ELSI Practices in University and Research Institution projects: A Case Study of Molecular Robotics

大学・研究機関プロジェクトにおけるELSI：分子ロボットの実践例

Konagaya Akihiko, Professor Emeritus
Tokyo Institute of Technology

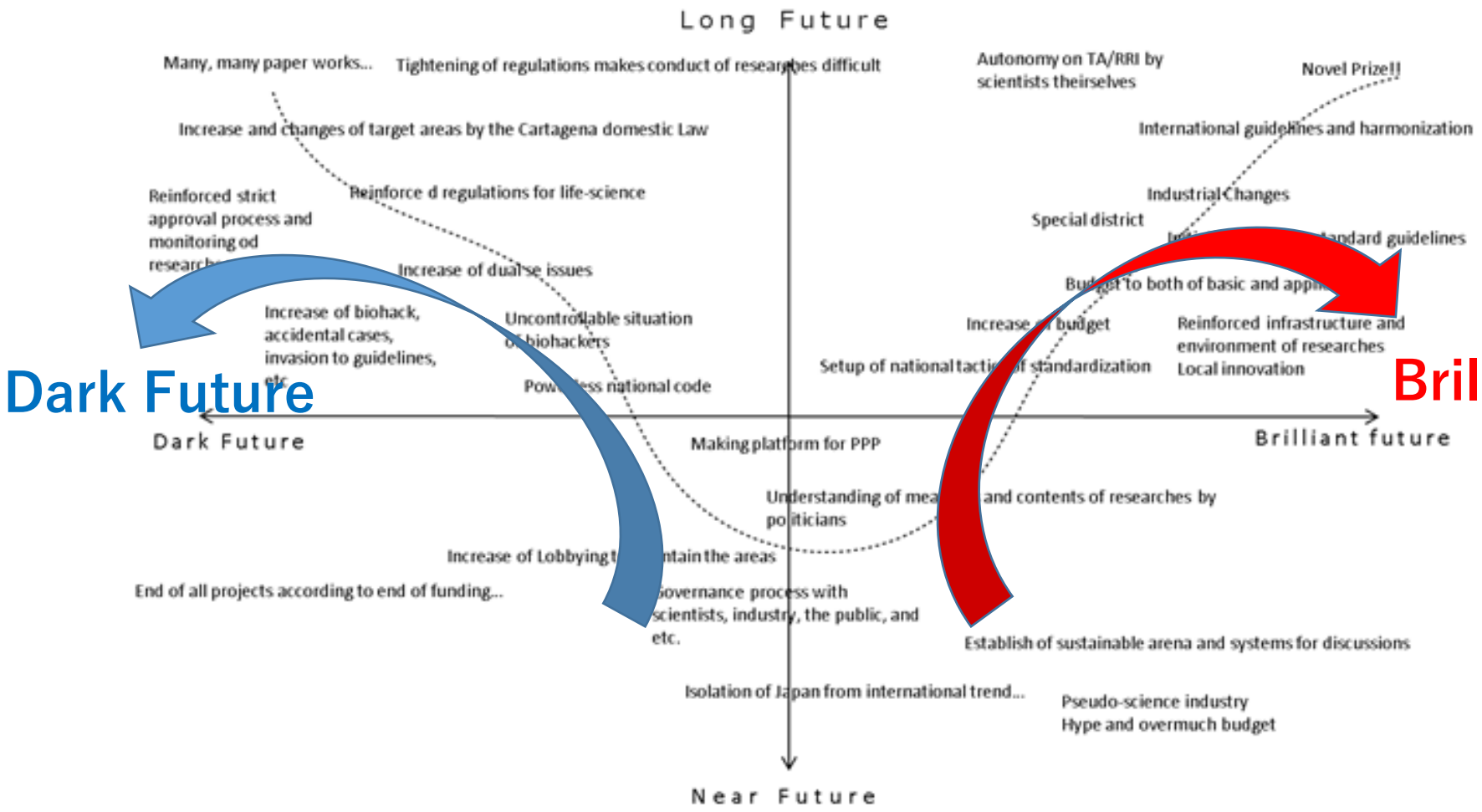
小長谷明彦　（東工大、名誉教授）

Why ELSI?
Because No Signpost before Emerging Technology!

新興技術の前に道しるべはない

だからこそ、ELSIが必要！

Consensus Conference including journalists and citizens about “Future Prospects and Issues of Molecular Robotics”



ジャーナリストや市民を含めた
「**コンセンサス会議**」による
「**分子ロボットの未来と課題**」

Mar, 2018 RRI workshop, @Tamachi CIC

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- What is Molecular Robotics?
- It's Applications
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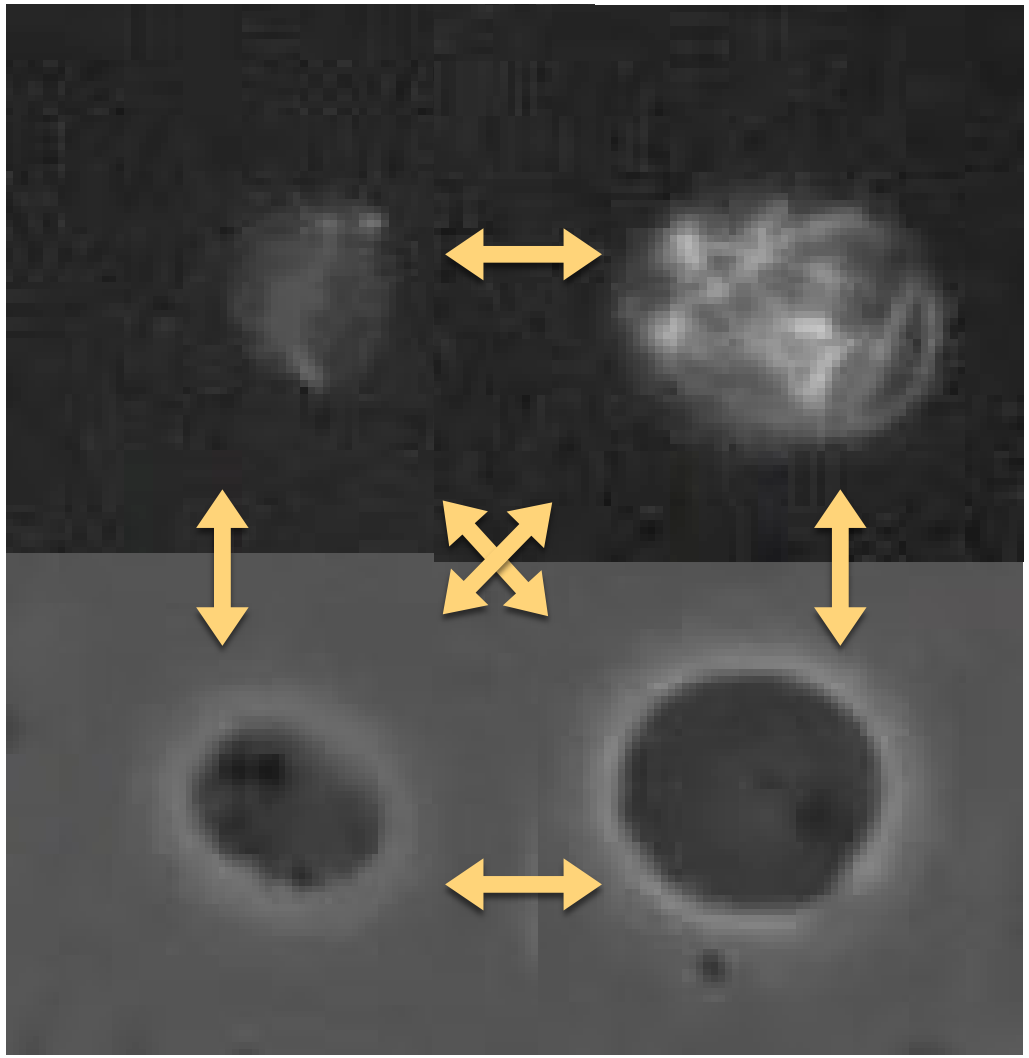
- 分子ロボットとは何か？
- その応用
- そのELSIの実践

Molecular Robot is a **self-propelling artifact** made of bio-molecules with **sense** and **intelligence** as like life things.

分子ロボットとは生物のように生体分子から構築され、**知性**と**感覚**を持ち**自律的に動作**する**人工物**である。

Amoeba-Type Molecular Robot @ Tohoku University
アメーバ型分子ロボット（東北大学, 2017）



Y. Sato
(Tohoku Univ.)
佐藤　佑介
（東北大、現東工大）

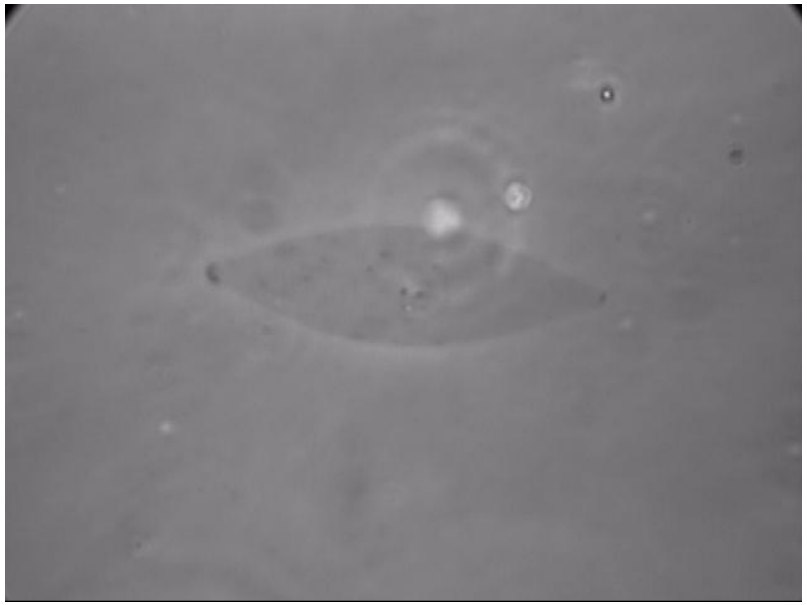
S. M. Nomura
(Tohoku Univ.)
野村　慎一郎
（東北大学）

Science Robotics, 2, eaal3735 (2017)

The amoeba-type robot consists of a **bacteria-size artificial membrane** containing biological and chemical components. **Cell-like motion** can be observed in a fluid environment. The motion can be **turned on and off** with **DNA signals** responding to light.

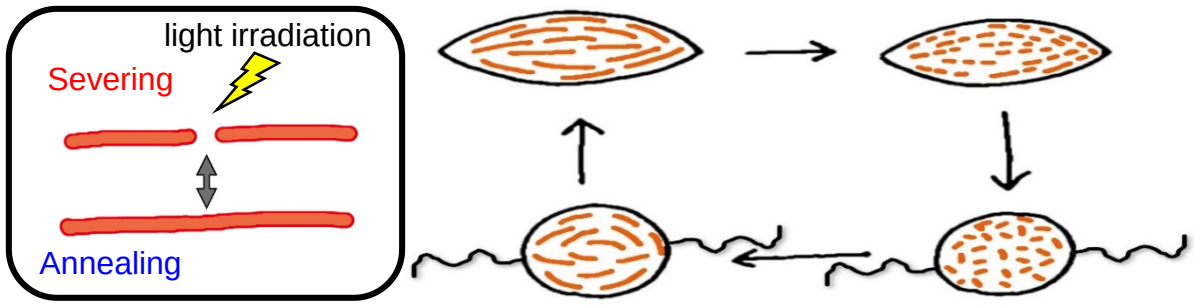
東北大学で創生した**アメーバ型分子ロボット**はバクテリアサイズの**人工細胞膜**で構成されており、中に、生体分子や化学的に合成した分子が含まれている。液体中で細胞のような動作を示し、**光に応答するDNA**を使った信号により動作の**オン/オフ**を制御できる。

Amoeba-type Molecular Robot @Nagoya University
アメーバ型分子ロボット（名古屋大学,2018）



M. Hayashi (Nagoya Univ.)　**S. Takiguchi (Nagoya Univ.)**

The amoeba-type molecular robot changes its shape by **light irradiation**, accompanied with **stretching and shrinking** of filopodia-like extensions.

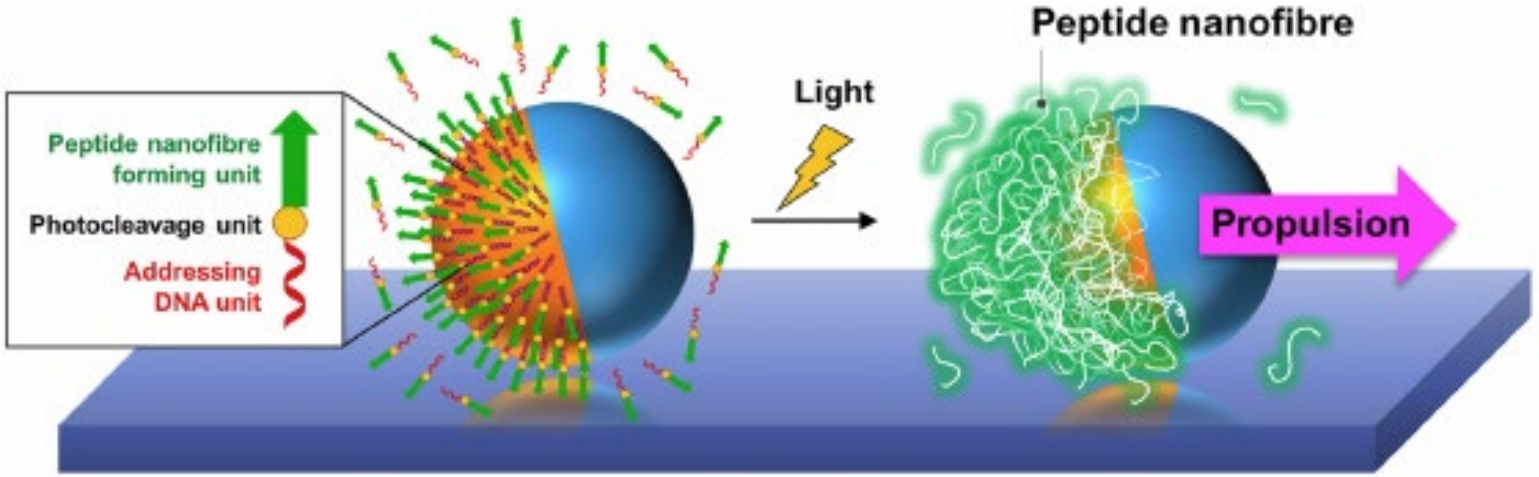


名古屋大学で作成したアメーバ型分子ロボットはアクチン線維を内包した人工細胞膜に光を照射すると、糸状偽足のような突起の伸長と収縮が生じ、細胞が大きく変形する。

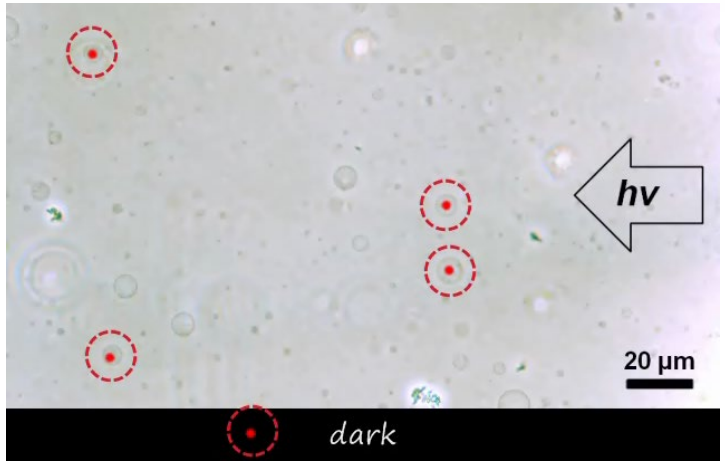
Communications Physics, 1 (18), (2018)

Amoeba-type Molecular Robot @Tottori University
アメーバ型分子ロボット（鳥取大学, 2018）

K. Matsuura
(Tottori Univ.)
松浦　和則
（鳥取大学）



The amoeba-type molecular robot achieved pure chemical molecular actuator of giant liposomes driven by **light-induced peptide nanofibre growth** on their surface similar to **actin comet tails of Listeria**.



鳥取大学で開発したアメーバ一型分子ロボットはバクテリア(Listeria)がアクチン線維を彗星の尾のように束ねて推進するように、**光照射**すると**ペプチドを束ねて**人工細胞膜を**推進**させる。

Scientific Reports, 8 (6243), (2018)

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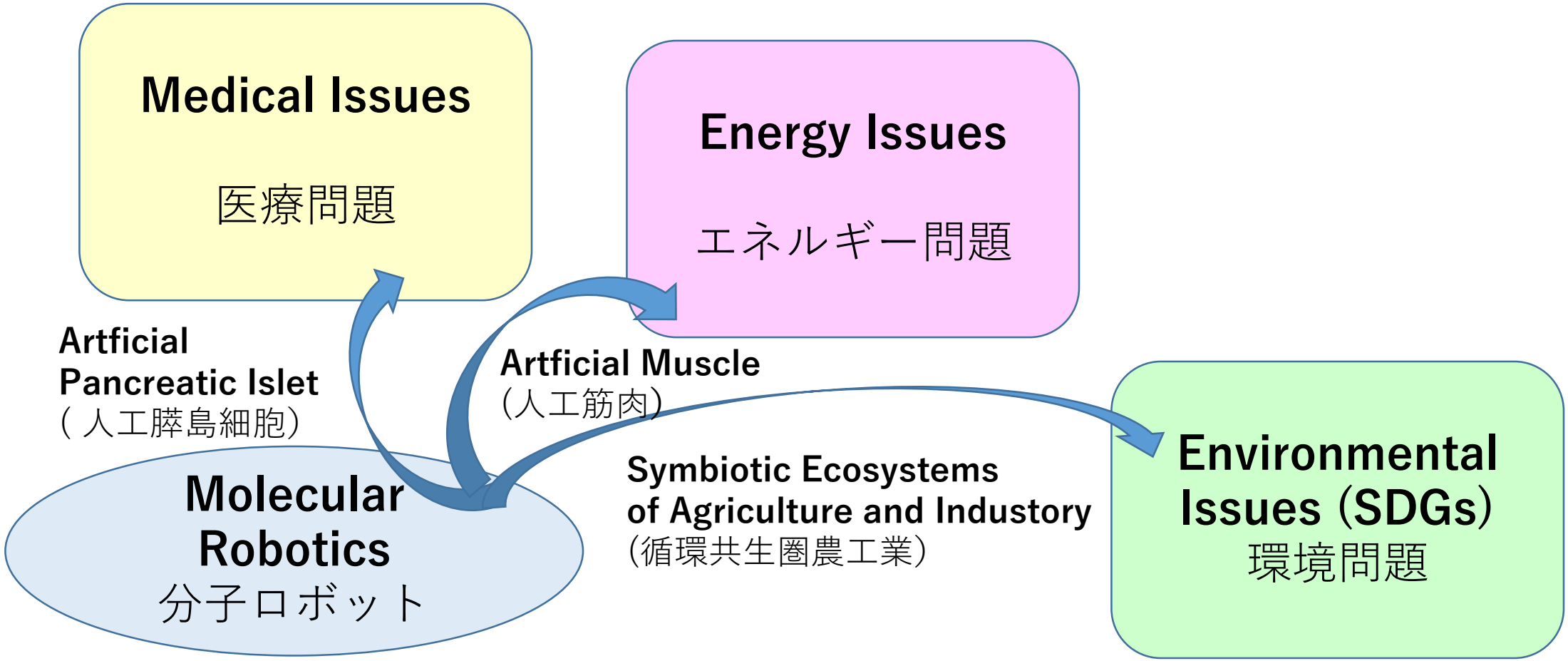
Molecular Robotics for Real Problem Solving
分子ロボットによる実問題解決



Molecular Artificial Pancreatic Islet:

“Smart drug” with sensors and intelligence

分子人工膵島細胞
（科研費2016-2019）

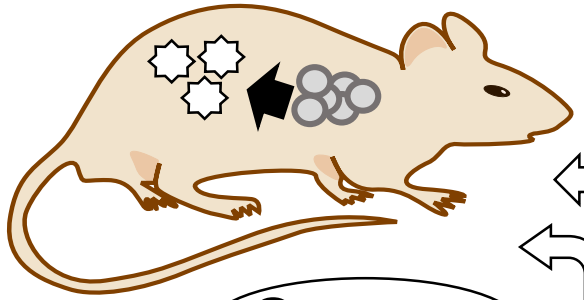
H31

H30

H29

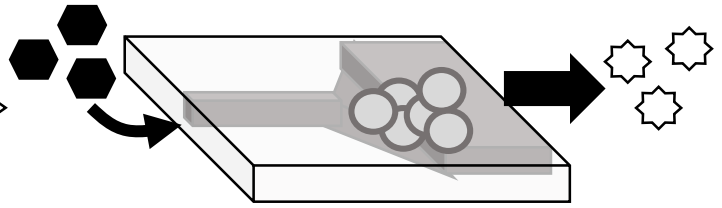
マウスでのin vivo試験

***in vivo* experiments with mice**



マイクロ流路でのin vitro試験

***in vitro* experiments on micro fluidic devices**



Sensor

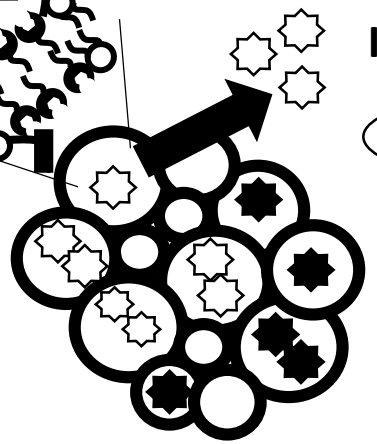
Glucose

DNA sensor

Insulin

Actuator

Intelligence



Molecular Artficial Pacreatic Islet

分子人工膵島細胞

Precision Medicine (2019)

Konagaya A.
（TITECH）

Noguchi H.
（Ryukyu U.）

Toyota T.
（U. Tokyo）

Yukawa H.
（Nagoya U.）

Umeda T.
（Kobe U.）

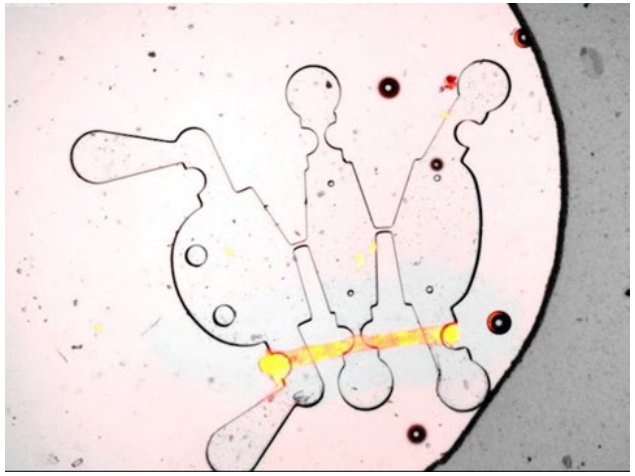
Ikeda M.
（Gifu U.）

Yanagisawa M.
（U. Tokyo）

Kawamata I.
（Tohoku U.）

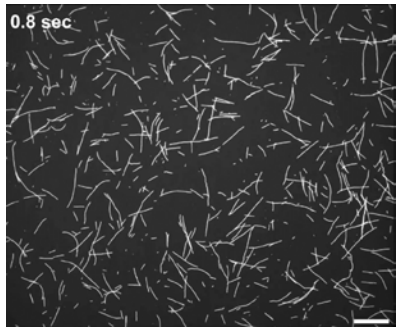
Molecular Artificial Muscle:
Chemical Energy Actuators for Clean World

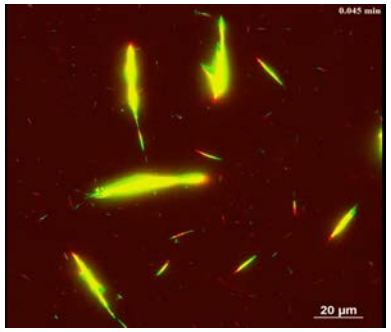
分子人工筋肉 (NEDO 2016-2019)
化学エネルギー駆動装置による
クリーン世界の実現

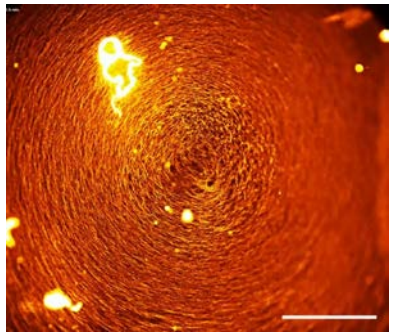


- **No Oil / No Electricity**
- **Propelled by Renewable Chemical Energy (adenosine triphosphate; ATP) as like as Life Things**

・石油や電気不要
・生物と同じ再生可能化学エネルギー
(アデノシン三リン酸; ATP)で動作







nm　μm　mm　cm

Nano Letters (2019), *ACS Nano* (2019)

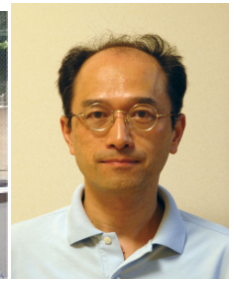
A.Kakugo (Hokkaido Univ.)

Akihiko Konagaya (TITECH)

A.Kuzuya (Kansai Univ.)

Yuichi Hiratsuka (JAIST)

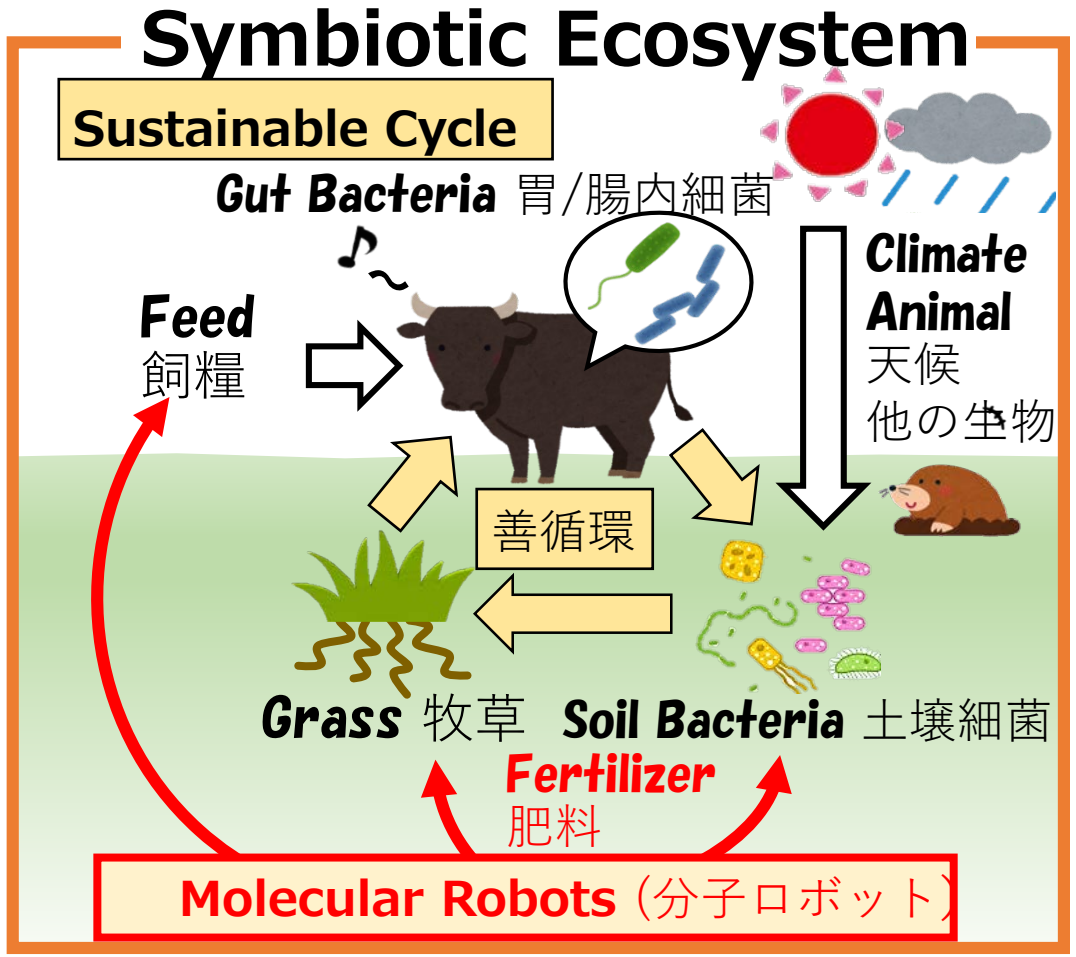
Yusuke Morishima (Osaka U.)



Yutaka Ueno (AIST)

Symbiotic Ecosystem Agriculture and Industry

- Sustainable agriculture enhancing carbon cycles
- From “efficiency-oriented” to “sustainability-oriented”



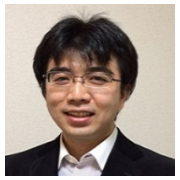
循環共生圏農工業(2019-)

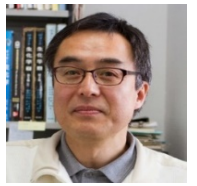
・炭素循環を促進する農業へ
・「効率重視」から「持続性重視」へ



M. Yamamura


A. Konagaya


M. Takinoue


M. Wachi


N. Yamamoto


Y. Muromachi


M. Yoshimoto


M. Sanpei

The Innovative Research Project for Symbiotic Ecosystems of Agriculture and Industry (TITECH)
https://symbiotic-ecosystems.info/

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ELSI Practices of Molecular Robotics

分子ロボットELSIの実践

- Research Collaboration with an Ethics Group
- Organization of International Symposium and Workshops with regards to “**Molecular Robot Ethics**”
- Formulation of **Molecular Robot Principle** and **Guideline**
- **Real-time Technology Assessment** for Emerging Technology

- 倫理研究者との共創
- **分子ロボット倫理**に関する国際シンポジウムやワークショップの開催
- **分子ロボット原則**および**ガイドライン**の策定
- 新興技術への**リアルタイム技術評価**の実践

Molecular Robot Ethics Project
分子ロボット倫理(JST 2017-2020)

Co-creation of **Molecular Robot ELSI** and **Real-time Technology Assessment** Research

分子ロボットELSIと実時間テクノロジー評価との共創

PI Akihiko Konagaya (TITECH)

Satoshi Murata (Tohoku Univ.)

PI Ryuma Shineha (Seijo Univ.)

Mikito Tanaka (Waseda Univ.)

Points:

- **Molecular Robotics** is one of **emerging technologies** which may affect to real world.
  分子ロボットは社会に影響を与える可能性のある技術の一つである

- No one has ever applied "**Technology Assessment**" to "Emerging Technology" in real-time (not **retrospectively**) in Japan.
  日本では,「**技術評価**」はこれまで**回顧的**にしか適用されたことがなかった

Go Yoshizawa（OsloMet, Norway）

Caution for self-duplicated nano robots

自己増殖ロボットに対する警告

Biology
生物学

Synthetic Biology
合成生物学

Xenobiology
非天然合成生物学

- Construction of DNA Devises and SB
- Synthetic metabolic pathway engineering
- Genome Cell Technology (Top Down)
- Genome Cell Technology (Bottom Up)
- Proto-cell Construction (Artificial Cell)
- Non-natural Biology (xenobiology)

Rinie van Est
(Rathenau University, Dutch)

Molecular robots may increase risk factor if it acquires self-duplication property

The 1st Int. Conf. on Molecular Robot Ethics (13 Mar. 2017, Tokyo)

分子ロボットが**自己増殖機能**を持つと**危険性増化**

Molecular Robots **分子ロボット**

DNA Robots DNAロボット

Category in The Convention on Biological Diversity（CBD）

Comments about “Technology Assessment of Molecular Robot”
（「分子ロボットの技術評価」に関する有識者コメント）

Erika Szymanski
(Univ. of Edinburgh, UK)

Importance of not to lock in the specific issues for various futures
(問題を**固定化しないで**)

Adaptive approach would be better than conventional rule approach to deal with risk governance
(**適応的**な方法が良い)

Kenneth Oye
(MIT Political Science, USA)

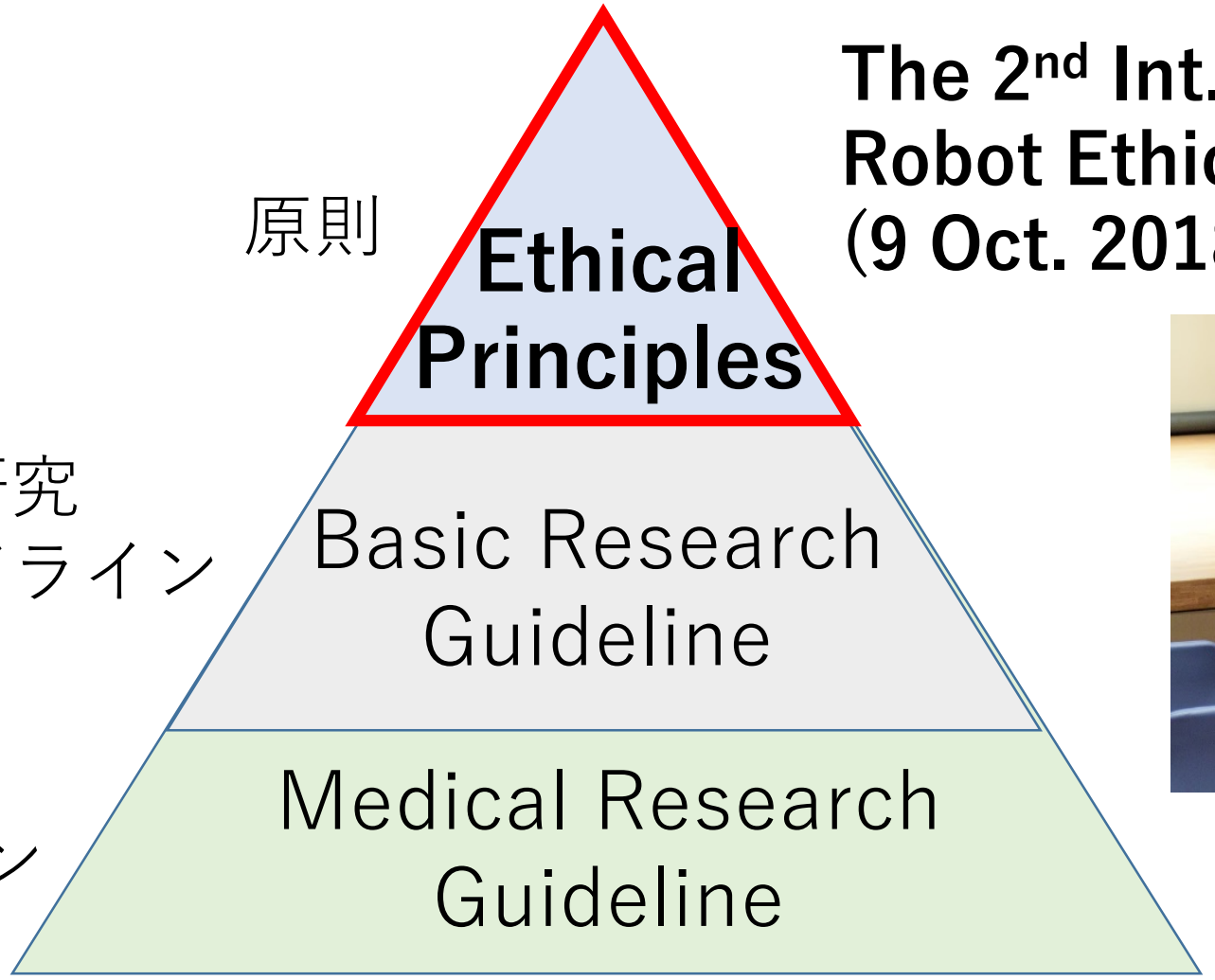
Importance of interdisciplinary technology assessment
(**領域横断的**な技術評価が重要)

Stephan Lingner（EATIA, Germany）

The 2nd Int. Conf. on Molecular Robot Ethics
(9 Oct. 2018, Tokyo)

Molecular Robot Principles and Guidelines

分子ロボットの原則とガイドライン策定



The 2nd Int. Conf. on Molecular Robot Ethics
(9 Oct. 2018, Tokyo)

Ethical Principles of Molecular Robotics (ver. 1.1)　分子ロボット原則

First Edition: Mar. 5, 2018 / Second Edition: Aug. 8, 2018

Naoto Kawahara
（ARO Center, Kyushu Univ.）

- **Preamble**
- Nowadays, it is an issue of extreme importance to establish an ethical framework with a new view of material, information and life according to a technological development. With ever-increasing progress in creativity and ingenuity of technology, new devices and systems appear continuously. However, there are concerns about the ethical scope of molecular robotics. In Japan, research and development of molecular robotics has been promoted, taking advantage of an important elemental technology concerning senses, motions and intelligence. More complicated configurations of systems in molecular robotics are conceivable, which will be applied to informatics, engineering, chemistry, biology and medicine in the near future. In this context, we formulate the following ethical principles. We also request any person who engages in molecular robotics to comply with these principles.

Ethical Principles

1. Comprehensive assessment of risks and benefits

▸ Any person who engages in molecular robotics shall make a comprehensive assessment of potential harm for human beings or the environment as well as predicted risks and benefits. Then they shall also take measures to minimize those burdens and risks.

リスク・ベネフィットの総合評価

2. Consideration for safety and environment

▸ Any person who engages in molecular robotics shall take containment and safety measures for the environment. This includes ethical responsibility and consideration for future generations.

安全と環境への配慮

3. Paying attention to security and dual-use issues

▶ Any person who engages in molecular robotics shall investigate security measures in consideration of physical, personnel, transport, material, and information aspects. They shall also pay attention to dual-use issues.

セキュリティとデュアルユース問題への留意

4. Ensuring accountability and transparency

▶Any person who engages in molecular robotics shall ensure accountability and transparency for the public good, making progress of the research and development rooted in social justice.

説明責任と透明性への担保

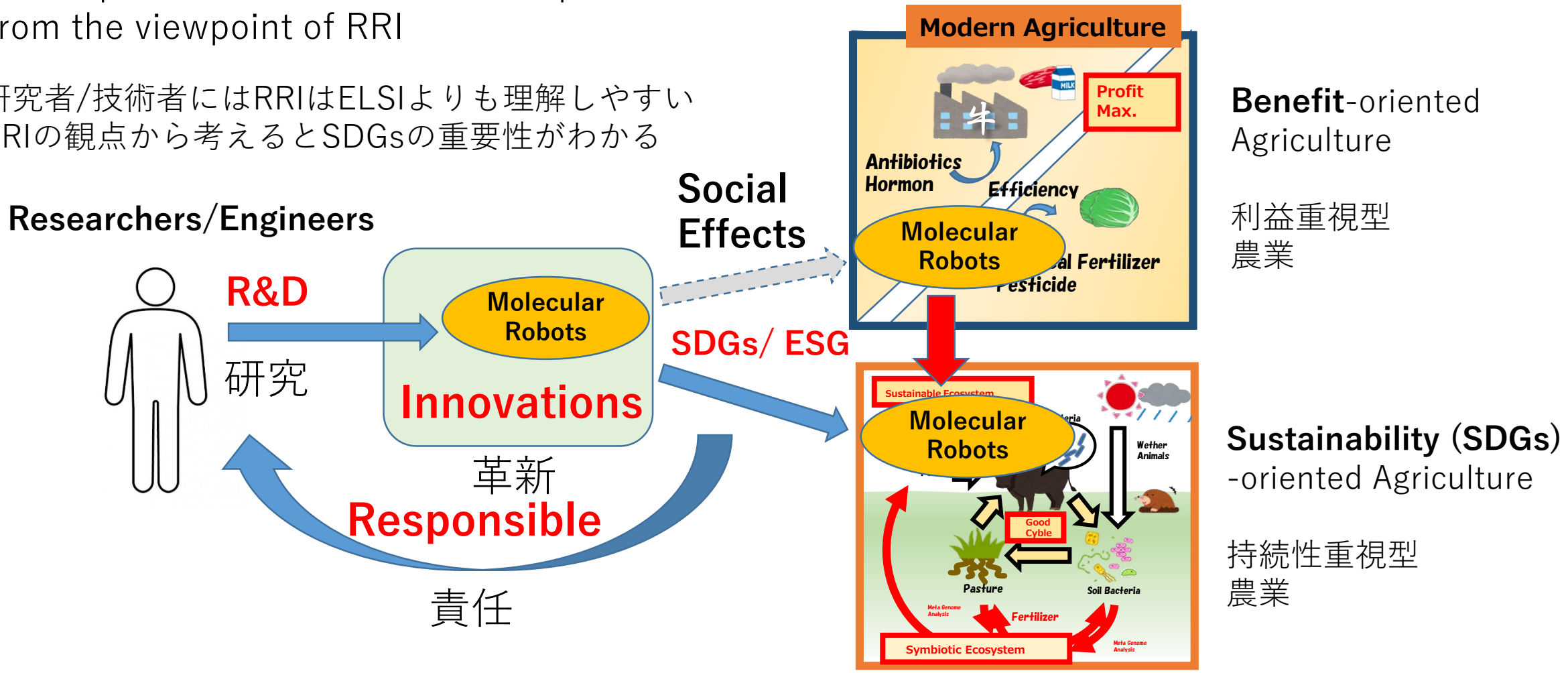
The above principles will continue to be revised as needed.

Responsible Research and Innovation

- Good Ethical Framework to change the philosophy of R&D
- The importance of SDGs can be explained from the viewpoint of RRI

責任ある研究と発明

- 研究者/技術者にはRRIはELSIよりも理解しやすい
- RRIの観点から考えるとSDGsの重要性がわかる



Benefit-oriented Agriculture

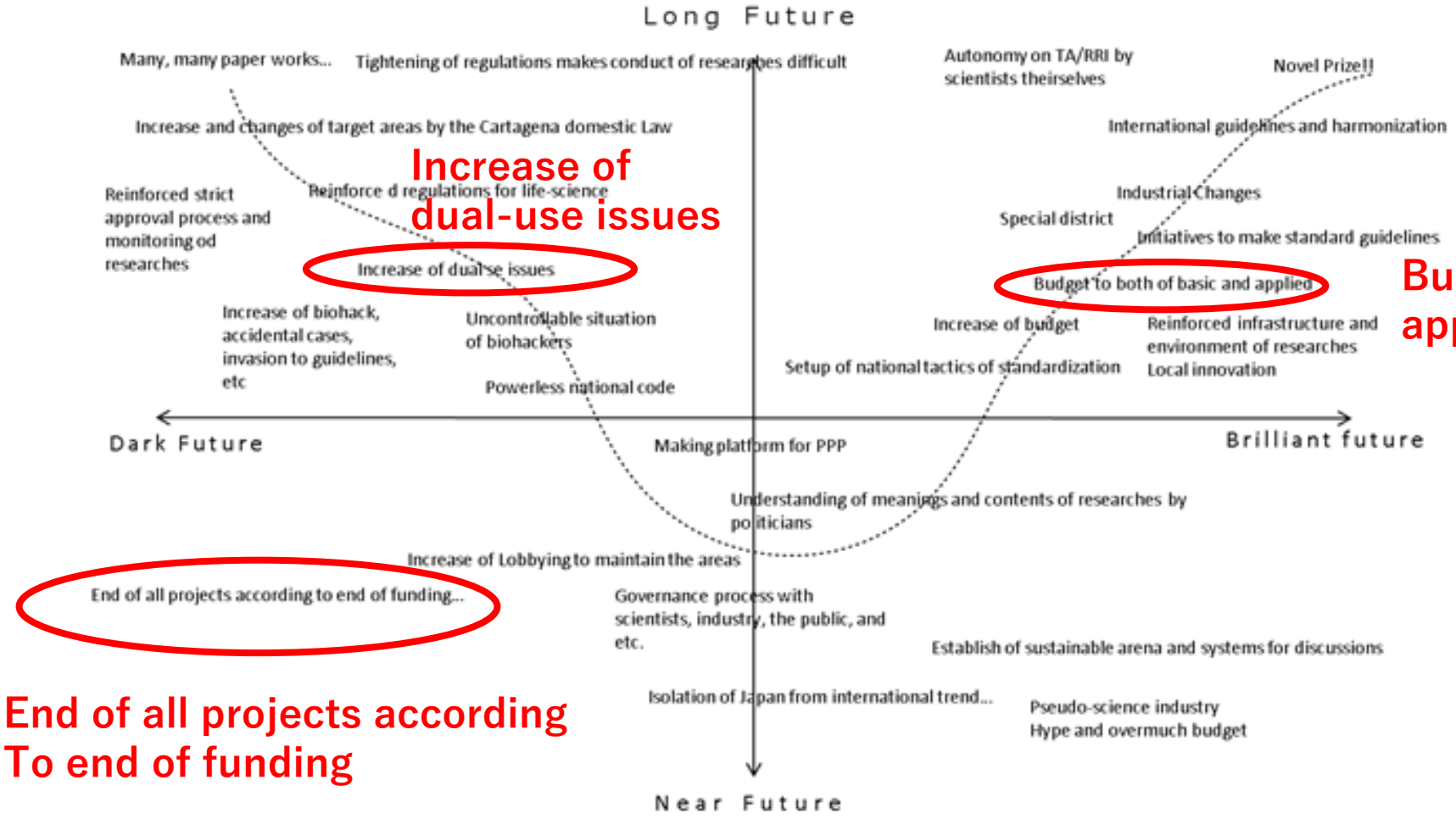
利益重視型農業

Sustainability (SDGs) -oriented Agriculture

持続性重視型農業

Consensus Conference including journalists and citizens about “Future Prospects and Issues of Molecular Robotics”

ジャーナリストや市民を含めた「コンセンサス会議」による「分子ロボットの未来と課題」



Budget to both of basic and applied

End of all projects according To end of funding

Mar, 2018 RRI workshop, @Tamachi CIC

Summary

- ELSI plays a very important role to promote emerging technology to **brilliant future**.
- Research collaboration between a research group and a ethical group produce fruitful results if the **leaders are committed to ELSI**.
- Ethical frameworks such as **Technological Assessment, Principle and Guideline Formulation, RRI and Consensus Conference** are worth practicing, although it takes **more than years** for researchers to understand the true meaning of such activities.
    - ELSIは新興技術に関する研究開発をより**望ましい方向**に進めるために重要な役割をする。
    - **研究開発リーダーがELSIにコミット**すれば、倫理研究者のグループとの協力により大きな成果をもたらす。
    - **技術評価、原則やガイドラインの策定、ＲＲＩ、コンセンサス会議**などのELSIの枠組みは十分実践に値する。ただし、そのことの本当の意味を研究者が理解するには**年単位の時間**が必要である。