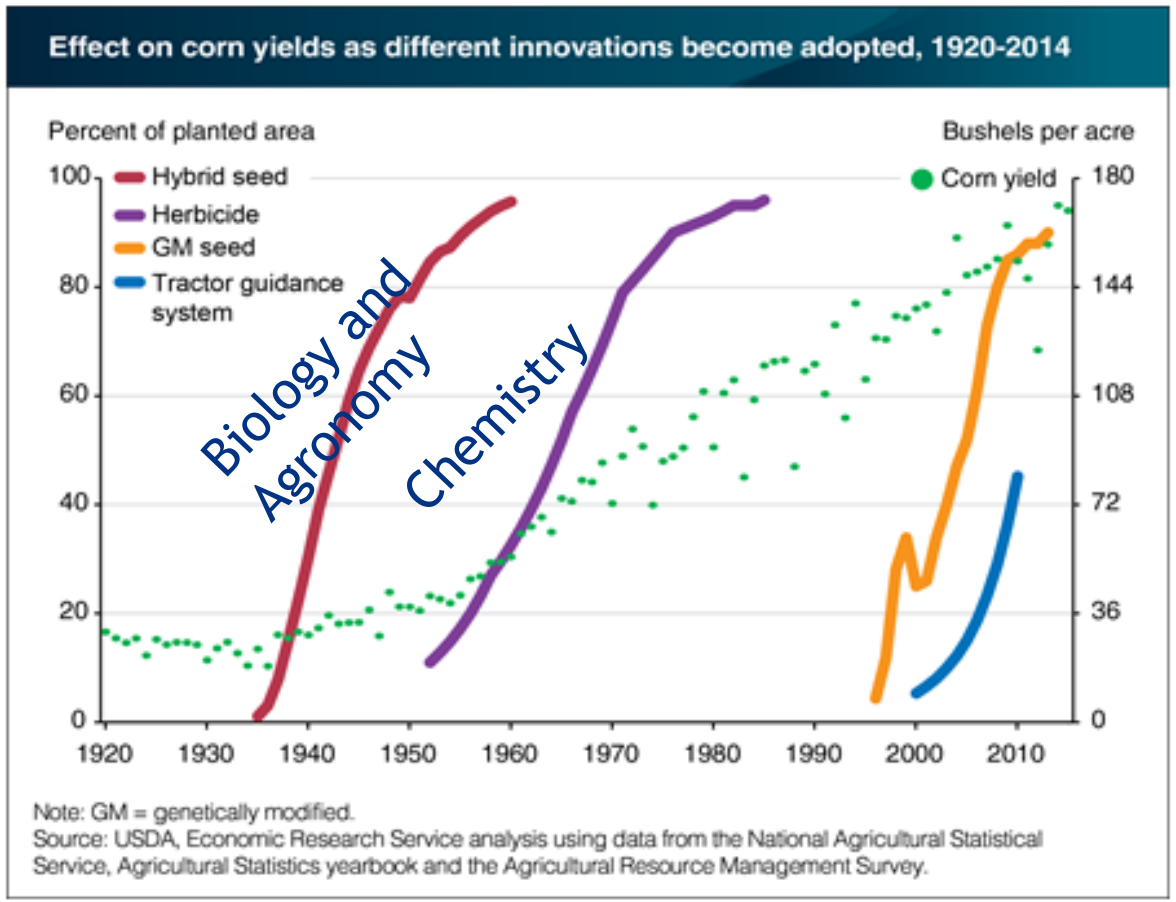
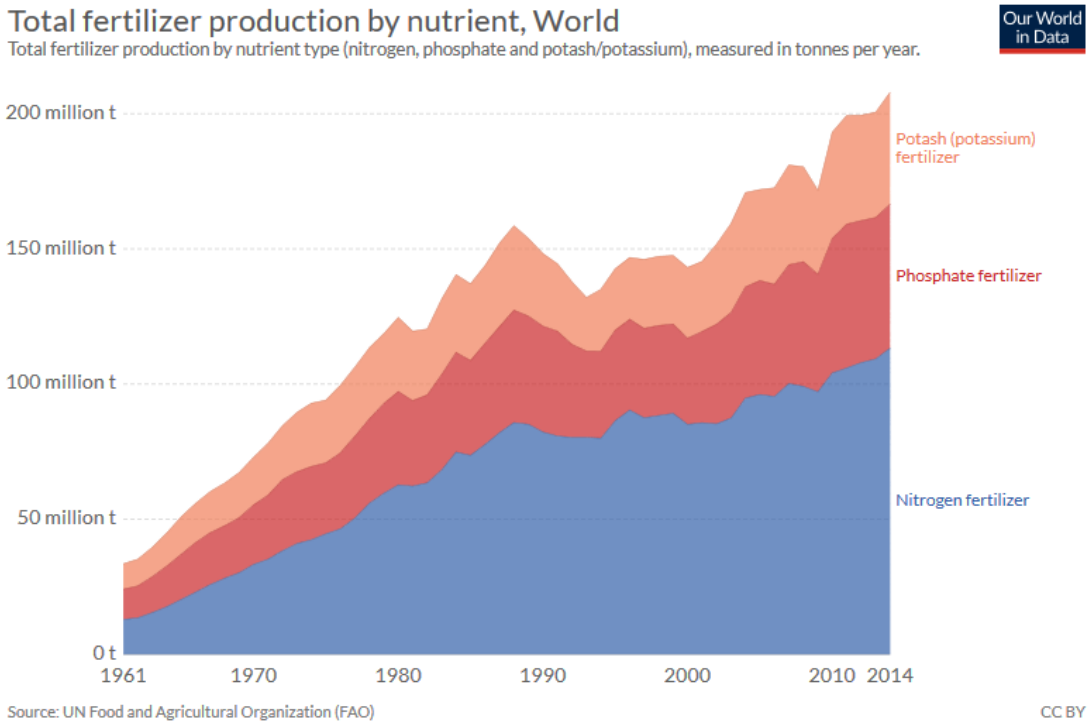
From Biology to IT tools to optimise yield





From Biology to IT tools to optimise yield





The Seed Industry in U.S. Agriculture: An Exploration of Data and Information on Crop Seed Markets, Regulation, Industry Structure, and Research and Development,

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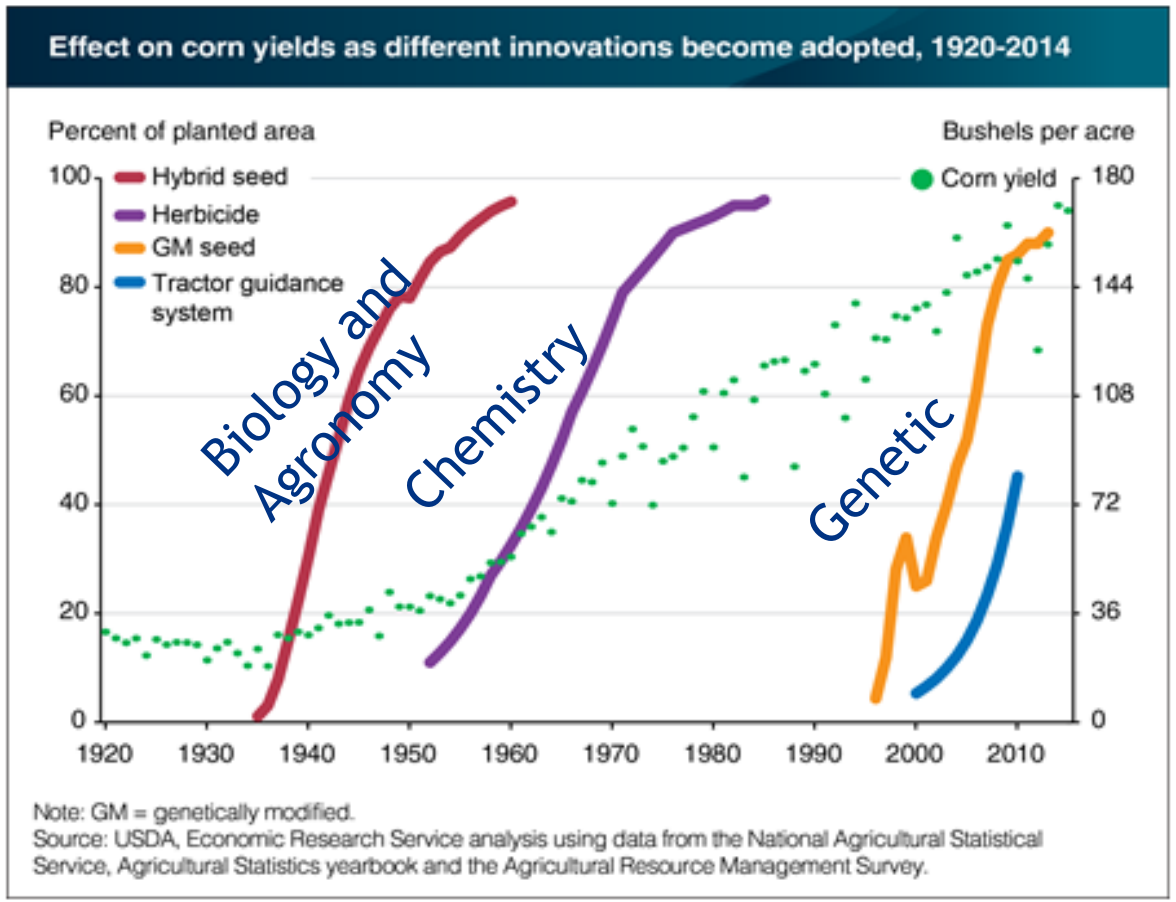

"Ninety percent of the world's food is derived from just 15 plant and 8 animal species."

"Biodiversity - and especially the maintenance of wild relatives of domesticated species - is essential to sustainable agriculture."

75% of the genetic diversity of crop plants has been lost in the past century.

The Seed Industry in U.S. Agriculture: An Exploration of Data and Information on Crop Seed Markets, Regulation, Industry Structure, and Research and Development,

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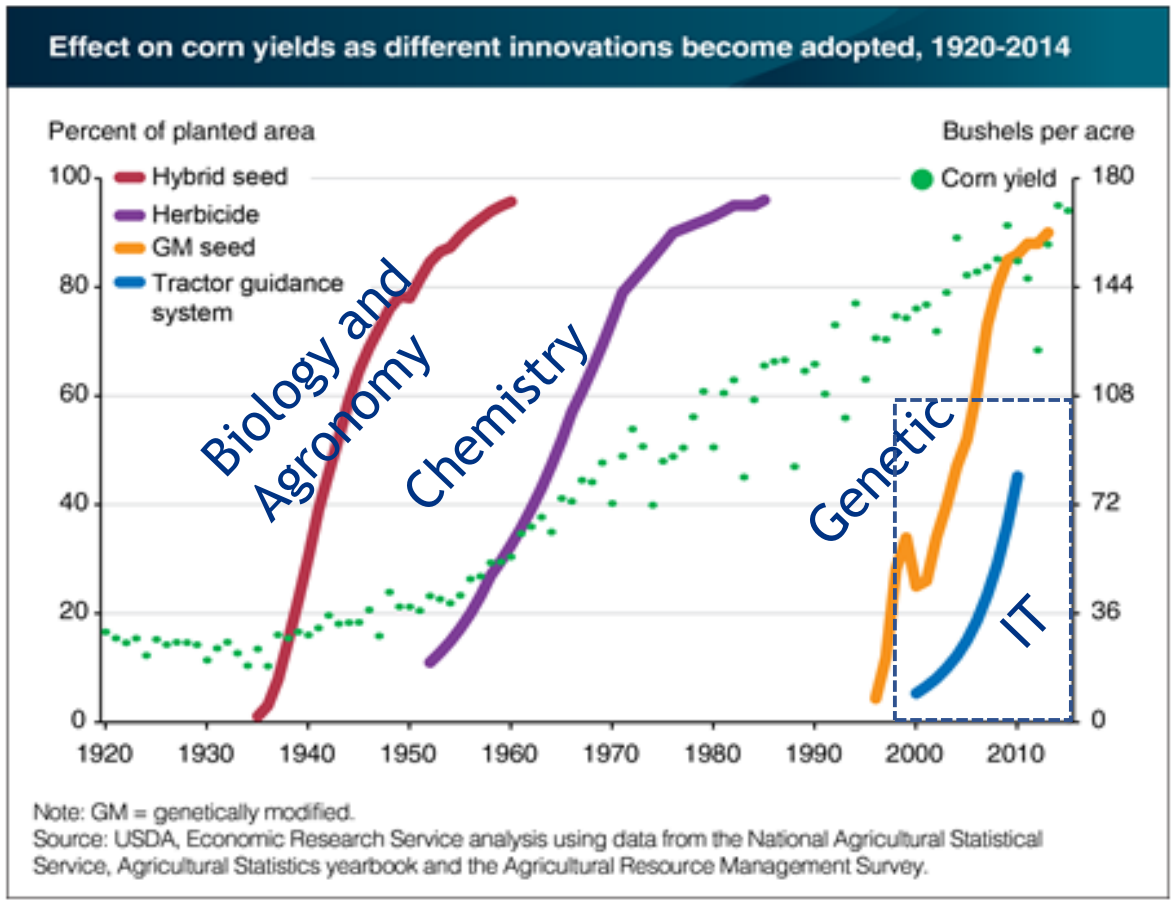

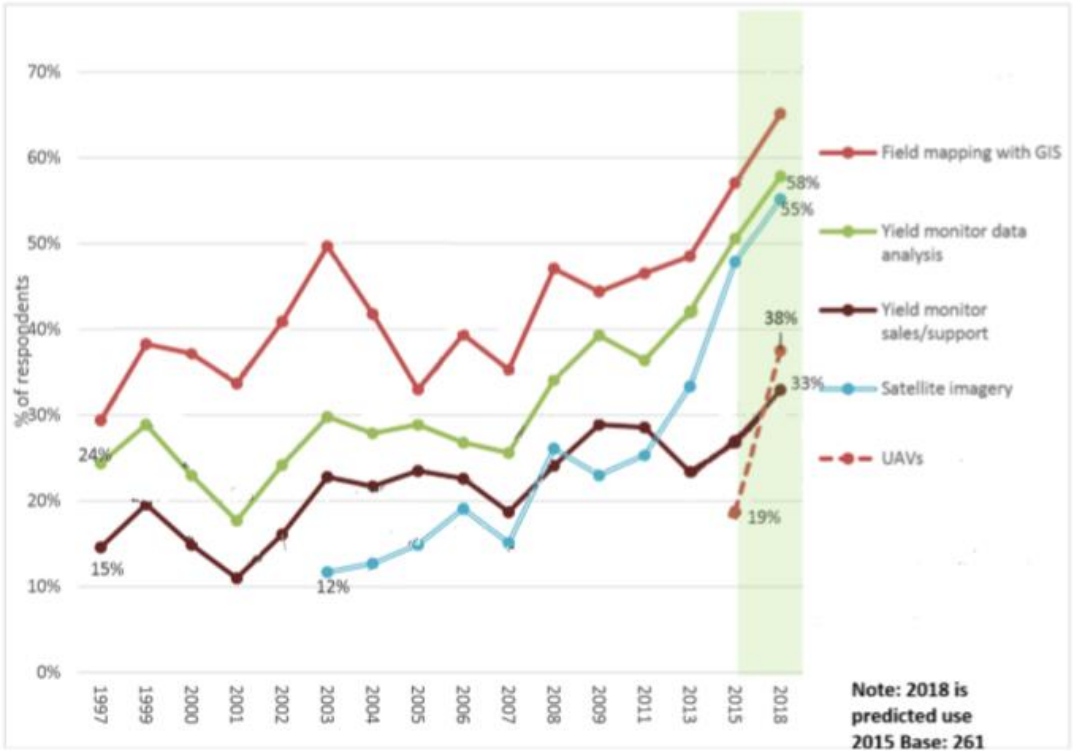

Precision agriculture deployment in USA since 1997 (Source : Croplife report 2015, Purdue University)

The Seed Industry in U.S. Agriculture: An Exploration of Data and Information on Crop Seed Markets, Regulation, Industry Structure, and Research and Development,

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Systemic Cascade Impact

More people to feed

Systemic Cascade Impact

More people to feed

More calories to produce

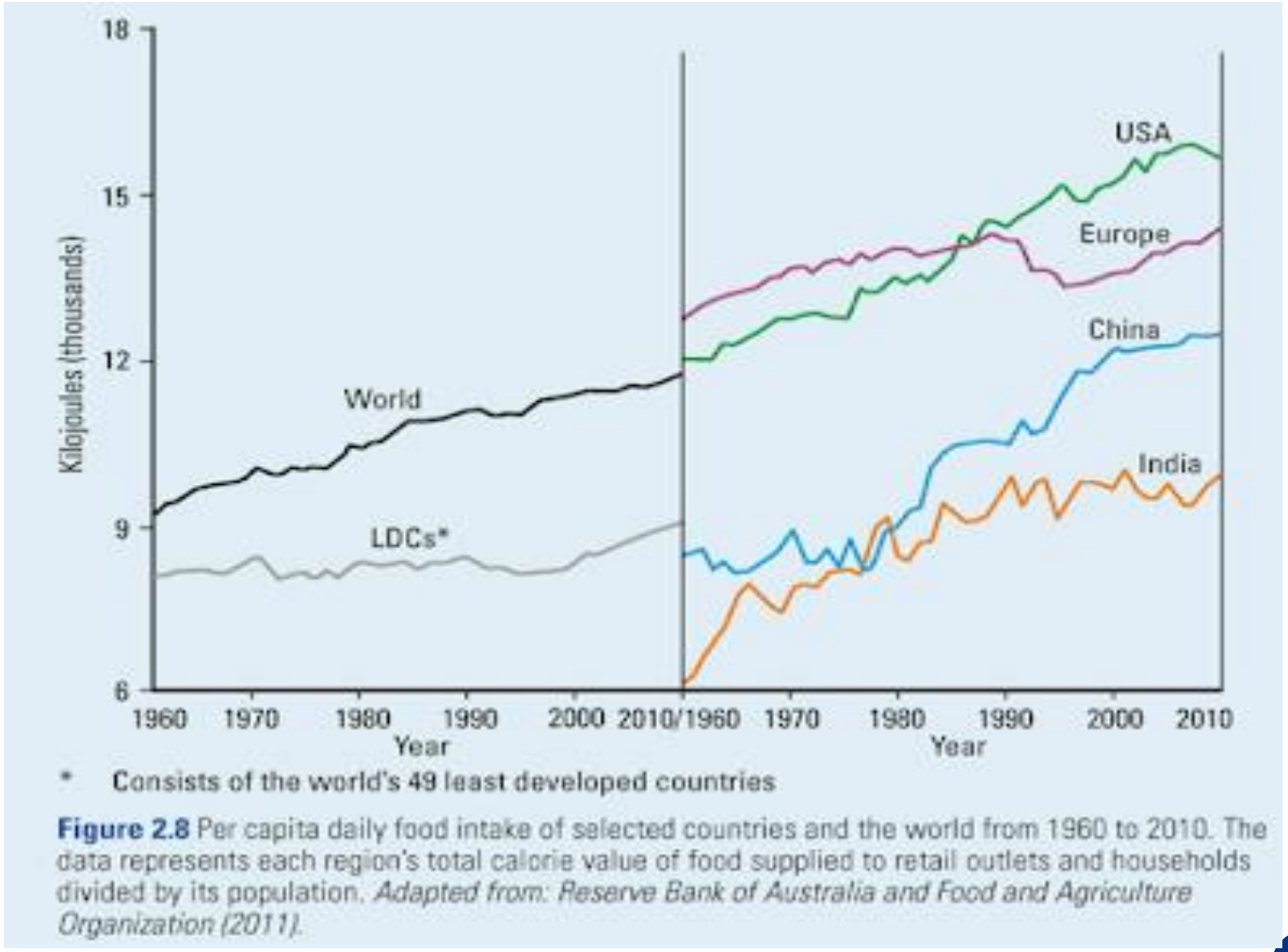

Figure 2.8 Per capita daily food intake of selected countries and the world from 1960 to 2010. The data represents each region's total calorie value of food supplied to retail outlets and households divided by its population. *Adapted from: Reserve Bank of Australia and Food and Agriculture Organization (2011).*

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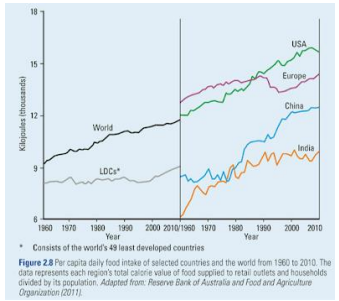
Systemic Cascade Impact

More people to feed



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More calories to produce

More agro products to harvest and transform

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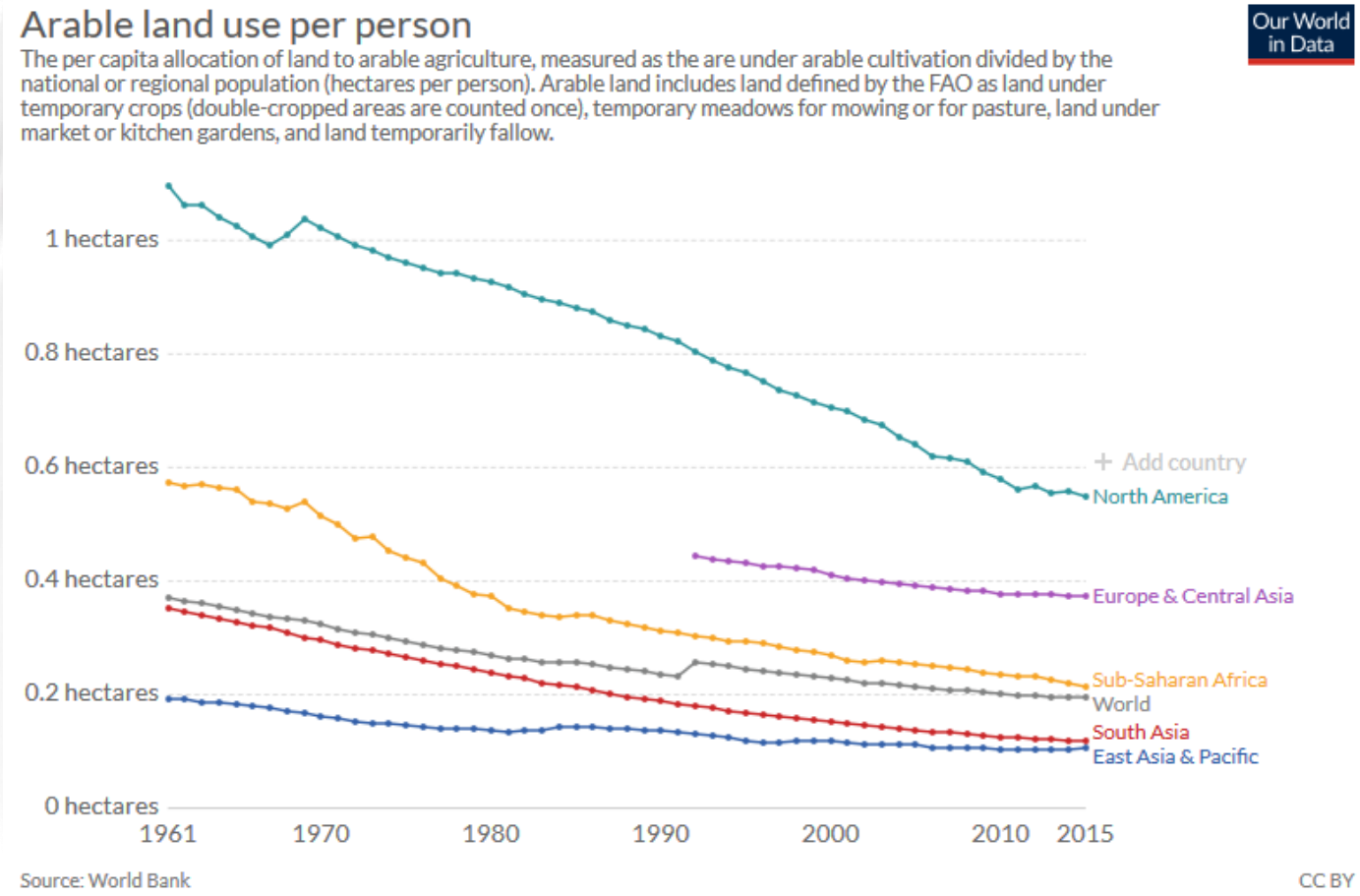
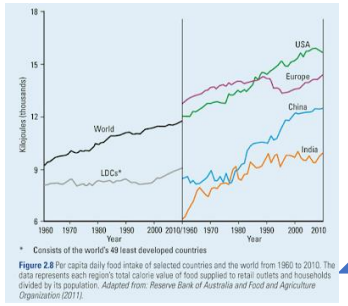
Systemic Cascade Impact



Boundaries in arable soils

Systemic Cascade Impact

More people to feed



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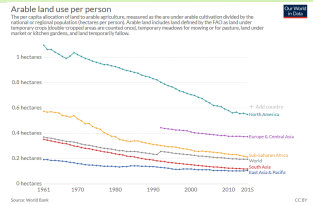
More calories to produce

More agro products to harvest and transform



Boundaries in arable soils

More, N, P, Water used in AgroProduction

Soils Pollution
Less Biodiversity

No sustainability

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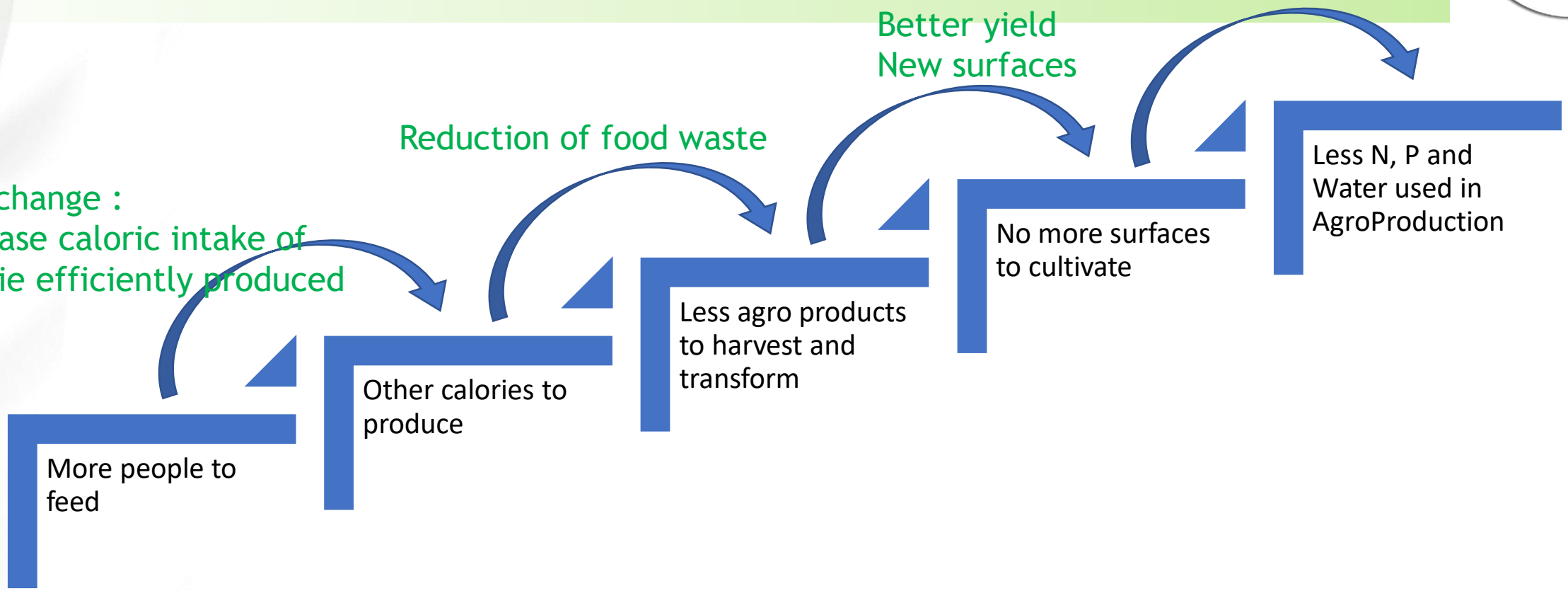
Earth and ethic boundaries and issues for sustainability

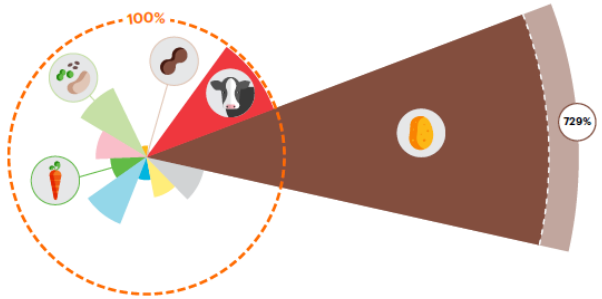
Earth system process	Control variable	Boundary (Uncertainty range)
Climate change	GHG emissions	**5 Gt CO_2-eq yr^{-1}** (4.7 – 5.4 Gt CO2-eq yr^{-1})
Land-system change	Cropland use	**13 M km^2** (11–15 M km^2)
Freshwater use	Water use	**2,500 km^3 yr^{-1}** (1000–4000 km^3 yr^{-1})
Nitrogen cycling	N application	**90 Tg N yr^{-1}** (65–90 Tg N yr^{-1}) * (90–130 Tg N yr^{-1})**
Phosphorus cycling	P application	**8 Tg P yr^{-1}** (6–12 Tg P yr^{-1}) * (8–16 Tg P yr^{-1})**
Biodiversity loss	Extinction rate	**10 E/MSY** (1–80 E/MSY)

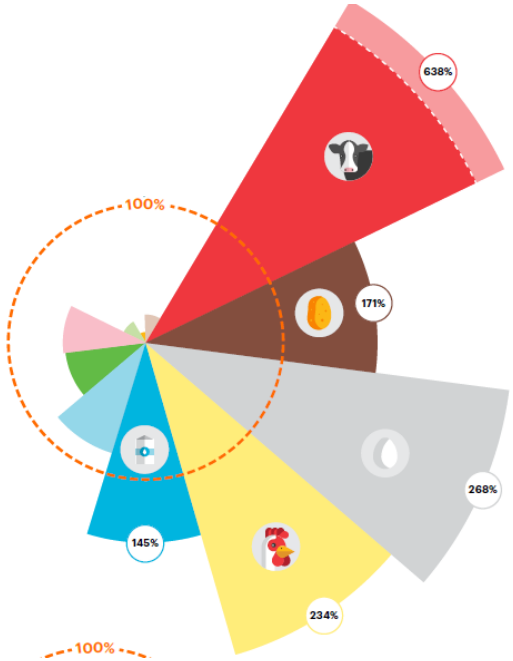
This report was prepared by EAT and is an adapted summary of the Commission *Food in The Anthropocene: the EAT-Lancet Commission on Healthy Diets From Sustainable Food Systems*. The entire Commission can be found online at *thelancet.com/commissions/EAT*.

Systemic Cascade Impact



Photonics for Diet change ?





New expectations from consumers about food origin, nutritional quality and transformation process

Collecting information along all the supply chain, from production area to household.

Photonics Portfolio

Infrared Isotopic analyzer

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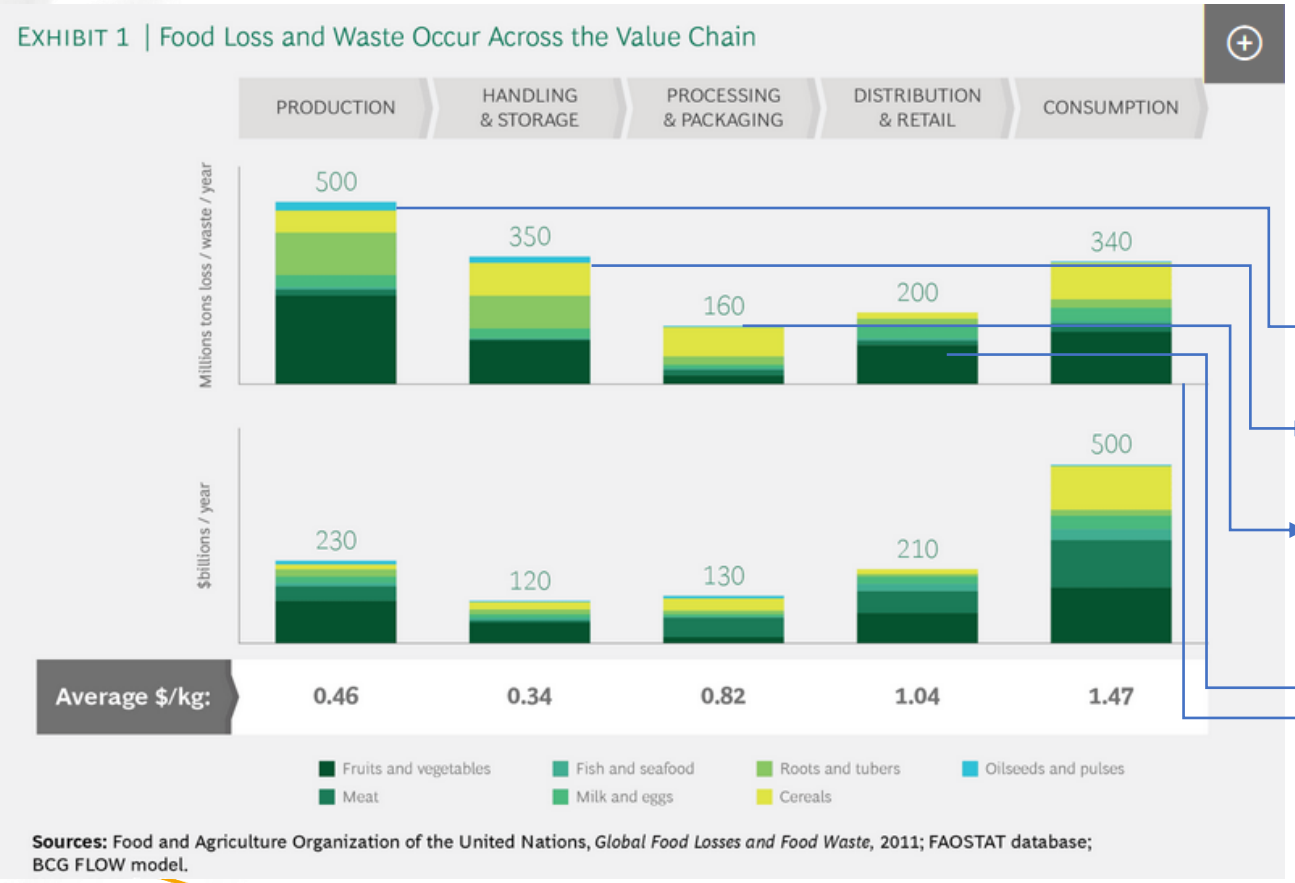
Photonics for Food Waste ?



Data :
25 to 30% of food is lost and wasted.
Between 1,3 and 1,6Bt/year
Around 1.180 B$/year

TECHNOLOGY PORTFOLIO

Sorting devices on Production areas

Gas sensing in Handling and storage

Imaging and Process control devices in Processing and packaging

Spectroscopic and imaging device in retail

Spectroscopic device for consumer

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Not enough cropland ?

- LEDs for Urban farming,
- LEDs for Greenhouses
- LED and Sunlight Fiber Collection for Vertical farm
- LEDs and Sunlight Fiber collection for Underground farming

Better yield, better quality and 4D Mitigation of pests ?

Traits	Tools					TRL (Technological readiness level)								
	RGB	Multi/hyperspectral	LIDAR	Thermal	Fluorescence	1	2	3	4	5	6	7	8	9
Plant density @ emergence	■					■	■	■	■	■	■	■		
Cover fraction	■					■	■	■	■	■	■	■	■	
Plant/canopy height	■		■			■	■	■	■	■	■	■		
Ear density	■					■	■	■						
Fruit/inflorescence size	■		■			■	■	■	■					
Grain number and size	■					■	■	■	■					
Leaf/plant glaucousness	■					■	■							
Phenology (e.g., heading, anthesis...)	■	■		■		■	■							
Lodging	■		■			■	■	■	■	■	■	■		
Weed infestation	■					■	■	■	■	■	■	■		
Diseases	■	■		■	■	■	■							
Vegetation index monitoring	■	■				■	■	■	■	■	■	■		
Green area index (GAI)	■	■	■			■	■	■	■	■				
Senescense	■	■				■	■	■	■	■	■			
Fraction of intercepted radiation	■	■	■			■	■	■	■	■	■			
Leaf orientation	■	■	■			■	■	■	■	■				
Leaf rolling	■	■	■			■	■	■	■					
Chlorophyll content	■	■				■	■	■	■	■	■			
Leaf/canopy temperature		■		■	■	■	■	■	■	■				
Leaf/canopy chlorophyll fluorescense					■	■	■	■	■					

- Strong maturity in RGB and multispectral application
  - ✓ cover fraction,
  - ✓ NVDI,
  - ✓ chlorophyll content,
  - ✓ weed infestation
- Next generation in LIDAR and hyperspectral application
  - ✓ leaf orientation,
  - ✓ canopy height
- Strong technological issues with remote detection of diseases and pathogens and phenology.

Translating High-Throughput Phenotyping into Genetic Gain, Article *in* Trends in Plant Science · March 2018, DOI: 10.1016/j.tplants.2018.02.001

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Exploration of photonics markets

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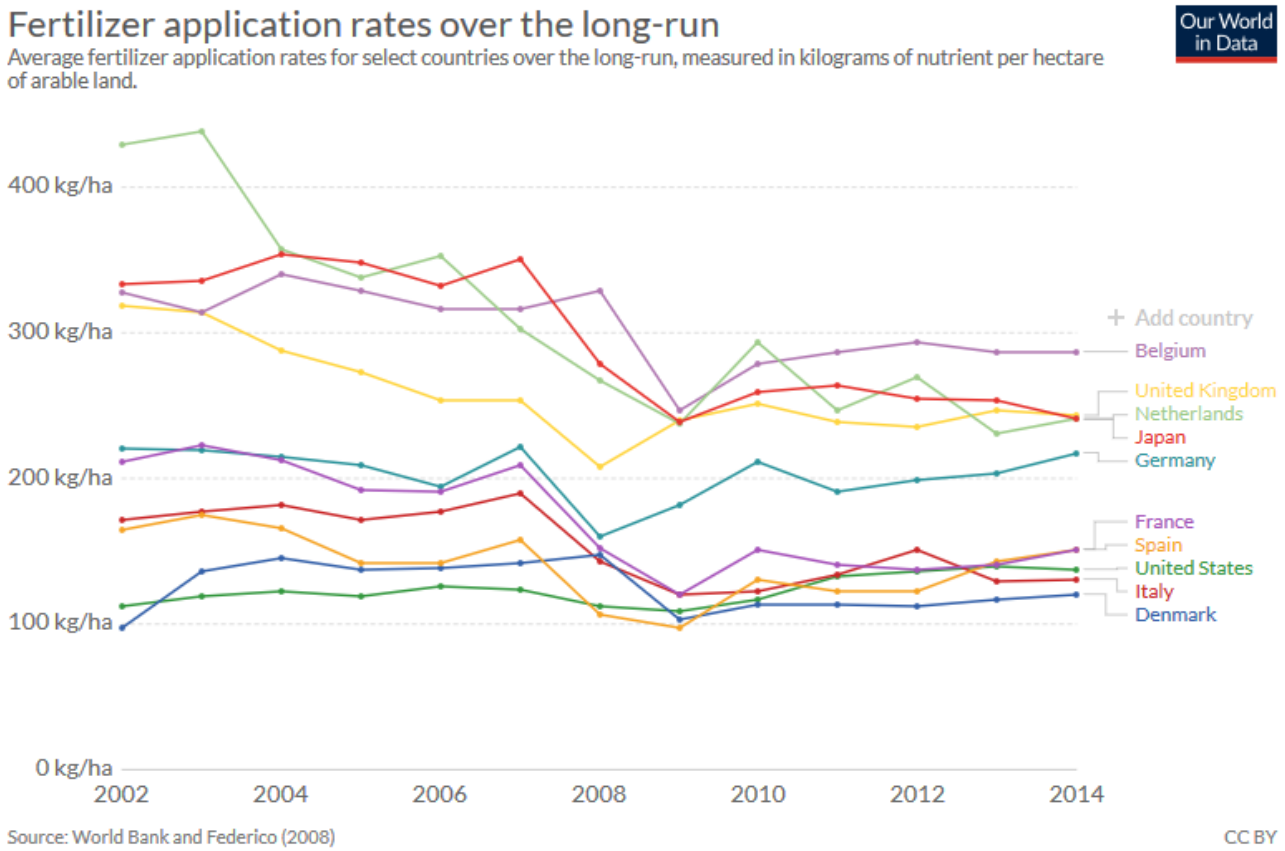

WorldBand and federico (2008)

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A unique Value Proposition

- The challenge for modern agriculture and farming is to increase food production by 70% within 30 years to cope with the increasing world population while reducing global impact upon ecosystems and meeting the requirements of transparency in the field of food safety.
- This increase in production should be done at
  - constant agricultural surface, as a major part of arable land is already cultivated,
  - with no more fertilizers to increase yield
  - with less phytosanitary products to limit production losses.
- With some strong issue linked to agricultural area in comparison to same problem in industry :
  - large and variable areas to cover, a high variability of objects of interest (soils, climate, plants) and their complex interaction.
  - several strict constraints with regard to data acquisition and sensor development: small markets, low margins, rough conditions of use, and a low-to-medium level of ICT understanding from users.
- Photonics-based devices provides **non-contact**, **potentially long-range, real-time, sensitive and specific information** on the physical structure, plant metabolism / meat quality and their chemical compositions (lipids, proteins, sugars , water, vitamins ...), and can solve these different issues, on-the-field, on processing lines but also in artificial environments (urban farms, greenhouse).

Along all the supply-chain…

Phenotyping
Seed development
Seed quality

Yield forecast & Maturity control
Disease & pathogen detection
Urban Farming

Fruit calibration
Sorting

Process control
UV Treatment
Process cleaning and disinfection

Quality Control
Rapid microbiology Methods
Foreign bodies detection

Packaging Control
Warehouse control
Retail control
,Consumers Quality Control

Source: Tematys, Feuille de route Photonique, 2018, France Photonique

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Amortization of developments among various application

Markets	Functions	Technologies
Agriculture & agro-equipement	• Varietal innovation, adaptation of plants to climates and soils (phenotyping), plant protection, biocontrol • Systems and management of field crops, vines, including agricultural machinery / robotics • Remote sensing and spatial information systems	• 3D Laser Scan, active and passive Hyperspectral active et passive imaging, Terahertz imaging and spectroscopy (hydration sensing), Thermal imaging (evapotranspiration), NIR-MIR & Raman Spectroscopy, High resolution machine vision • CMOS and CCD cameras, NIR and UV handheld spectroscopy, Multispectral and Hyperspectral Cameras, UV lighting, Biosensors, • VIS-NIR-SWIR-MIR imaging, SWIR sensors, High resolution satellite imaging, anemometer,
Agriculture in synthetic environment	• Greenhouses, Vertical farm, Urban farms • At home greenhouse	• LED lighting (UV-B and Vis), Fibre optics Solar lighting, Fibre optic sensing, Various Spectroscopic devices, holographic and interferometric measurement (fish farms)
Breeding and aquaculture	• Feed, additive, nutrition • Precision breeding • Diagnostic, veterinary drugs • slaughterhouse • Fish farms	• Spectroscopy (handheld, on-line) • CMOS cameras, High speed cameras (biomechanics, Vision, Stereovision) • Biosensors (SPR, PIC) • 3D imaging, UV lighting, , Spectroscopy • Holographic and other interferometric devices
Food industry	• At-line & On-line control • Rapid Microbiology methods (detection, identification, characterization of particles below 10µm) • Foreign bodies detection	• Infrared spectroscopy (SWIR & MWIR), Hyperspectral Terahertz and Raman imaging, Cytometry, PIC, laser scanning, Plenoptic imaging • Cytometry, Plasmonic devices, Spectroscopy (Raman, SPR), Non conventional imaging (Holographic, speckle), PIC • Machine vision, X-rays, Terahertz imaging,
Retail	• Presentation of food products at the point of sale (freshness, ripeness)	• LED lighting, RGB imaging, Hyperspectral and SWIR imaging • Embedded Micro spectrometers

Source : TEMATYS, Fench AgriPhotonics Roadmpa, www.hdigitag.fr

And possible return of experience form other industries

Markets	Functions	Technologies
Agriculture & agro-equipement	• Varietal innovation, adaptation of plants to climates and soils (phenotyping), plant protection, biocontrol • Systems and management of field crops, vines, including agricultural machinery / robotics • Remote sensing and spatial information systems	• 3D Laser Scan, active and passive Hyperspectral active et passive imaging, Terahertz imaging and spectroscopy (hydration sensing), Thermal imaging (evapotranspiration), NIR-MIR & Raman Spectroscopy, High resolution machine vision • CMOS and CCD cameras, NIR and UV handheld spectroscopy, Multispectral and Hyperspectral Cameras, UV lighting, Biosensors, • VIS-NIR-SWIR-MIR imaging, SWIR sensors, High resolution satellite imaging, anemometer,
Agriculture in synthetic environment	• Greenhouses, Vertical farm, Urban farms • At home greenhouse	(UV-B and Vis), Fibre optics Solar lighting, Fibre optic sensing, Various ic devices, holographic and interferometric measurement (fish farms)
Breeding and aquaculture	• Feed, additive, nutrition • Precision breeding • Diagnostic, veterinary d •	• Spectroscopy (handheld, on-line) • Holographic and other interferometric devices
Food industry	• At-line & On-line control • Rapid Microbiology methods (d • Foreign bodies detection	• Infrared spectroscopy (SWIR & MWIR), Hyperspectral Terah ging, Cytometry, PIC d PIC • Machine vision, X-rays, Terahertz imaging,
Retail	• Presentation of food products at th (freshness, ripeness)	, RGB imaging, Hyperspectral and SWIR imaging Micro spectrometers

Smart building

HEALTH technologies, Pharmaceuticals, Sports management

Process control, Process analytical technologies, Microbiology

Machine Vision

Source : TEMATYS, Fench AgriPhotonics Roadmpa, www.hdigitag.fr

New trade-off in CAPEX / OPEX

Principal bottlenecks of photonics deployment (high cost, size, not power efficient, requirements of skilled people to operate) are to be solved within the next years. Current developments in photonics (LIDAR for automotive, fiber optic sensors) lead to compact, frugal, resilient devices and allow the development of Building blocks in :

- High volume manufacturing
  - integrated circuits (from Telecom/Datacom to MedTech and process monitoring)
  - Wafer-level packaging and coupling (from Datacom to Sensing)
  - Optomechanical assembly with high accuracy
- Less parts per device
  - freeform optic (from Space to lighting and micro-optics devices)
  - 3D engraving (for multiple function on the same component)
- And befits from IoT developments
  - Frugal data acquisition and transfer (LTE, passive time-lapse monitoring)
  - 3G and 4G based devices
  - Standards in components

IA as photonics' enabler

While yield sensors provide very accurate maps, their interpretation remains difficult, in the absence of techniques to map with the same precision the potential root causes of yield variations (variations in the physical or chemical composition of the soil).

There is therefore a strong imbalance between the amount of descriptive information of crops (huge number of data), and the density of information on the factors that explain their yield potential (soil and climate information with lower spatial and temporal resolution).

As a result, it is difficult to quickly deduce fertilizer or pesticide application maps from the yield cartography, which could then be implemented by precision sprayers. **This imbalance between descriptive information and explanatory information is still a major limitation to transform data in diagnostics.**

Photonics is an enabler to develop High spatio-temporal data acquisition of various parameters but requires parallel development in artificial intelligence and further Modeling to extract the highest value from Photonic sensing.

- Example of predictive analysis to introduce beyond real-time sensing
  - Short term weather forecast to define irrigation tasks
  - Yield forecast to define fertilizer inputs
  - Pest infection timeline and trajectory

Take away

- Trade-off Population growth / Earth boundaries
- Evolution of diet (healthy diet) for sustainable development and healthy population
- Photonics as a global player for solving issues along the whole value chain (imaging, sensing, lighting)
- Decrease of cost and high volume manufacturing has started in photonics industry with consumer markets
- Reliability, packaging and system assembly will be developed with e.g. automotive markets
- Photonics still require IA to harvest the optimal value from optical sensors in agro food industry
- As in other application, ownership of data will become the next fighting frontier
- Decrease of CAPEX and OPEX in Photonics device as well as Increase of Value with Artificial Intelligence
- Improved productivity led to strong concentration of economic actors at all levels (farmers, equipment manufacturers, agrochemical manufacturers)
- Sovereignty and independence will enter in Agrofood issues.

REFERENCES

Thank you for your attention

Research Organizations

Alphanov – C2N - CEA – CNES – CNRS – ECE – FIST – Fraunhofer IAF (DE) – Fraunhofer HHI (DE) – Gravit – Group Fraunhofer (DE) – Helmholtz Zentrum München GmbH – (DE) - IMEC (BE) - Institut Fresnel - Institut Langevin - Institut de la Vision – JST (JP) - LNCMI – LPN - LSCE – NCSIST (TW) - Observatoire de Paris – RTI (US) - SATT AXLR - SATT IdfInnov – SATT Aquitaine Science Transfert – SATT Conectus - SATT Grand Est – SATT Linksium - SATT Lutech – SATT Nord – SATT Ouest Valorisation – SATT Pulsalys - Supelec - Synerjinov – Télécom Paritech – Université de Bourgogne – Université Joseph Fourrier - Université Paris-Dauphine – Université Paris-Sud – Université Technologique de Troyes – Welience

International Groups

AIR LIQUIDE – Amplitude systèmes – AZBIL Corp. (JP) - BERTIN Technologies – CANON (JP) - CASINO – COHERENT, Inc. (US) - DIEHL Group (DE) - Doro – ESSILOR – Groupe MAQUET – HORIBA Jobin Yvon - HUTCHINSON – INFINEON Technologies (DE) – LEICA Microsystems (DE) – NIKON Corp. (JP) - Ocktal-SE – ORANGE – OSRAM (DE) - Paramount Technologies (ZA) – PSA – QUANTEL – RÉSEAU FERRÉ DE FRANCE – REUNICA – Robert BOSCH (DE) - SAFRAN/Sagem – Sainte-Lizaigne/Groupe Claire – SCHOTT (DE) – SCREEN Holging (JP) - SIEMENS (DE) – Sofradir – SONY Corp. (JP) - SORIN Group – Sumitomo Electric Industries, Ltd. (JP) - TOPPAN Photomasks Inc. - THALES – Ymk Photonics (SK)

SMEs and Start-ups

Act-Light (CH) – Adveotec – AIM Infrarot Module GmbH (DE) – AKA Optics - Altechna R&D (LT) - Apollo Medical Optics, Ltd. (TW) - Archimej – Armelio – Aurea – Bioaxial – BLOCK Engineering (US) - CAMBRIDGE Technologies (US) – Dreem - Elcarim Science (SG) - Eureva – GLOphotonics - Hublex - I2S – Imasonic - Indatech – Innoeco - Innov+ - ISP System - Ivea – Lake Shore Cryotronics (US) - Le Verre Fluoré – LightFab (DE) - LMDC – Lytid - Novoptim – Optopartner – Phasics – Phonoptics – Prestodiag – Probayes – Pyxalis - Seno Medical (US) - Sensup - Silltec – Si-Ware (EG) - SourceLab – Spectral Engine (FI) - Surfactis - Think & Go – T-Waves – Vactec – Lyonix Intl (NL) - Yole Développement

Public Organizations & Clusters

Agoranov – Association ARMIR - BPI France - Bretagne Photonics – DGA - EPIC (EU) – EUREKA Secretariat - Incubateur Descartes – Ministère Industrie/DGE – Medicen – Normandie Aéroespace - Optics Valley – Optitec – SwissMem (CH) – VDI (Photonics21)

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