Global Focus on Knowledge

Production and Application of matter

The University of Tokyo Hiroshi Komiyama

Lecture one: manufacturing processes, e.g., metal (iron and steel)

Lecture two: Conjugation (devices), e.g., semiconductors, soft matters

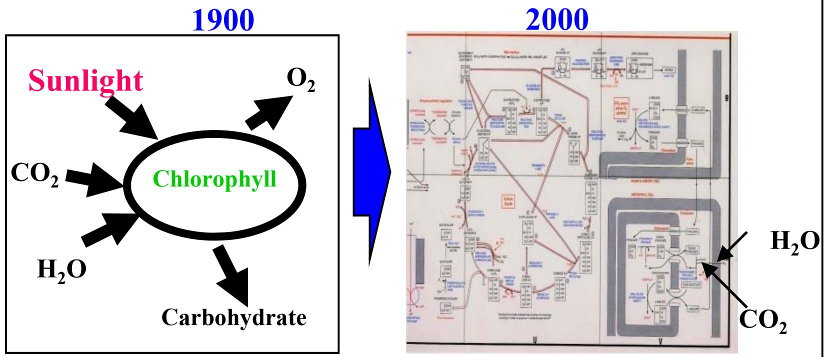
Lecture three: Materials (devices) science for a sustainable future

fuel cells and micro-chemical chips

thermodynamics, kinetics

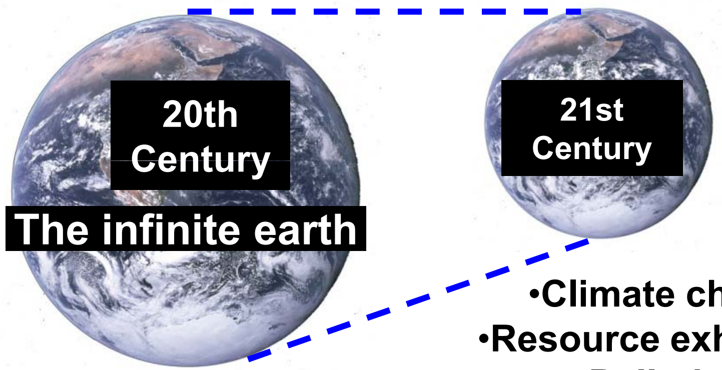
The 21st century trends

Increasing amount of knowledge



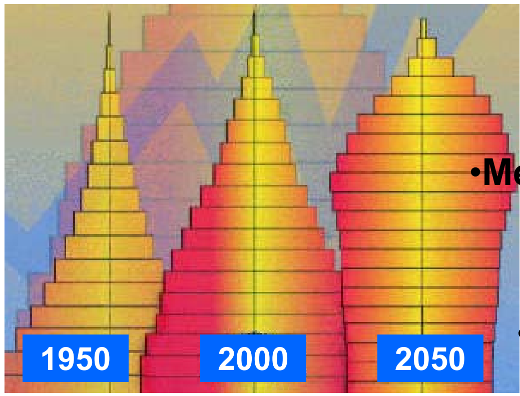
photosynthesis

the finite Earth



- Climate change
- Resource exhaustion
- Pollutions
- Food and water

Aging society



- Longer life
- Fewer children
- Medical advancement
- Social security
- Worksharing
- accessibilities…

From wikipedia

Global focus on the「earth」×「100 years」

What will become of matter and energy on 2050?

Now is the time of “paradigm shift”

“the finite Earth”

“saturation of artificial materials”

“climate change increases”

“exhaustion of resources”

Vision for 2050: “the answer”

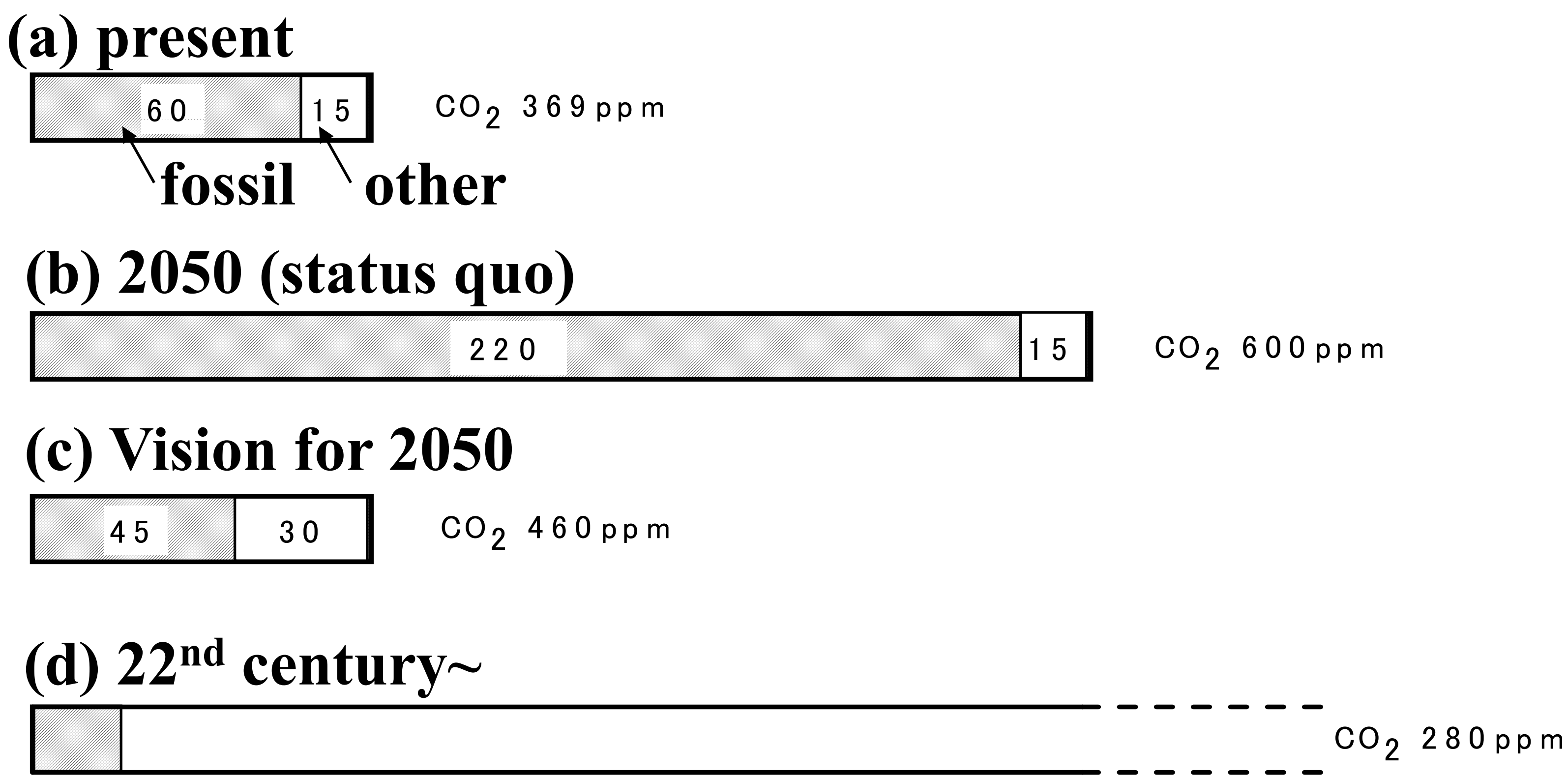
Energy efficiency improves

Constructing circularizing systems

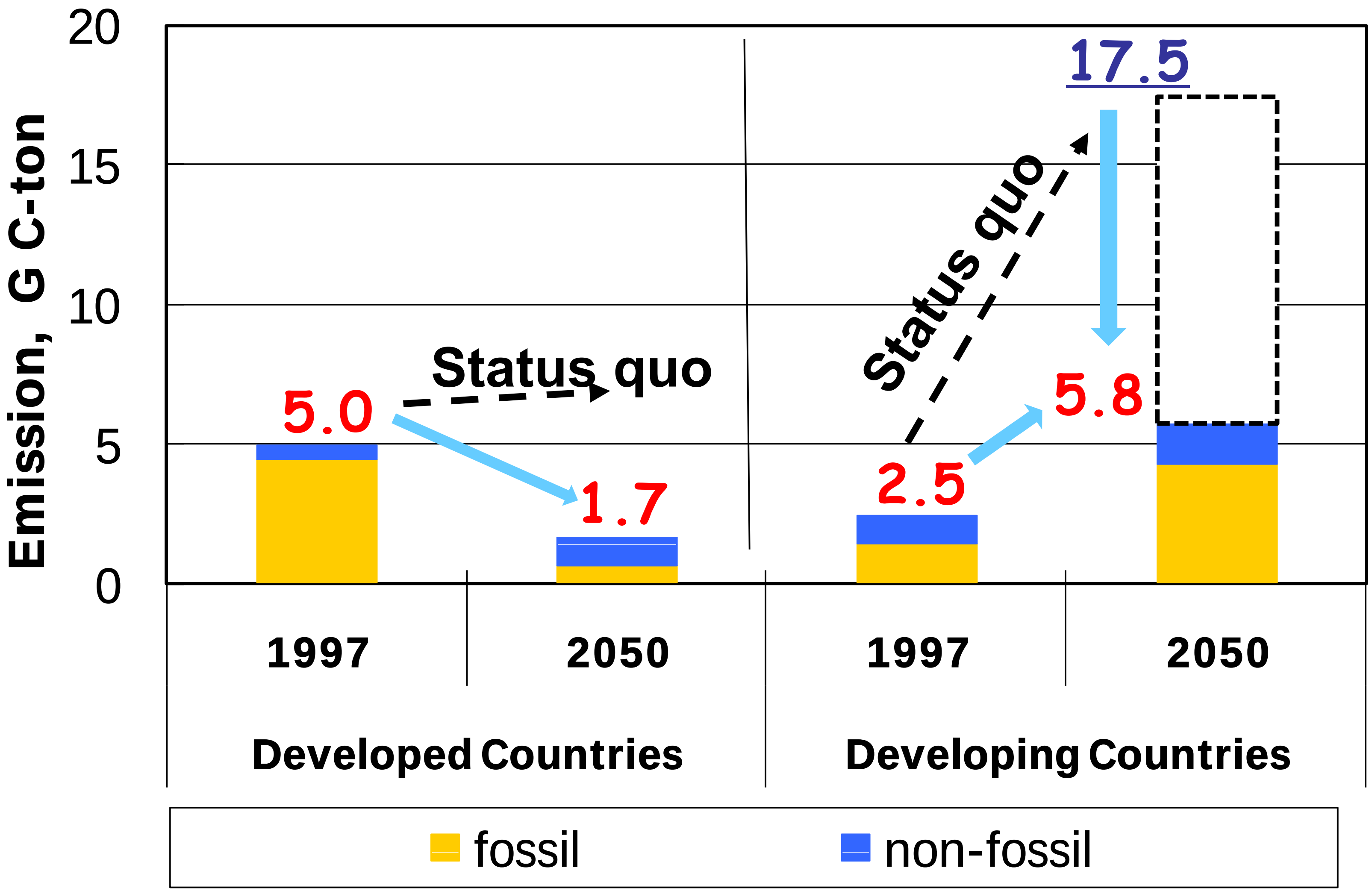
Recyclable energy double

Appropriate from a theoretical and technical point of view
Also, it is possible to gain the international consensus

Vision for 2050



developed countries and developing countries should compromise



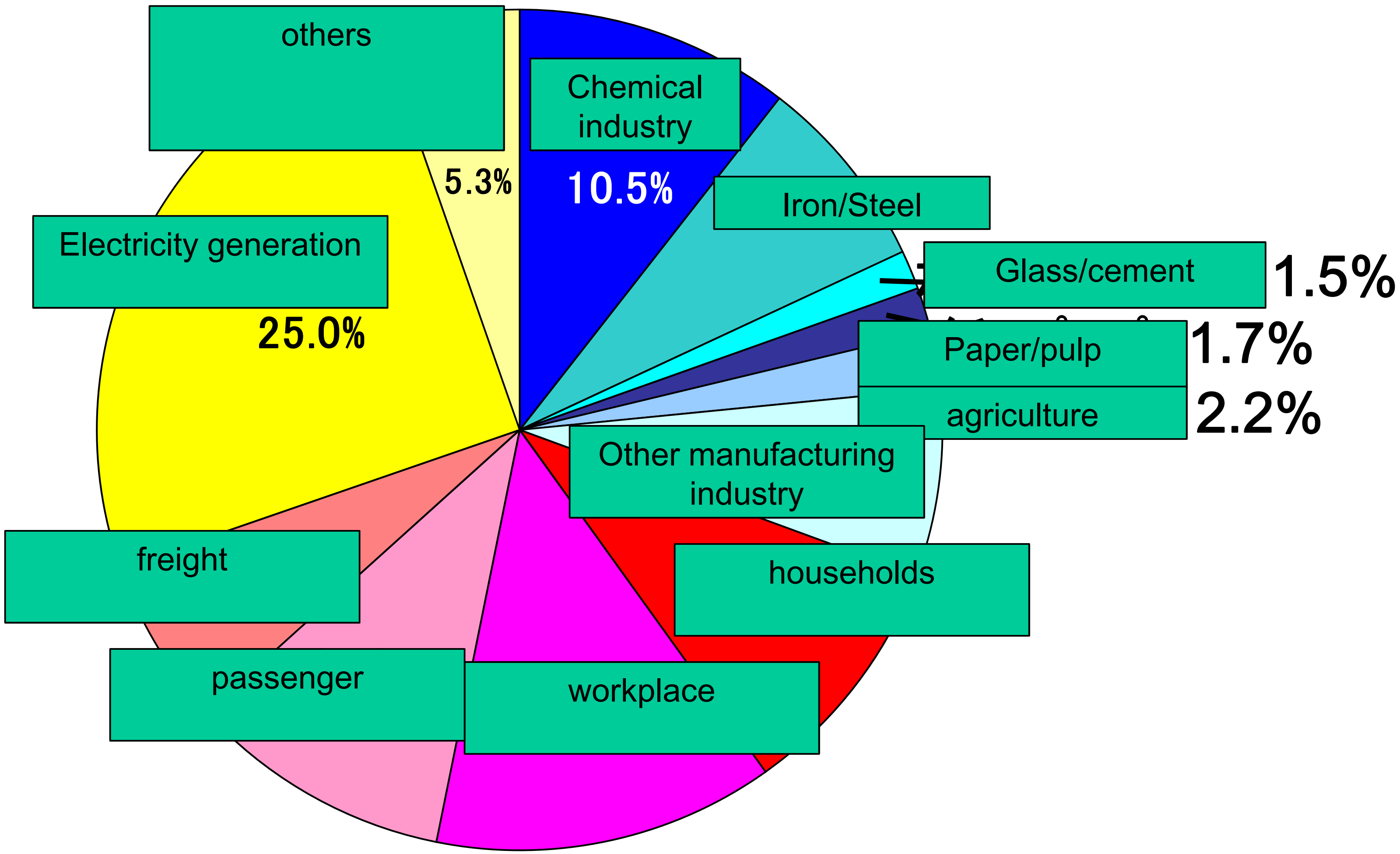
Energy efficiency triple

Energy resource : primary energy

Energy : secondary energy
electricity, hydrogen, gasoline

Transfer efficiency……electricity generation,
petroleum refinement
Utilization efficiency…steelmaking, automobiles,
air conditioning

Energy consumption in Japan

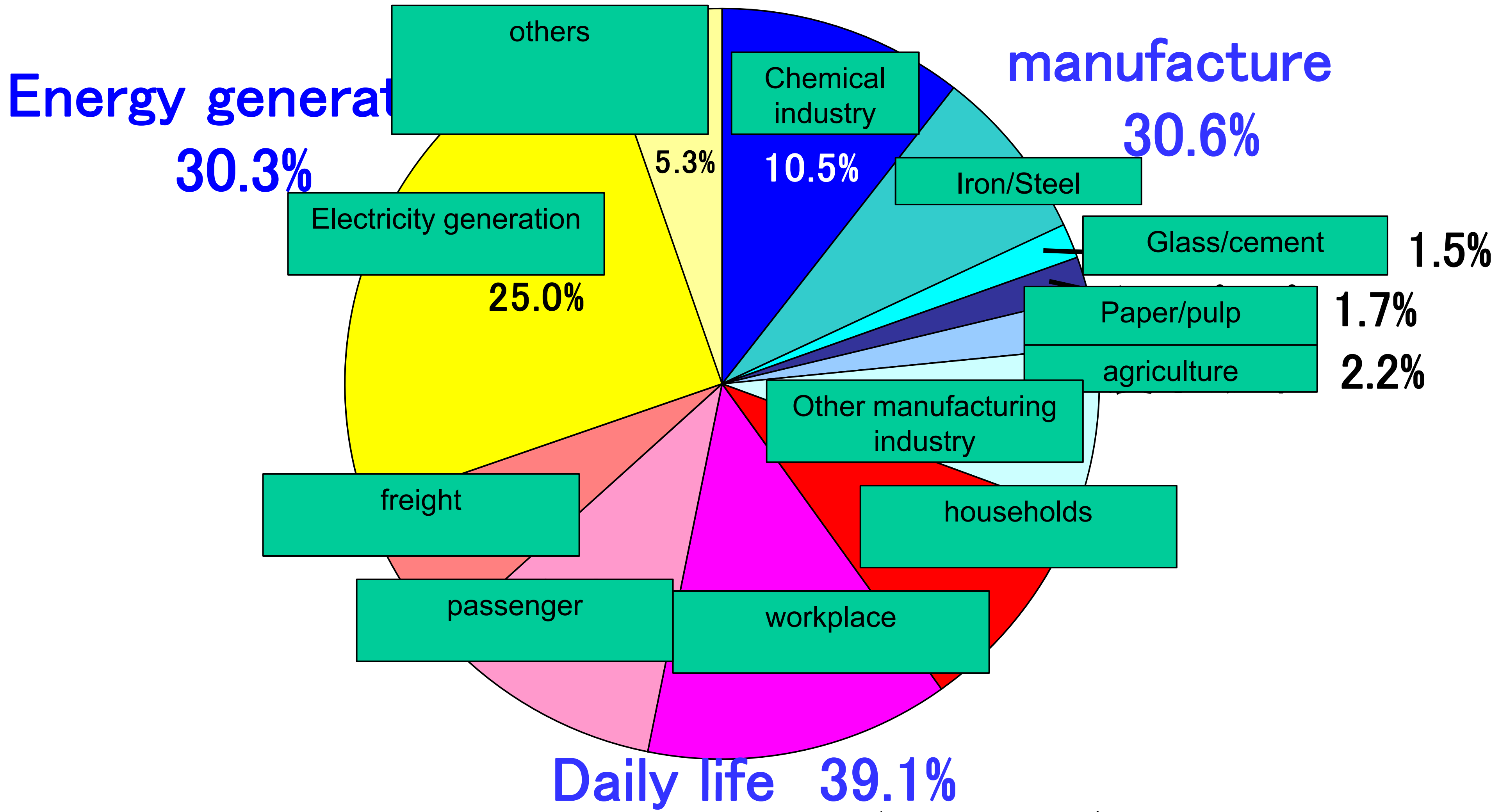


Energy in Japan 2007 （data 2005）

Note: the energy generating cites themselves consume some of the energy they generate, and also it is not possible, in reality, to put all of the available energy to use.

Structuration of knowledge :

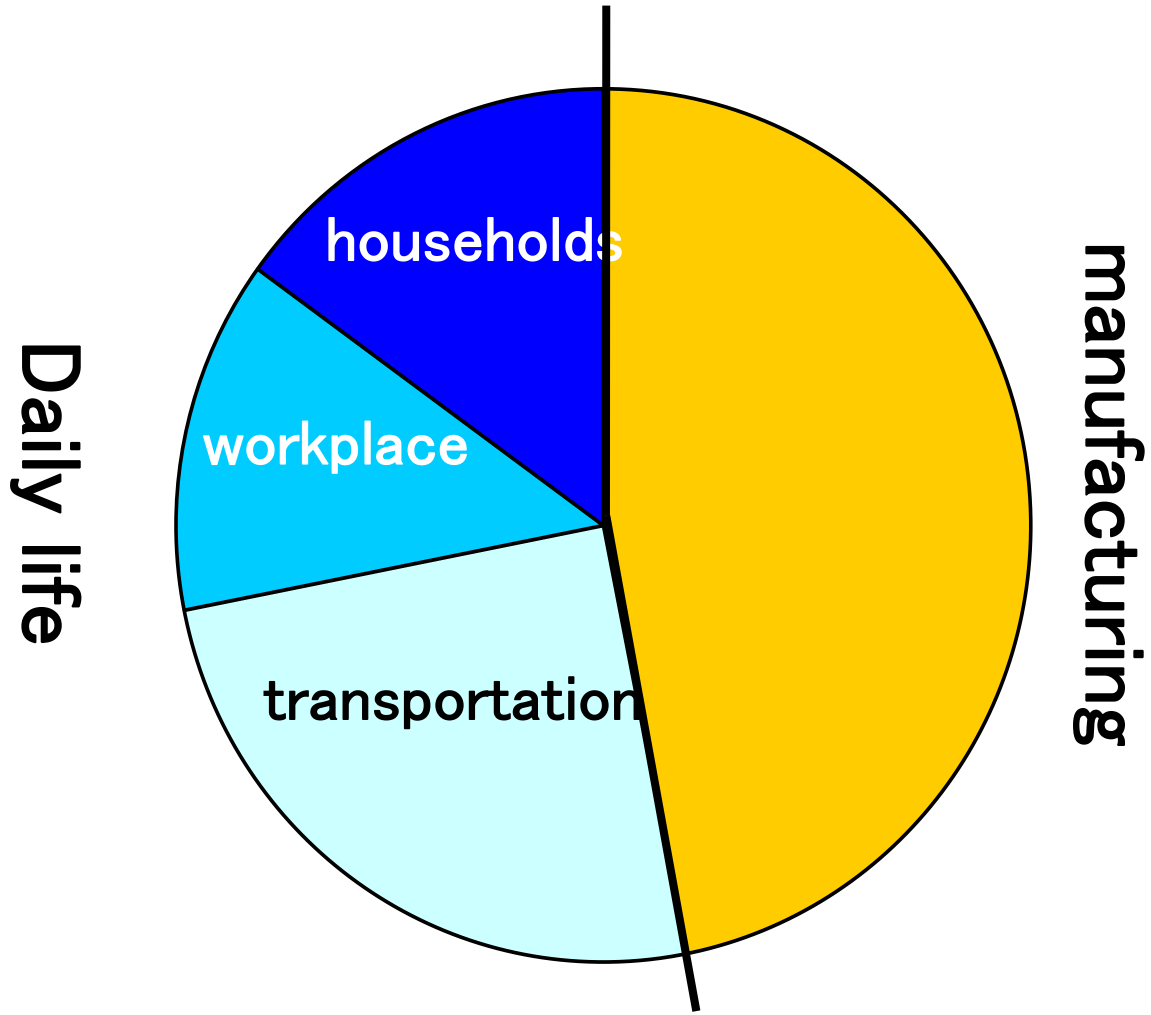
Energy consumption in Japan



Energy in Japan 2007（data 2005）

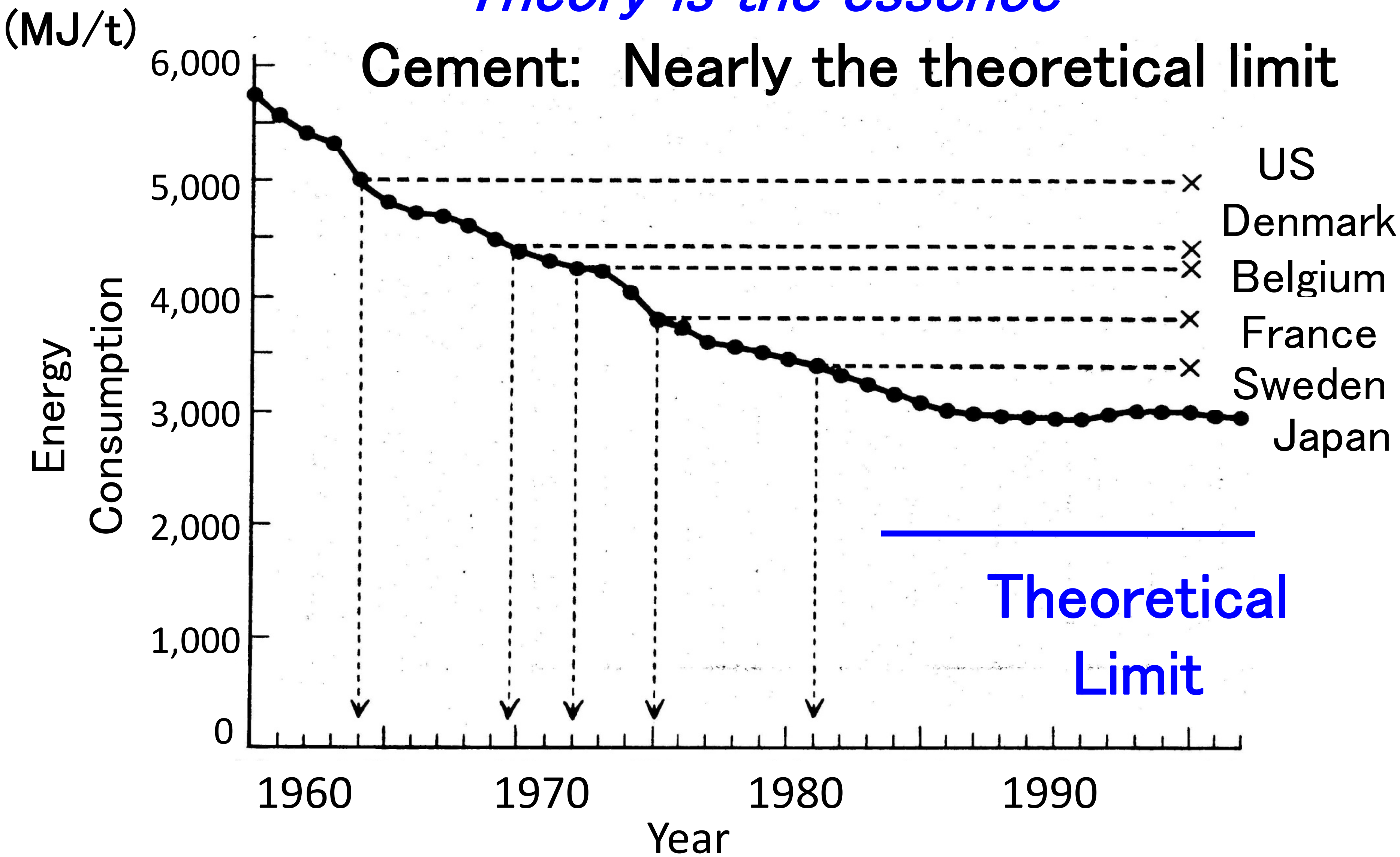
Note: the energy generating cites themselves consume some of the energy they generate, and also it is not possible, in reality, to put all of the available energy to use.

That Japan is taking a low-carbon strategy is clear



Reduction in everyday life and energy-saving manufacture

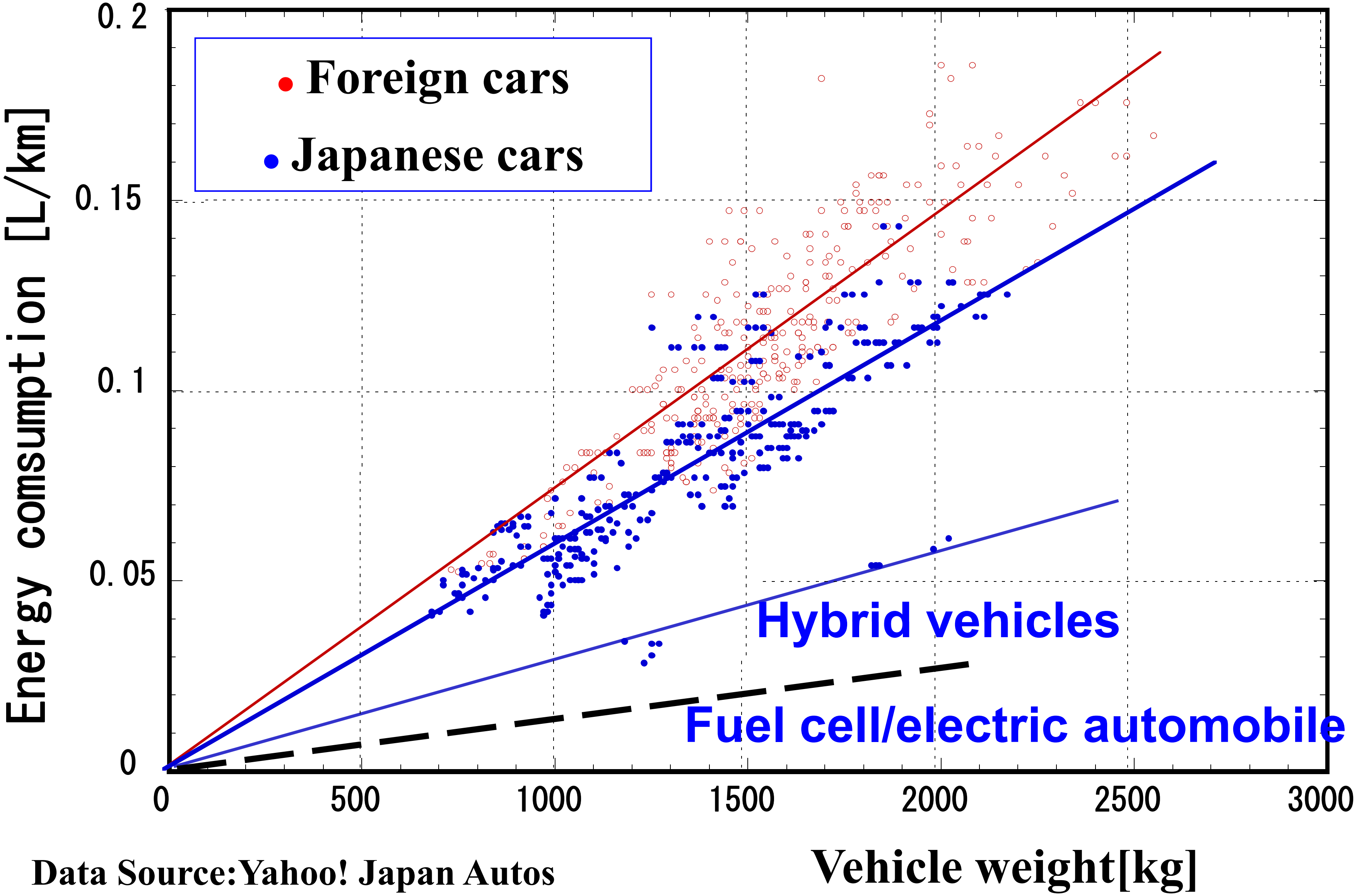
Theory is the essence



Source: Japan Cement Association

Expression is the essence

Automobiles :energy consumption could be 1/10



Data Source:Yahoo! Japan Autos

Energy efficiency of automobiles
（tank to wheel)

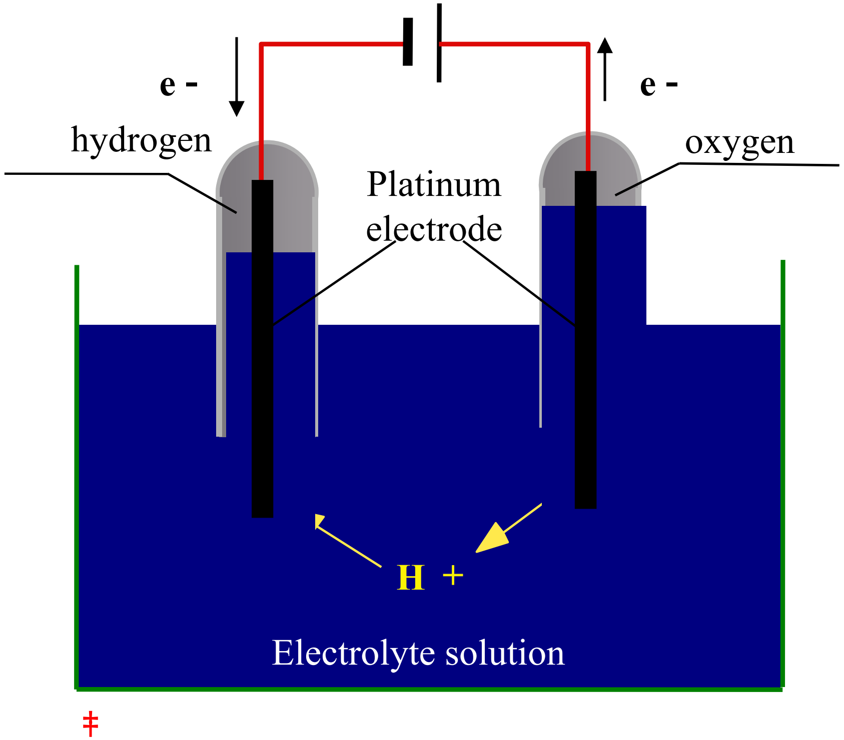
Current vehicles	13%	unchanged
Limit of hybrid cars	35%	3 times
Electric automobile (energy generation rate: 55%)	50%	4倍
0.96V fuel cells	80%	6 times
half weighted		12 times

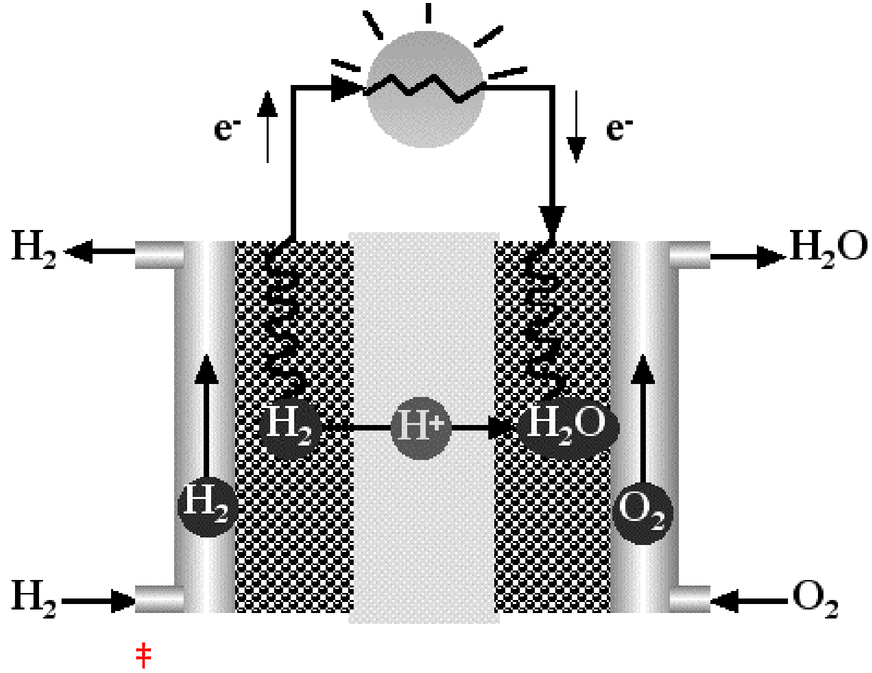
Theoretical value is zero→crosses the origin

Principles of fuel cells

Water electrolysis ⟷ **Fuel cell**

Reverse reaction





Greater than 1.2 V is required

Electrochemical reaction

Hydrogen pole : $H_2=2H^++2e^-$

Oxygen pole : $2H^++1/2O_2+2e^-=H_2O$

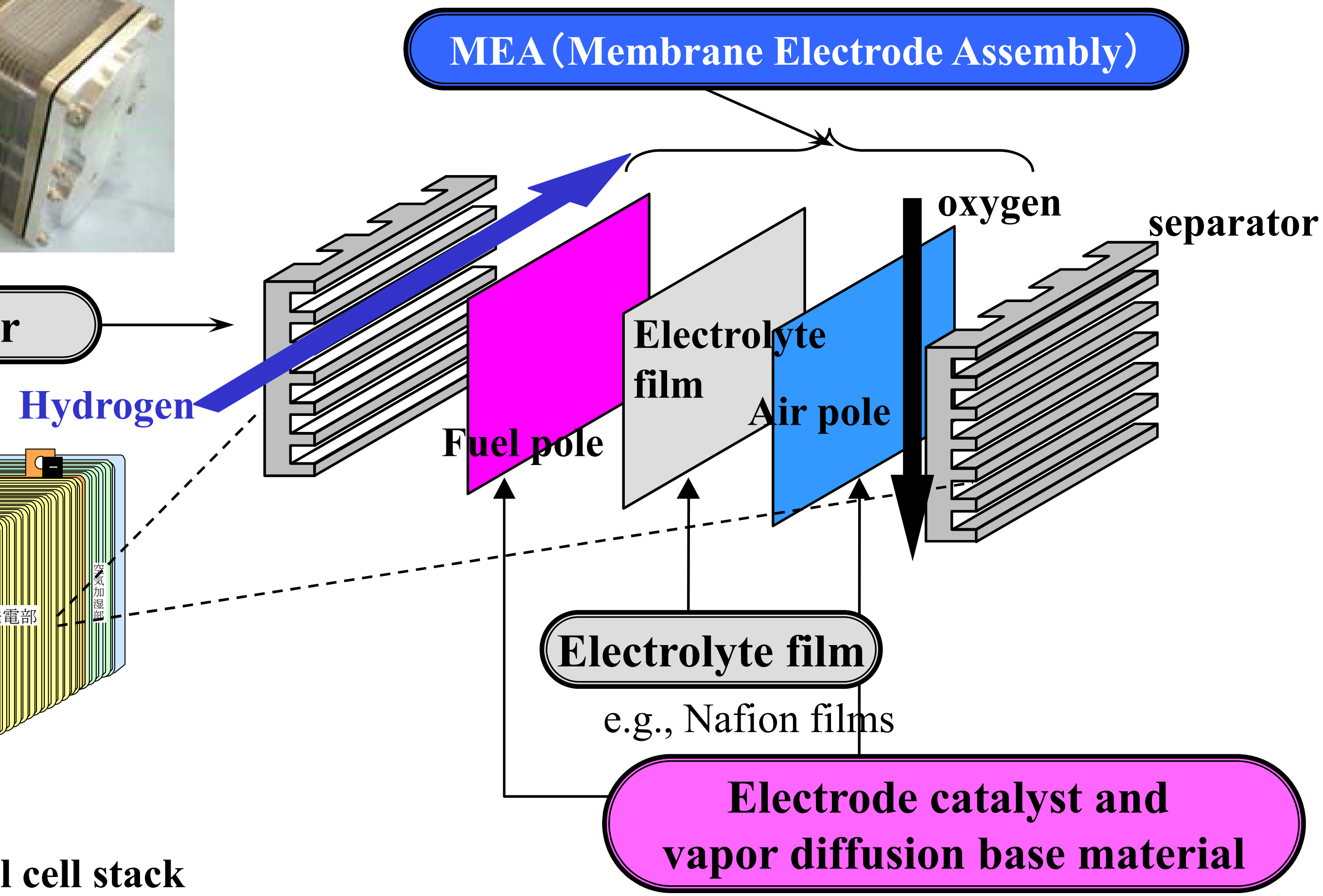
max 1.2 V

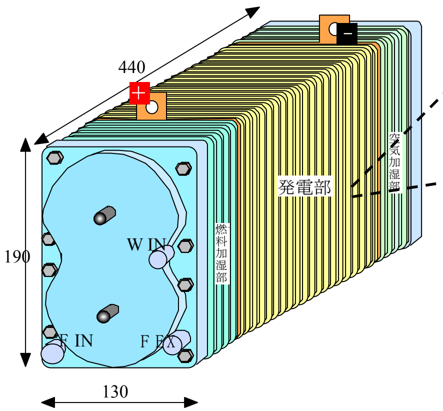
Provided by Prof. Yamaguchi, Tokyo Institute of Technology

Fuel Cell System and Materials

Separator

Carbon resin



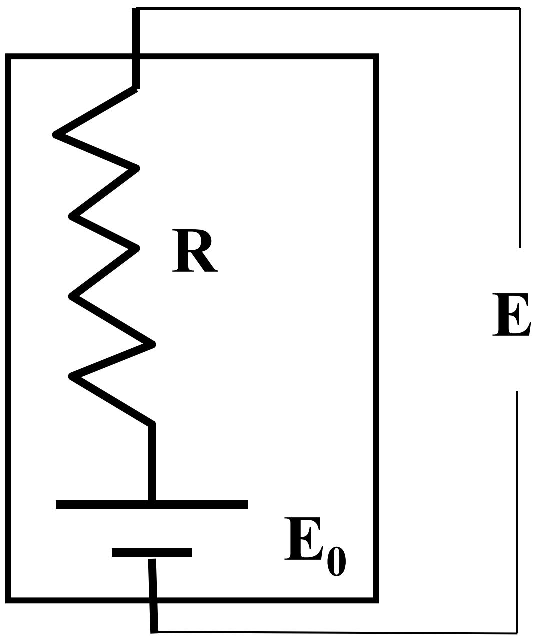


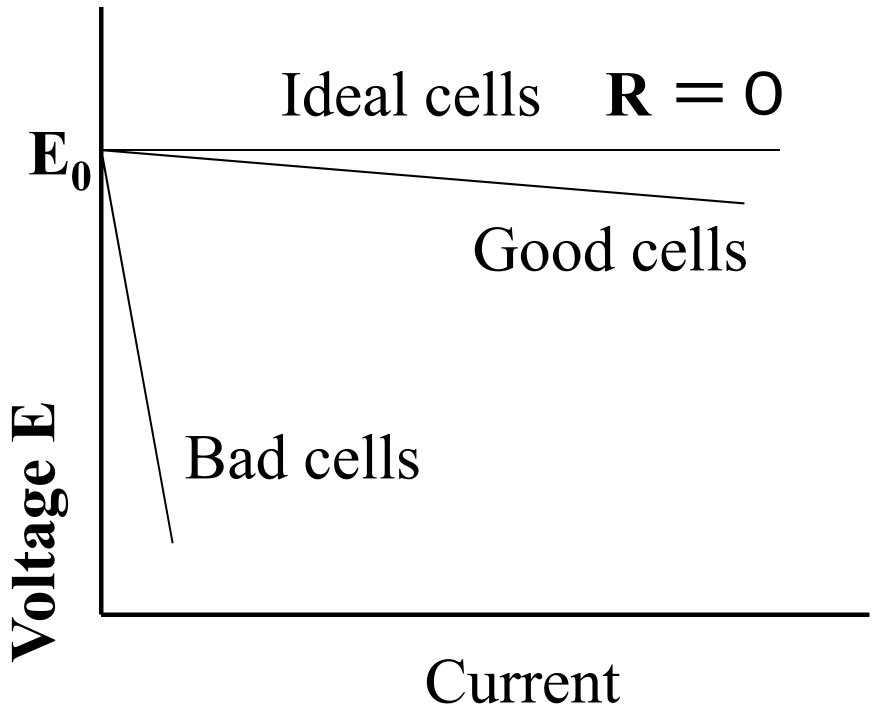
Fuel cell stack

‡ (sources: Mitsubishi Electric Corp.)

Provided by Prof. Yamaguchi, Tokyo Institute of Technology

The cause of efficiency (E/E_0) drop is internal resistance





Maximum efficiency is expected if the Electric current is zero, but it is useless. (Electric voltage :E_0)

the theory of energy is composed of: "thermodynamics" and "kinetics"

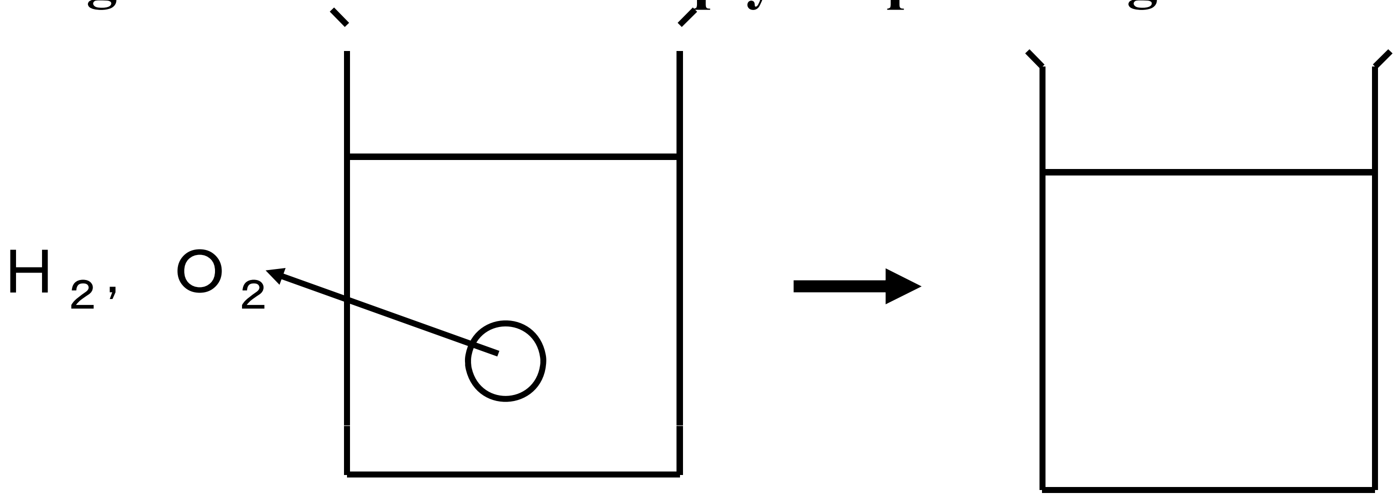
Thermodynamics：idealistic

Kinetics：realistic

Low Efficiency Processes

１　A fuel cell with electromotive force of 0.12 volts→ 10% efficiency

２　Ignite in water and simply keep burning → 0% efficiency



Ignition　　　Practically, there is no change.

Hydrogen and oxygen become water at 25℃.

Infinite processes that is not in ideal conditions

Thermodynamics : an idealization

change $H_2 + \frac{1}{2}O_2 = H_2O$ 25℃

changes during the process
do not have any effect in thermodynamics

Energy generation ＝ electric ＋shaft work＋light＋sound＋・・＋heat

ΔH **(constant)** $= \Delta G + T\Delta S$

The maximum value of all work (except for heat)!

Maximum theoretical efficiency $= \dfrac{\Delta G}{\Delta H}$

In the case of the fuel cell: 1.2V
$1.2 \times (2 \times 96500) = 237\text{kJ} = \Delta G$

Not yet fully proved

Water electrolysis minimum**1.2** [V]　25℃

Minimum energy = **1.2** [V] × Current[A]

If we can create a fuel cell that generates **2** [V],

$$H_2 + \frac{1}{2} O_2 \underset{\mathbf{1.2}\ [V]}{\overset{\mathbf{2}\ [V]}{\rightleftarrows}} H_2O$$

Single operation of water electrolysis and fuel cell can yield the energy of: **0.8** [V] × current

Which in fact violates the low of conservation of energy and matter → it must be impossible

Fuel cell of **1.2** [V] possesses the maximum energy conversion efficiency.

Expectations for Fuel Cells

although the theoretical efficiency are the same,

Power generation can be achieved by rotating the shaft of a generator.←bicycles

Thermal power generation←the turbines are spinning via steam power and combustion gas.
←Ideal conditions can be obtained by increase of temperature

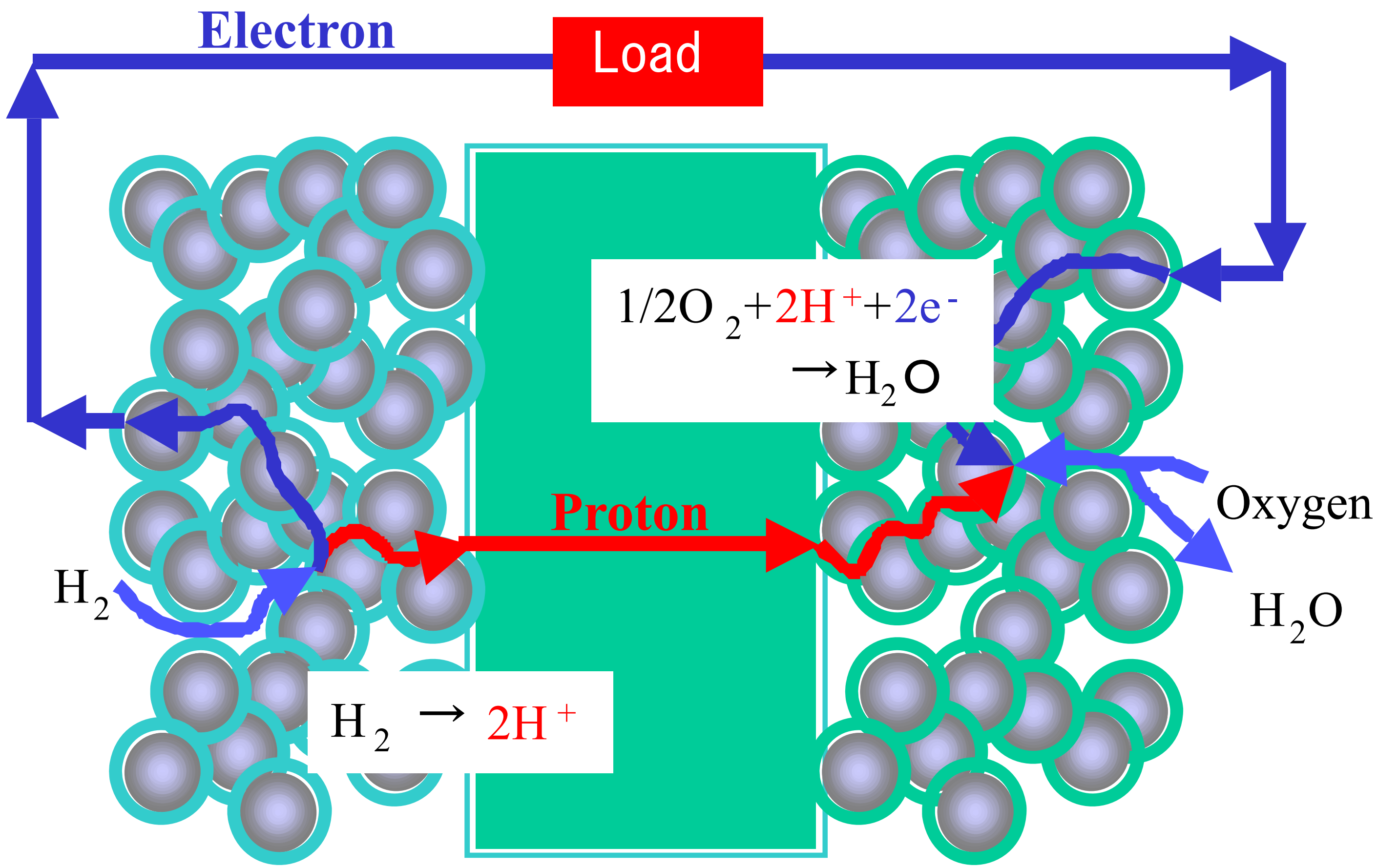
Steam turbines:	limit of steam temperature
gas turbines:	limit in materials

Fuel cells←there is no restriction of temperature
because there is no heat conversion concerned in the reaction

- possibility of efficient power generation at low temperature
- the solutions for efficiency improvement may become clear.
- Applications of miniaturizations, mobiles, dispersed stationary-types, and portable generators.

Be able to corresponds with the load fluctuation.

Nature is described by the kinetic theory



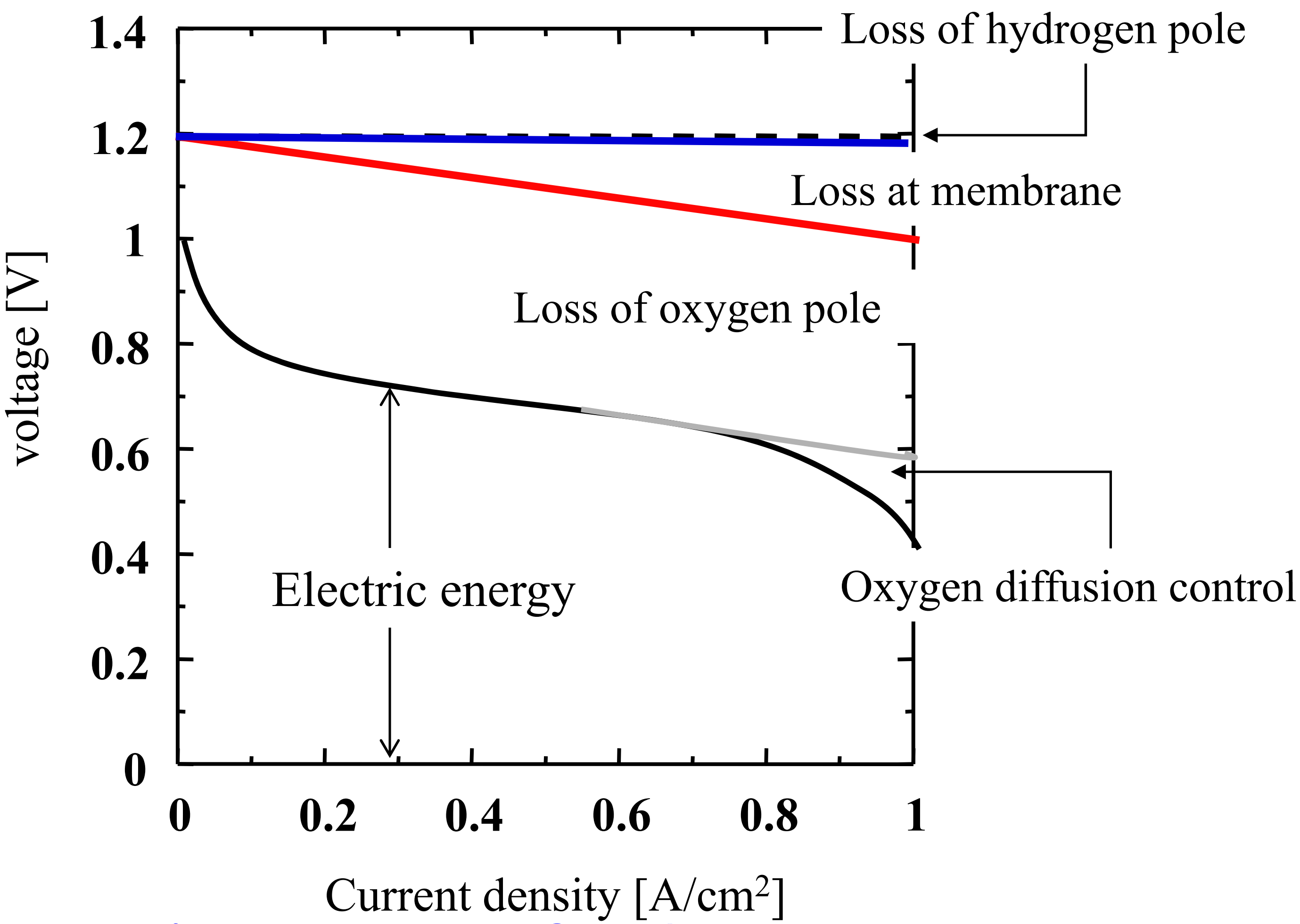
Hydrogen pole **membrane** **Oxygen pole**

The true nature of Internal resistance can be
the resistance of diffusion and reaction

Electric voltage (=concentration) drops where the resistance is large

‡ Provided by Prof. Yamaguchi, Tokyo Institute of Technology

Internal Resistance Analysis
$0.01A/cm^2$ (it is possible now)

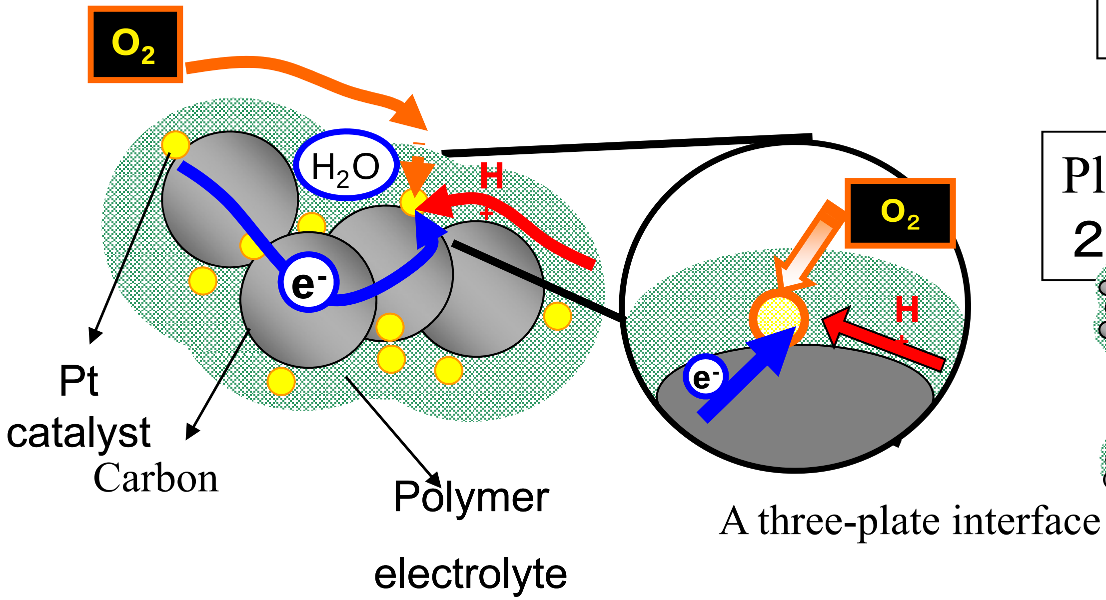


Improvement is necessary for Oxygen pole →Membrane

‡ Provided by Prof. Yamaguchi, Tokyo Institute of Technology

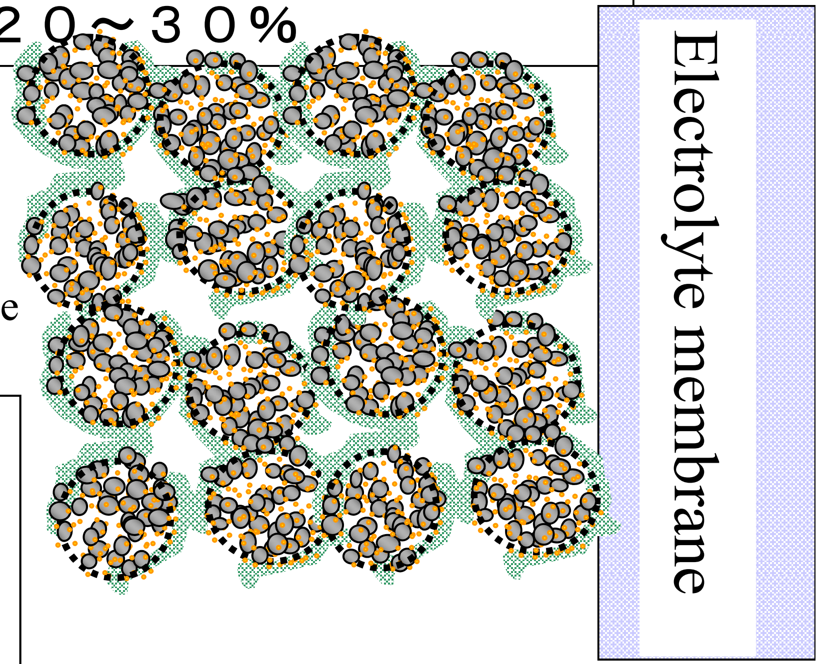
The molecules, ions, and electrons are being contacted with Platinum, Electrolyte, and Gas simultaneously

Nano-level structure of catalytic layers



Carbon carrier roduces agglutination so that polymer electrolyte cannot go in.

Platinum utilization factor is ２０～３０％



Nano-structural treatment is made to improve utilization rate at atomic level.

Size of carbon carrier：30 nm

Pt catalyst particle size：2 ~ 3 nm ← almost 100% exposure.

‡ Provided by Prof. Yamaguchi, Tokyo Institute of Technology

Q：what is the theoretical energy Consumed in cement production?

Hint 1：cement: limestone ->calcium oxide

Hint 2：energy dissipated in crush and deformation is assumed to be zero

Let’s return to the main subject…

skepticism arises with
rapidly increasing knowledge

There are many ways of thinking,
complicated phenomena,
No absolute truth

“common sense may be wrong”
“Both arguments should be included”

IPPC concluded with 95% reliability

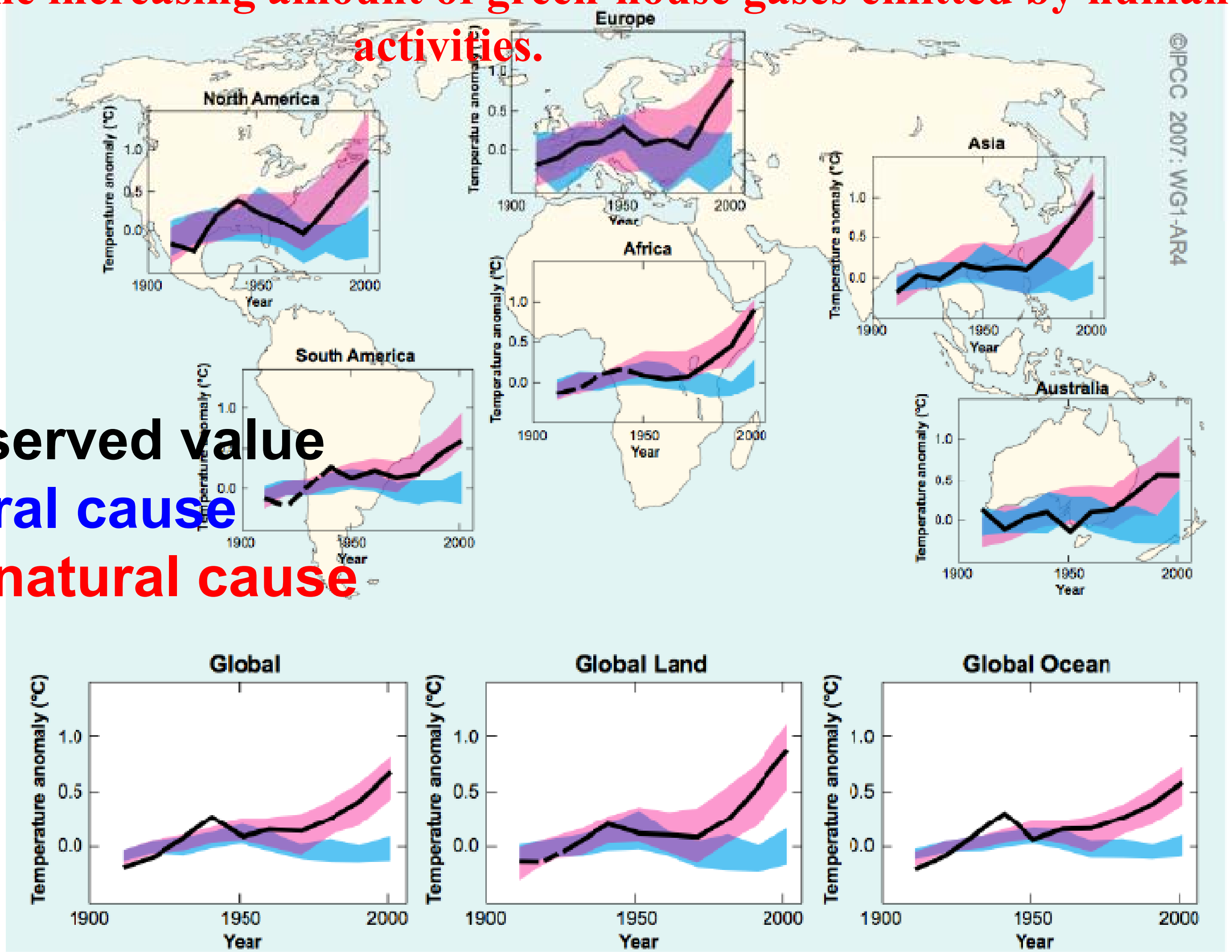
There is little room for skepticism

http://www.cir.tohoku.ac.jp/~asuka/

Global Climate Change (Temperature)

-Observations and simulations-

It is quite likely that the rise in global average temperature observed after mid 1970s is due to the increasing amount of green-house gases emitted by human activities.



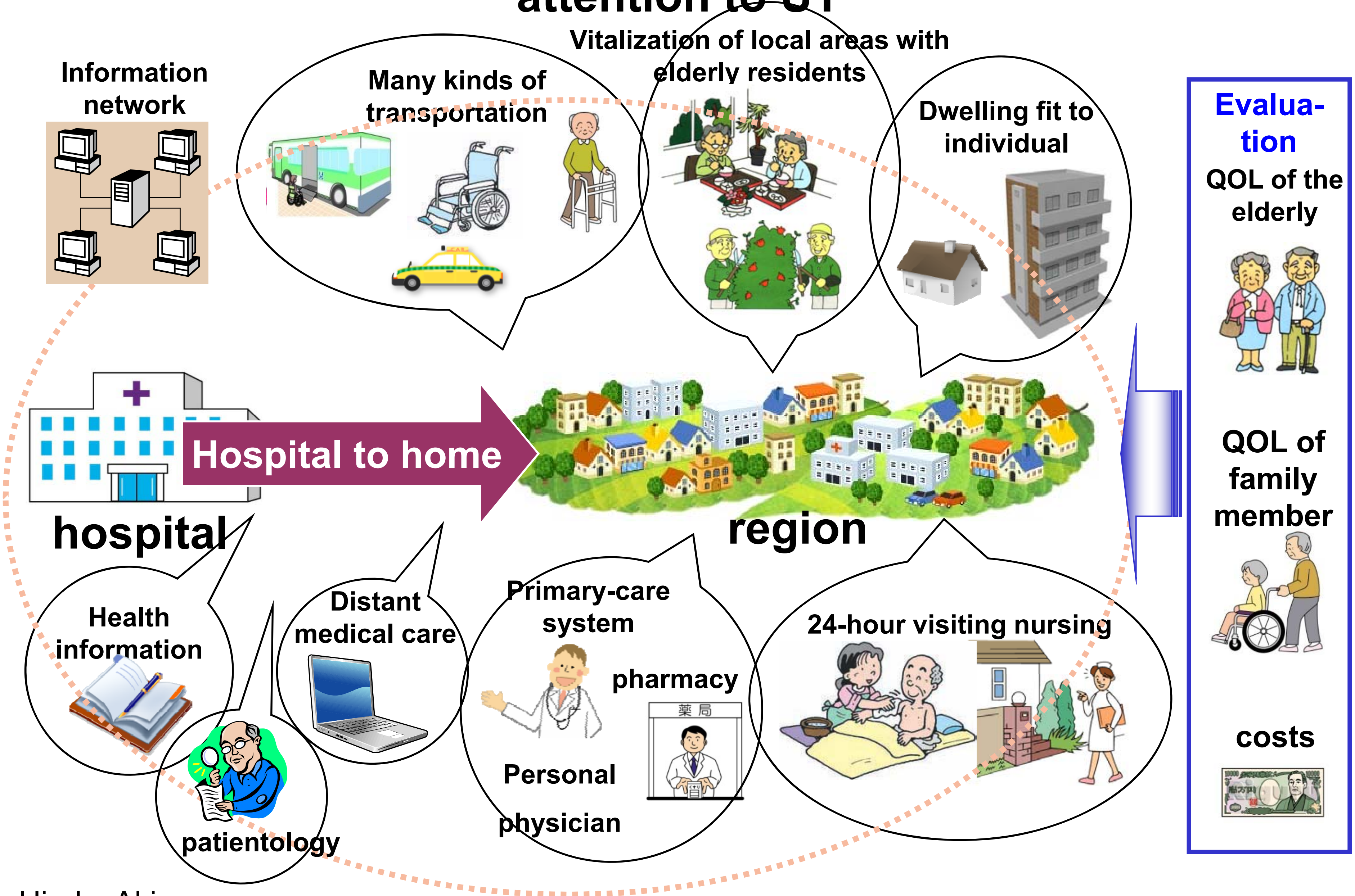
Solid line: observed value

Blue: natural cause

Red: Human + natural cause

‡From UCAR

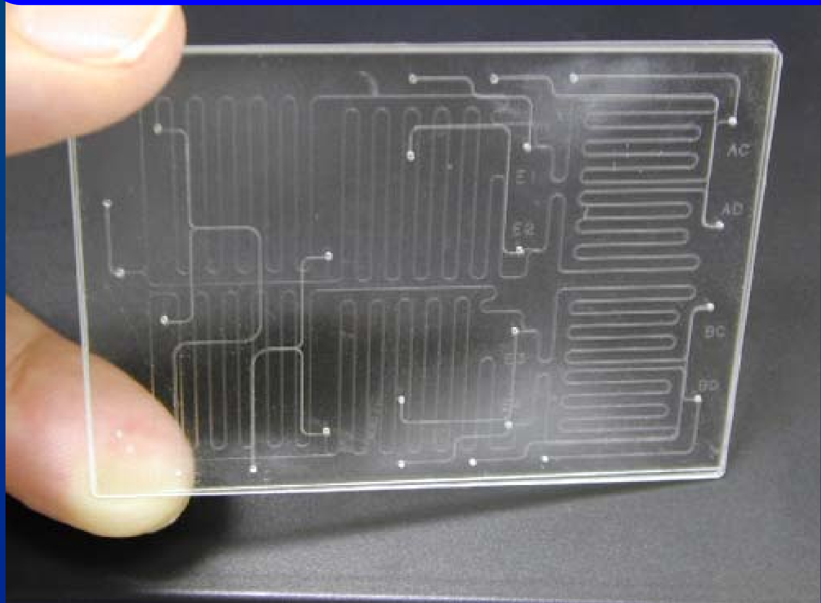
Gerontology international hub: people worldwide are paying attention to UT



Hiroko Akiyama

Swedish Parliament members visit

Examples of Micro-chemical Chips with Three-dimensional Structure



Advantages:

・High-function

・High-controllability

・High-designability

Unique technologies:

Micro unit operation (MUO)

Continuous-flow chemical process (CFCP)

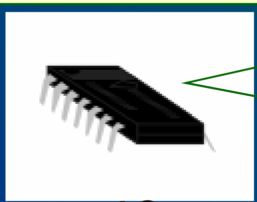
Thermal lens microscope (TLM)

‡ **Faculty of Engineering, Kitamori lab.**

Analogy of Electronics and Micro-chemical Chips

Electronics

Resistances, Capacitors, Diodes



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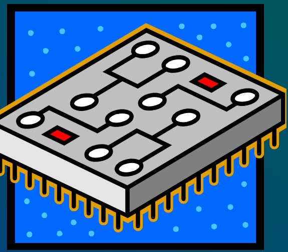
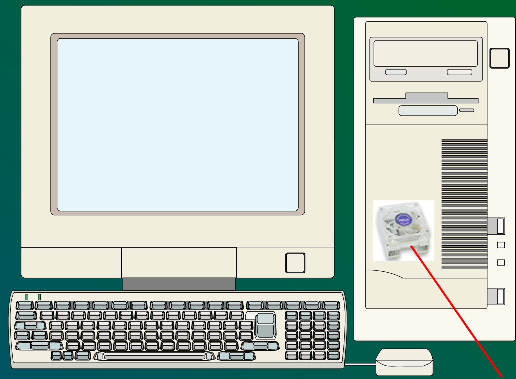
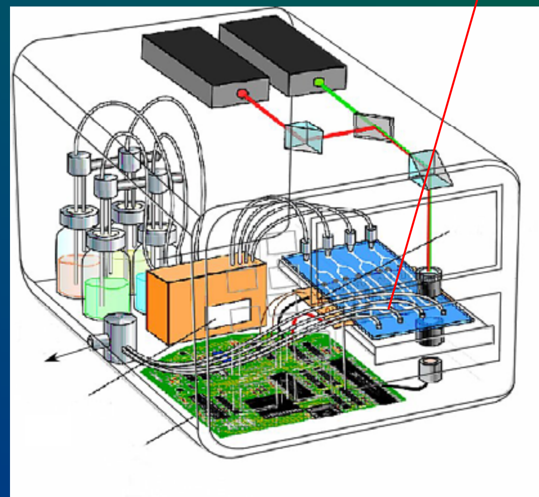




CPU

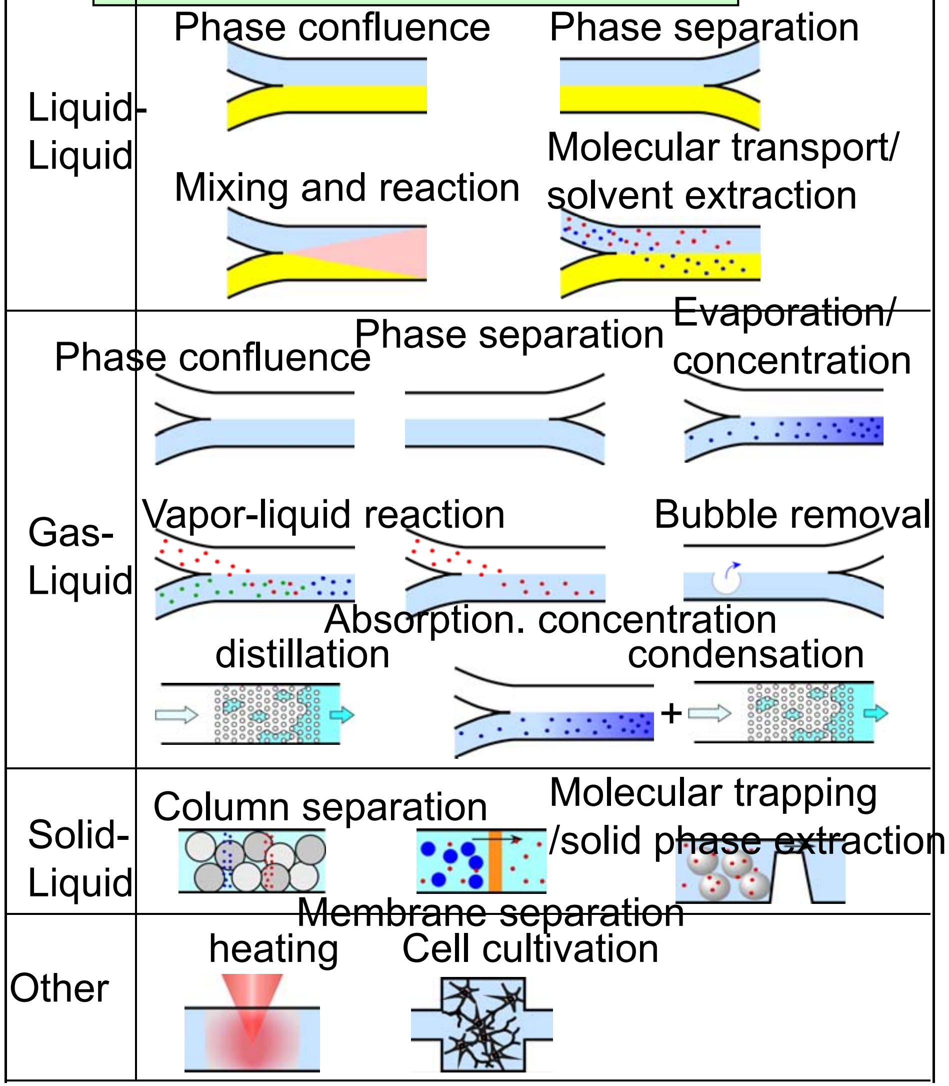
Microchemical Chips

Reaction, extraction, purification, and distillation



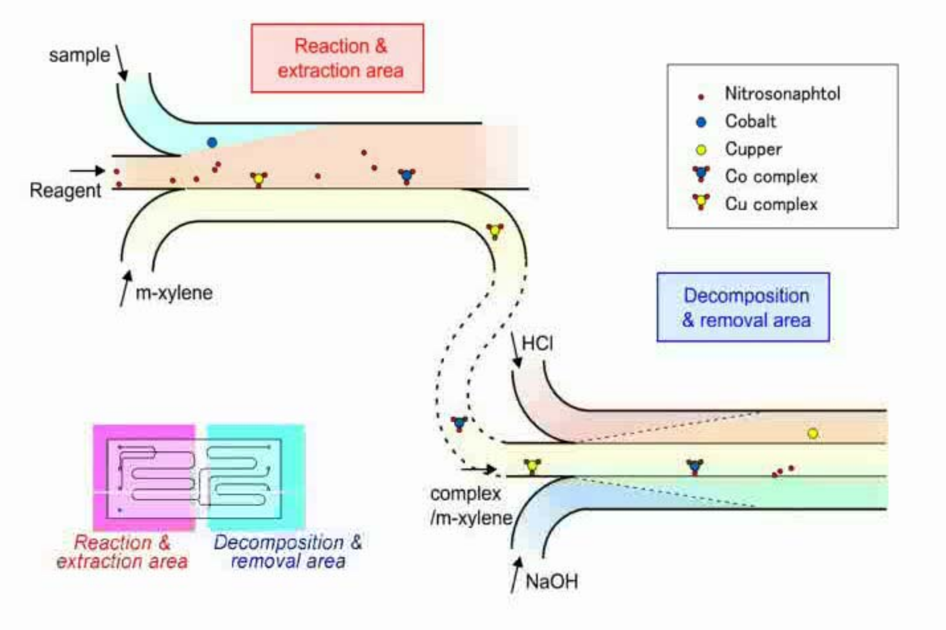
Integrated component of Micro-chemical chips , chemical unit operation

Micro Unit Operation（MUO）
＝Integrated components



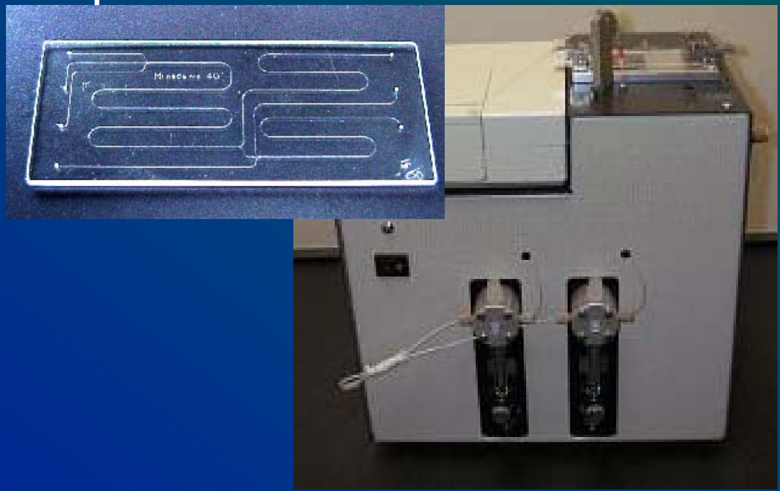
Continuous-Flow Chemical Process
（CFCP）＝Integrated circuit

unrestricted combination of MUO
using multiphase microflows
=chemical ICs



Bio instrument with micro chemical chip

μ-Extraction chip
Super-small environmental water analyzer



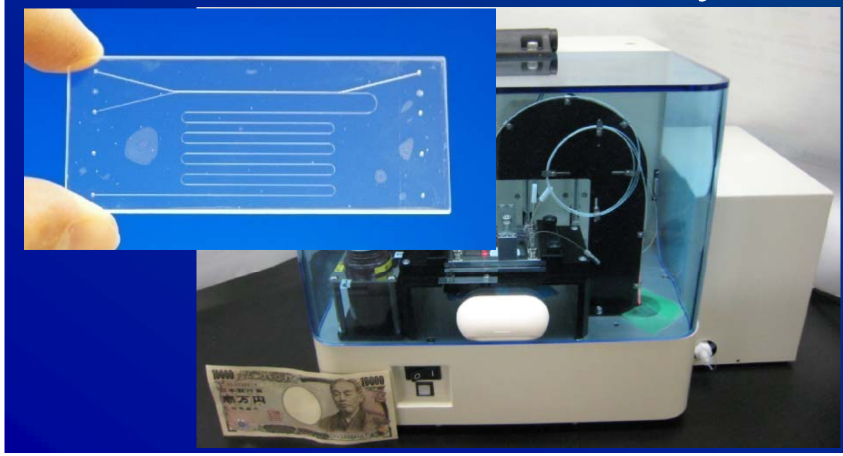
μ-ELISA chip
Micro diagnostic analyzer

Small

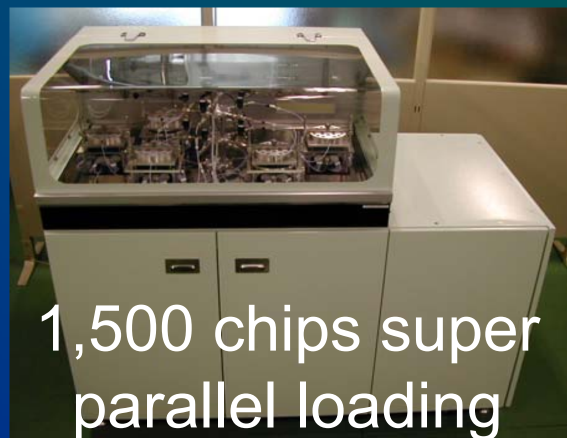
Fast

Easy

μ-Gas extraction chip
Clean-room ammonia analyzer



Desktop chemical plant
(gel microparticle production30t/year)

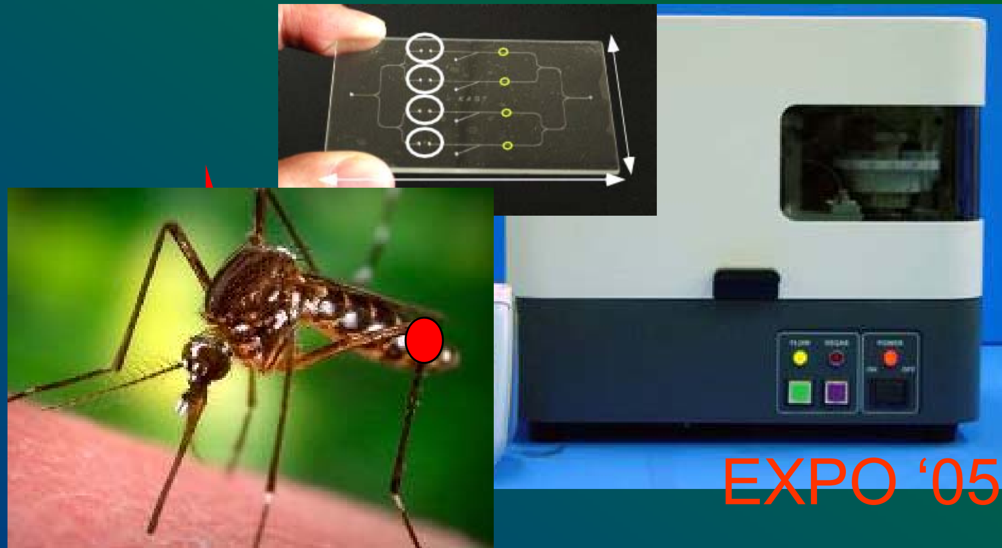


Example 1: microdiagnostics system

cancer, allergics, liver disease, heart trouble etc.

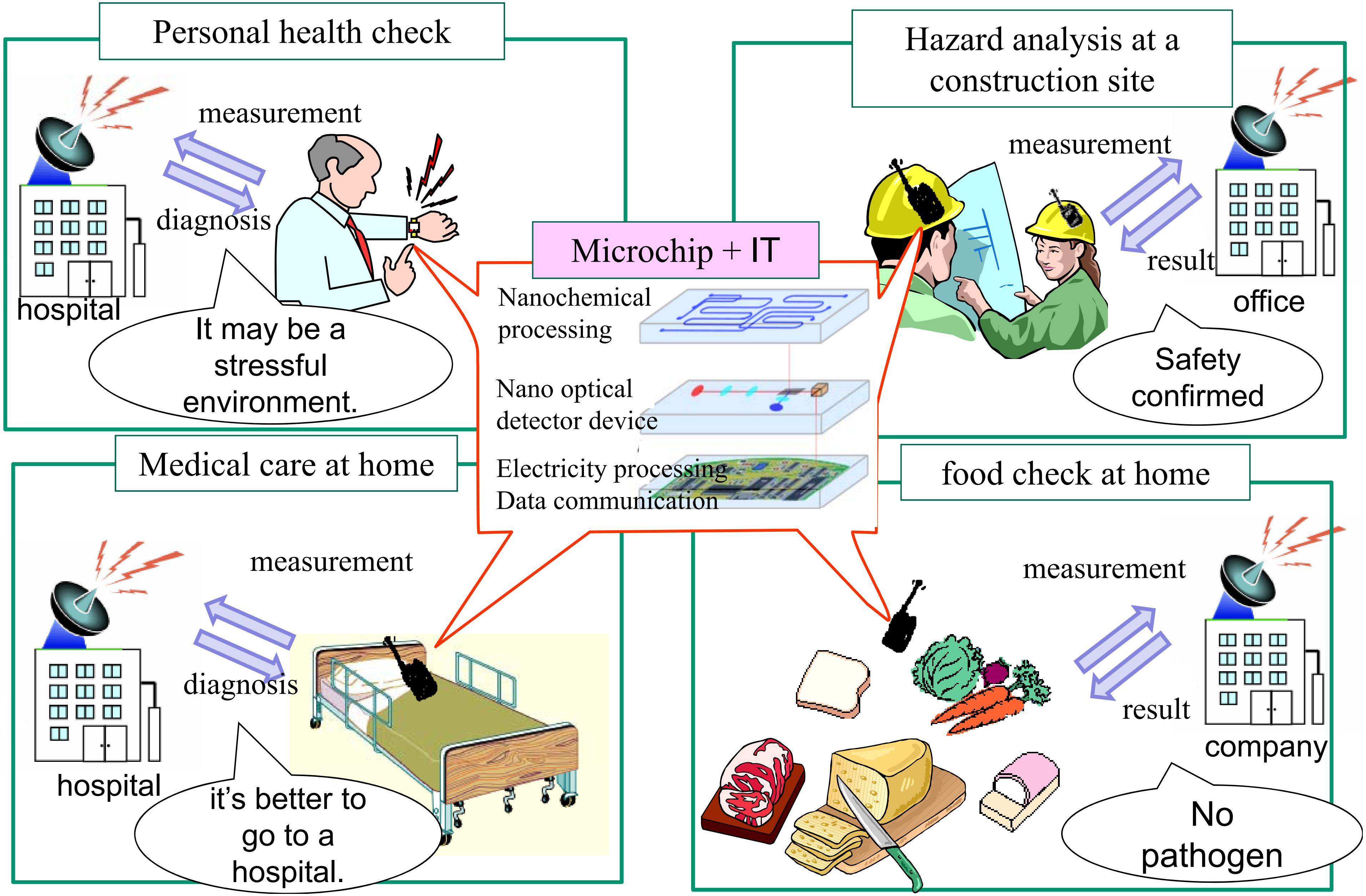
Conventional machine

Microchip machine

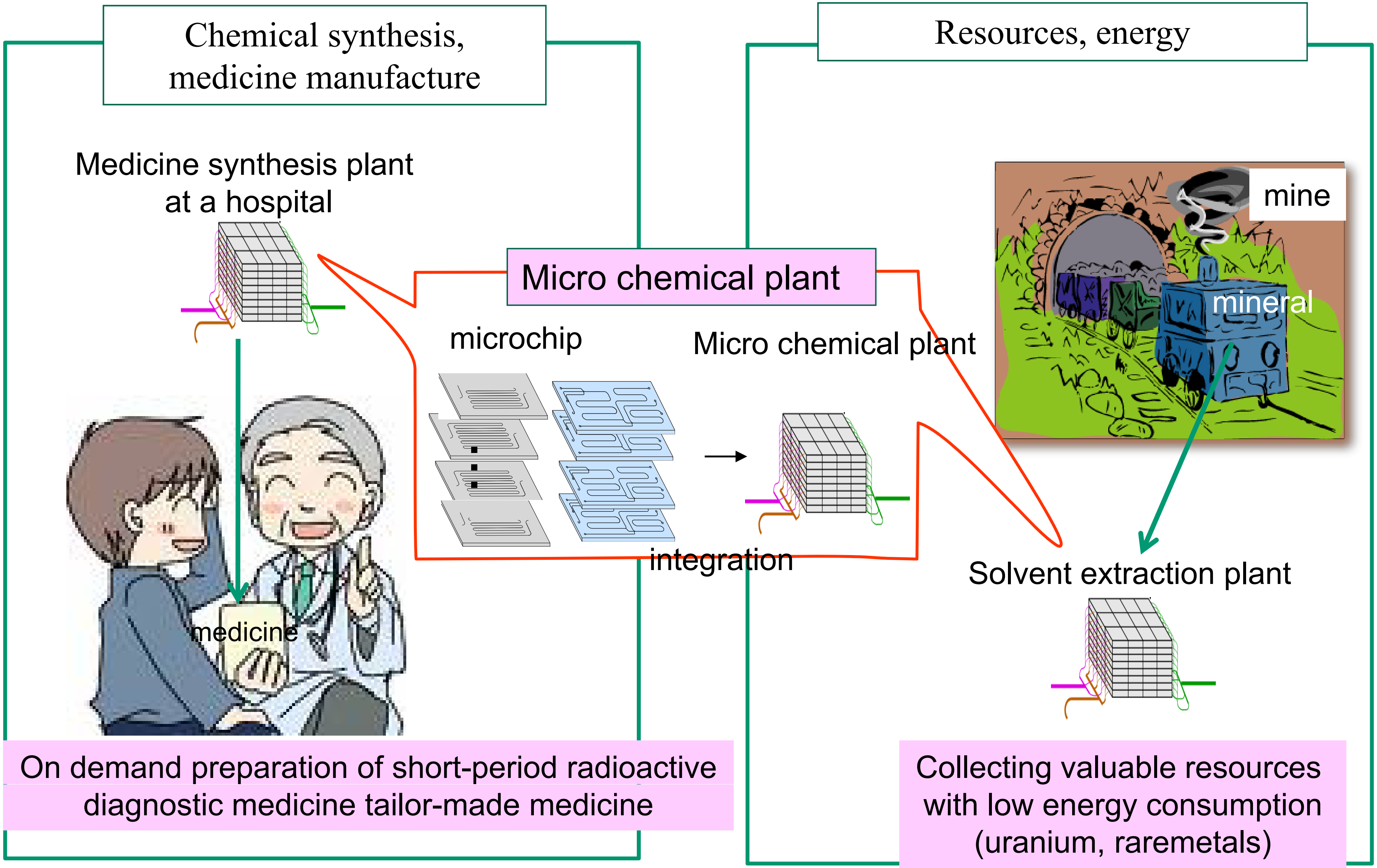


・blood needed	: mL	→	less than μL	no pain
・promptness	: days and hours	→	minutes and seconds	on site
・operated by	: professionals	→	laymen	
・prices	: ¥10 million~	→	~¥0.1 million	
・user	: hospitals, companies	→	individual	personalizing the checkup

Contribution to a safer society
analysis and diagnostics using devices on a network system



Contribution to Chemical syntheses, pharmaceutical technologies, resources /energy problems



Two-phase flow in micro-channel
―streamline tracing―

Ordinary system

・gravity does no work but instead, interfacial tension governs the flow → aligned both left and right

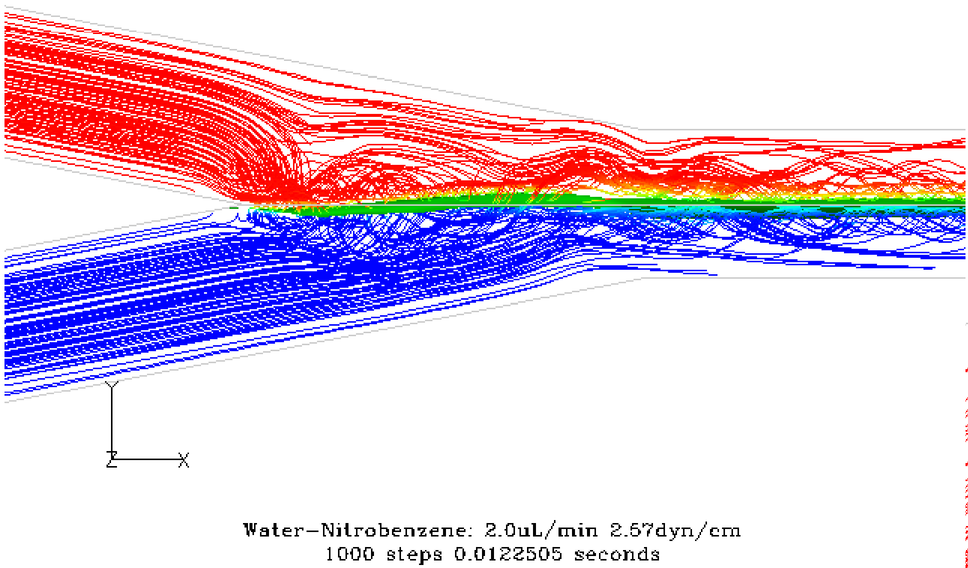
・Reynolds number can be 5 at its best → laminar flow

・the interface of laminar flow is stirred → it appears as turbulent flow (extraordinary)

Laminar flow (locally)

Turbulent flow (grobally)

‡



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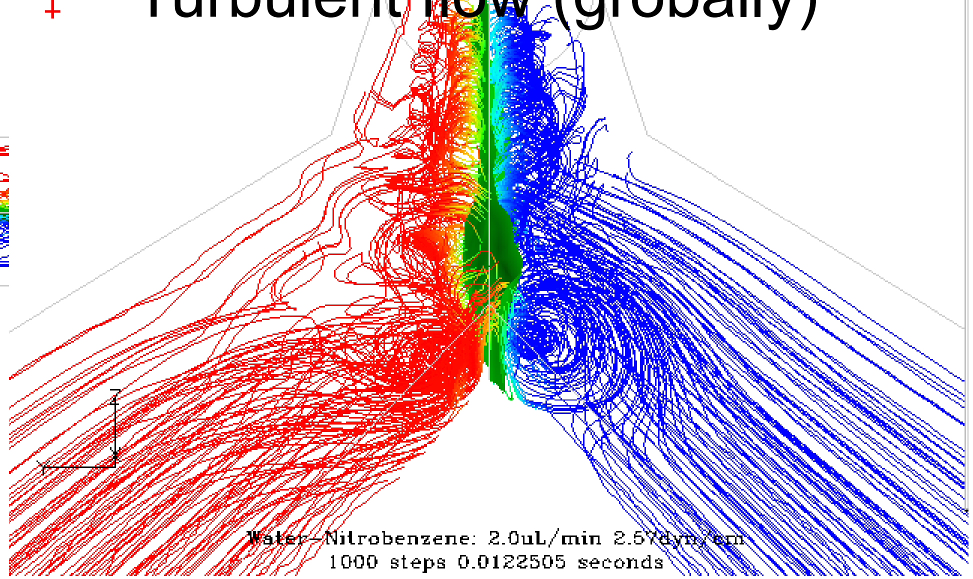
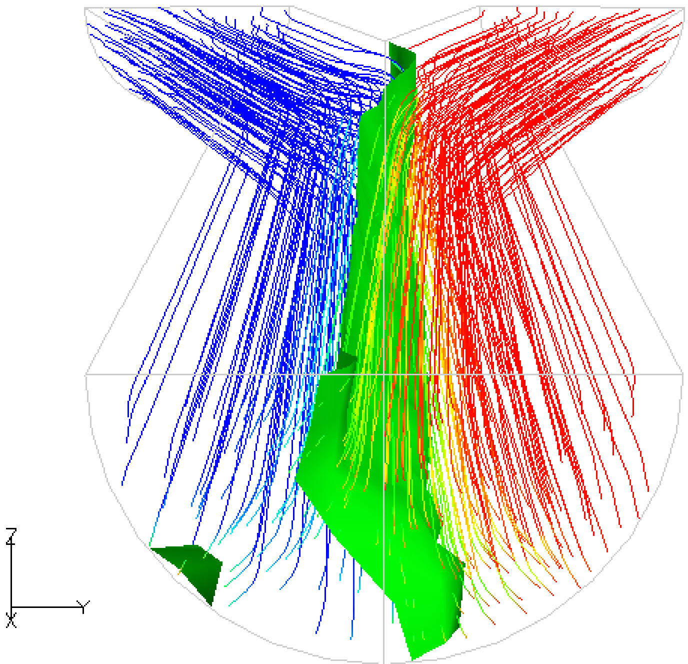
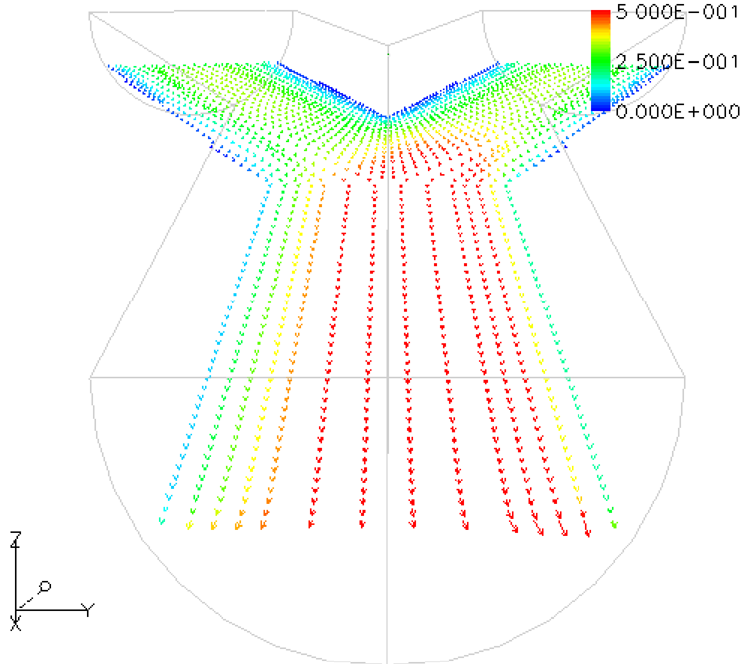


Three-dimensional simulation of micro-two-phase flow

Laminar flow (no turbulence) in macroscopic world



Water-Nitrobenzene: 2.0uL/min 0.0dyn/cm
1000 steps 0.233107 seconds



Water-Nitrobenzene: 2.0uL/min 0.0dyn/cm
20 steps 0.00230042 seconds

Three-dimensional simulations of micro-two-phase flow

Ordinary system

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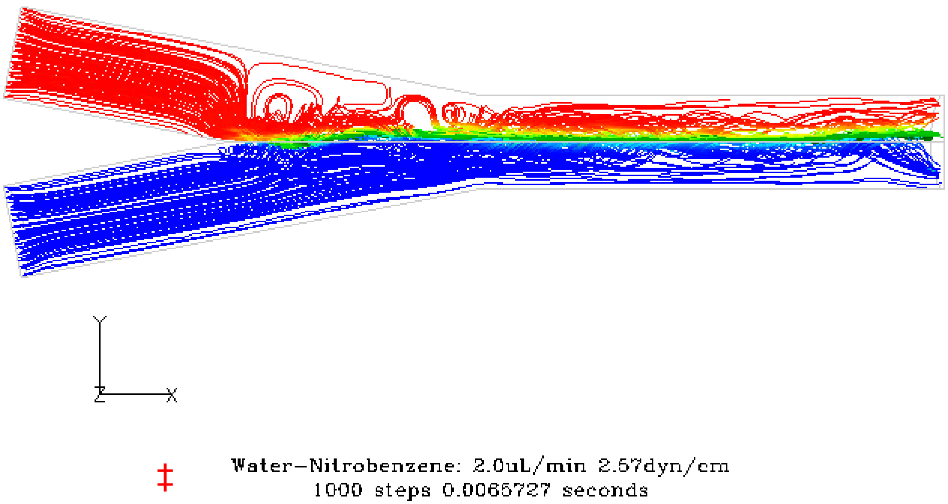
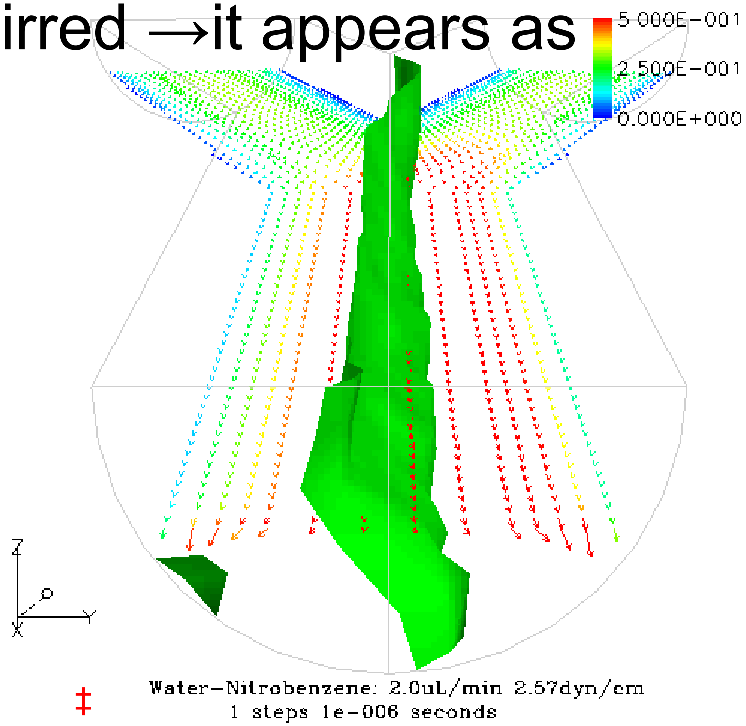
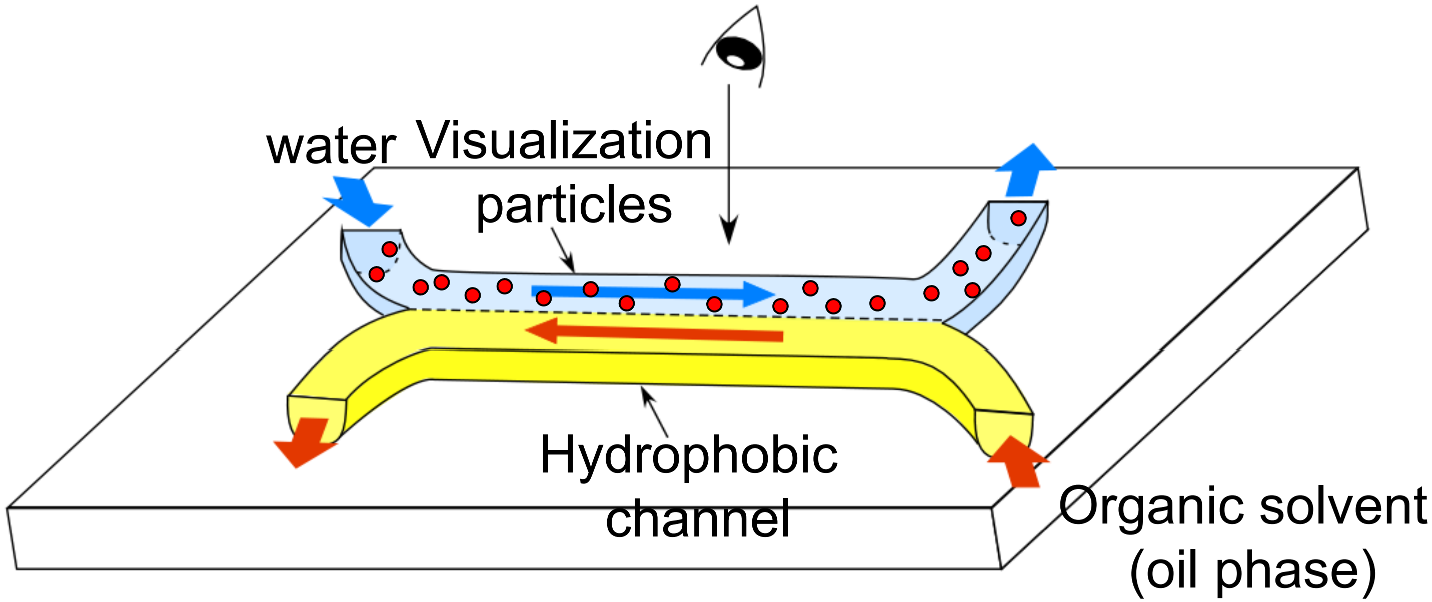
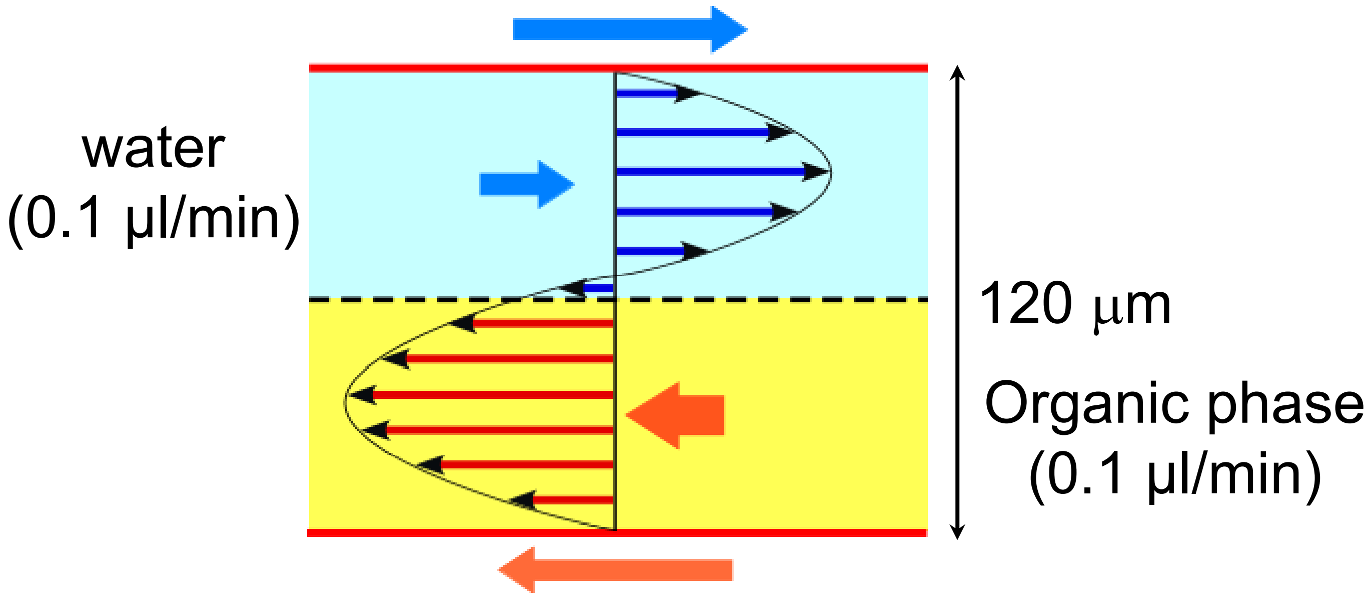




Water and Oil counter-flow





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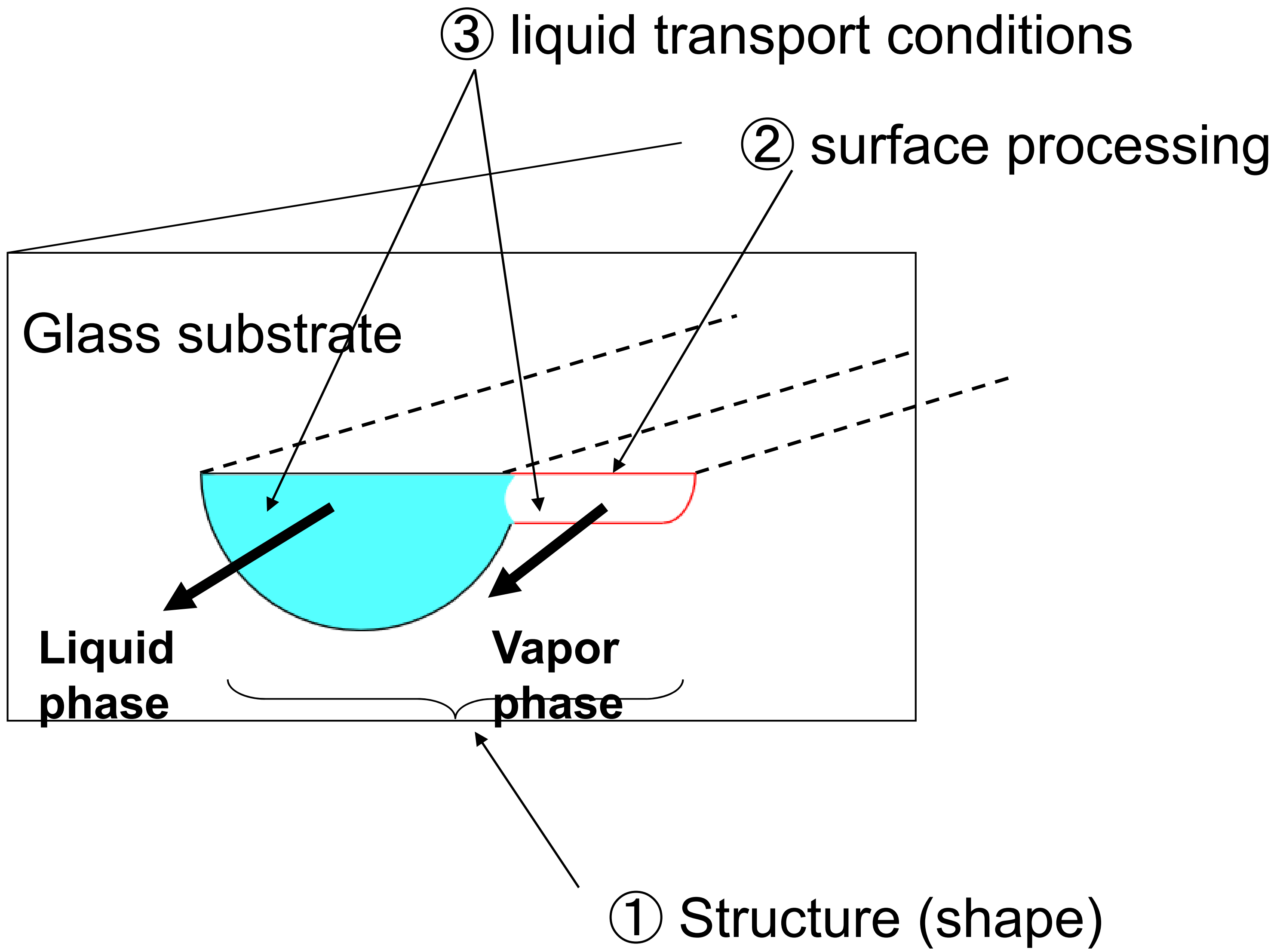
Parallel flow implementation of vapor phase and liquid phase(three conditions)



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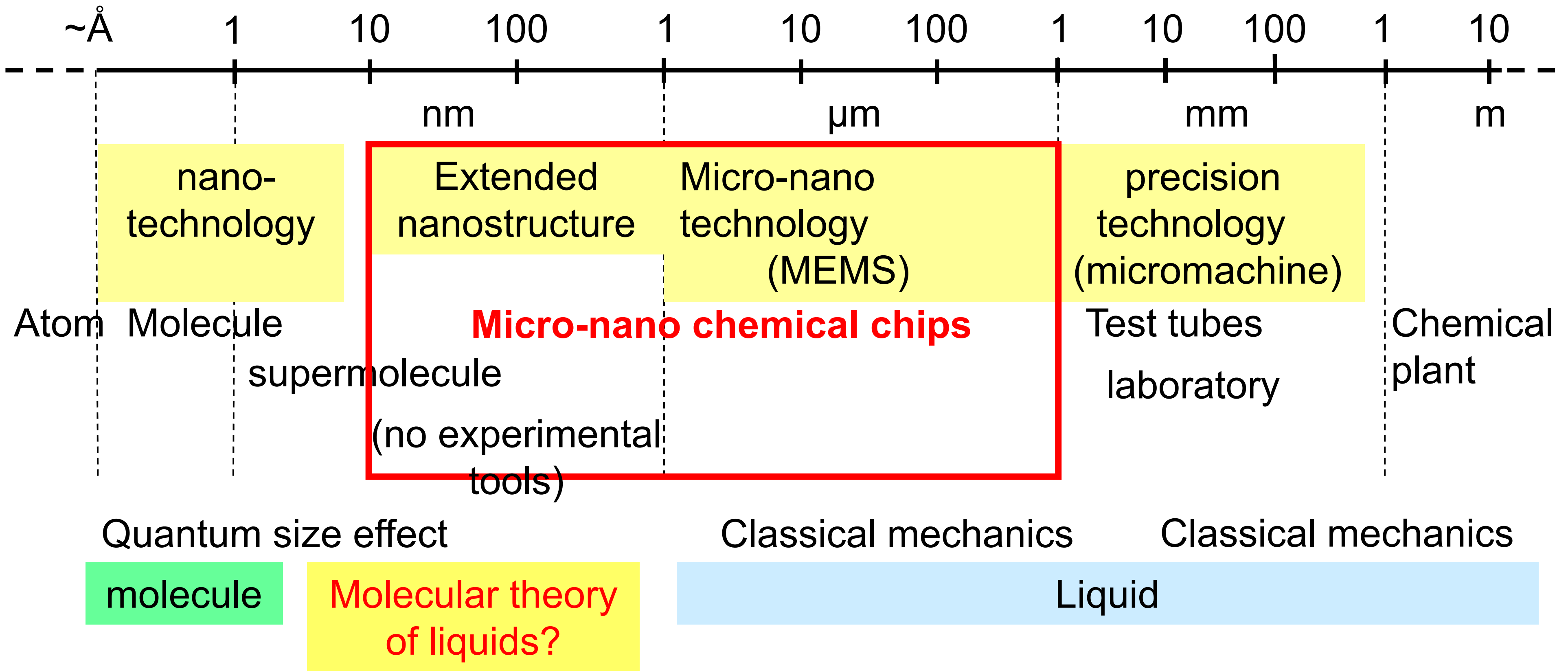
Size hierarchy and micro-nano chemical chips



Characteristics of the extended nanostructure:

Nano-liquid properties・

Liquid structure of nano-space・

Reactions ・

Characteristics of micro-space:

・small materials with extremely short energy diffusion distance

・Gravity << interfacial tension

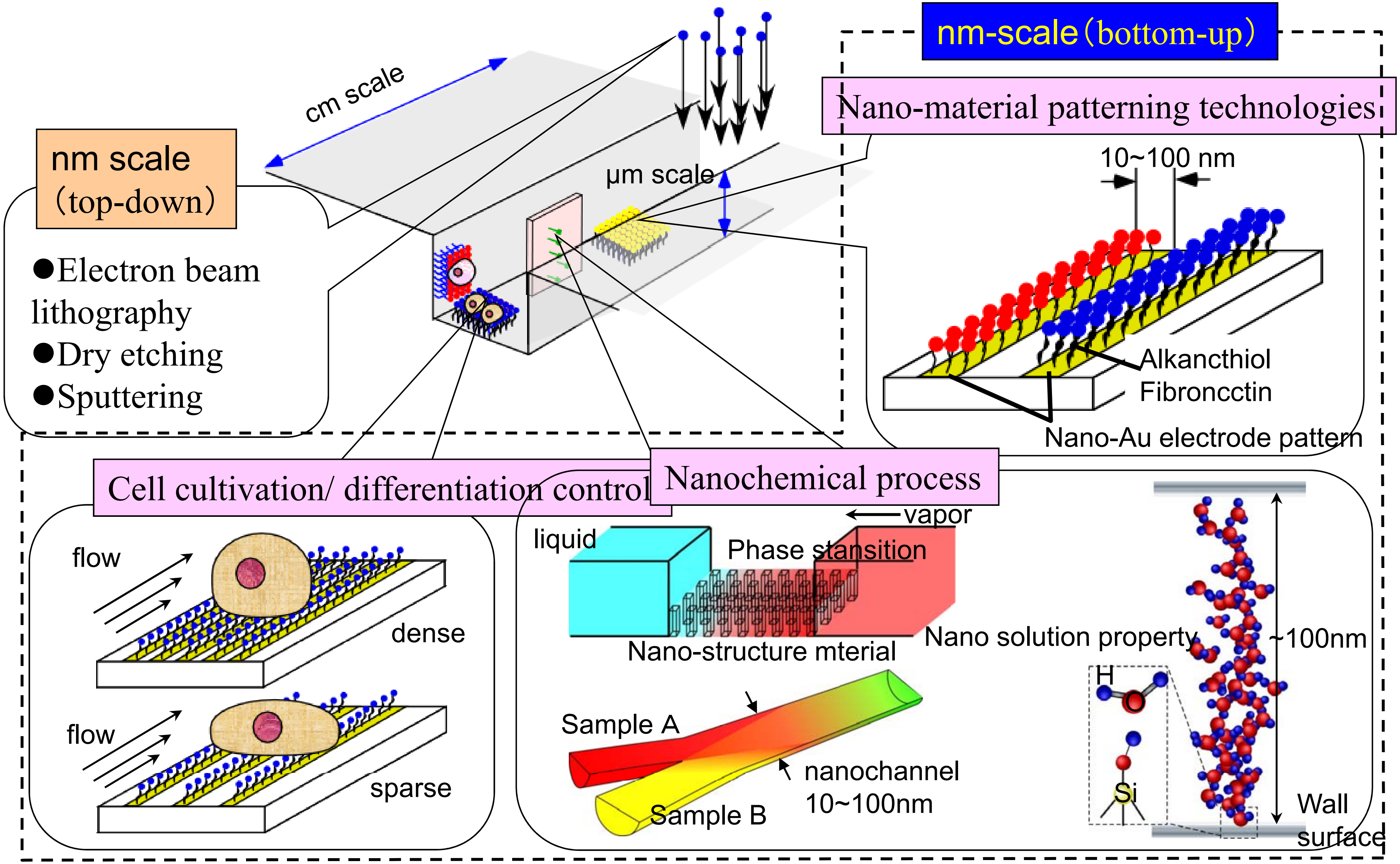
・Laminar flow

No conventional knowledge has been developed yet.

The conventional knowledge has gone too far and has become absurd.

‡

Nano-in-Micro Structuring



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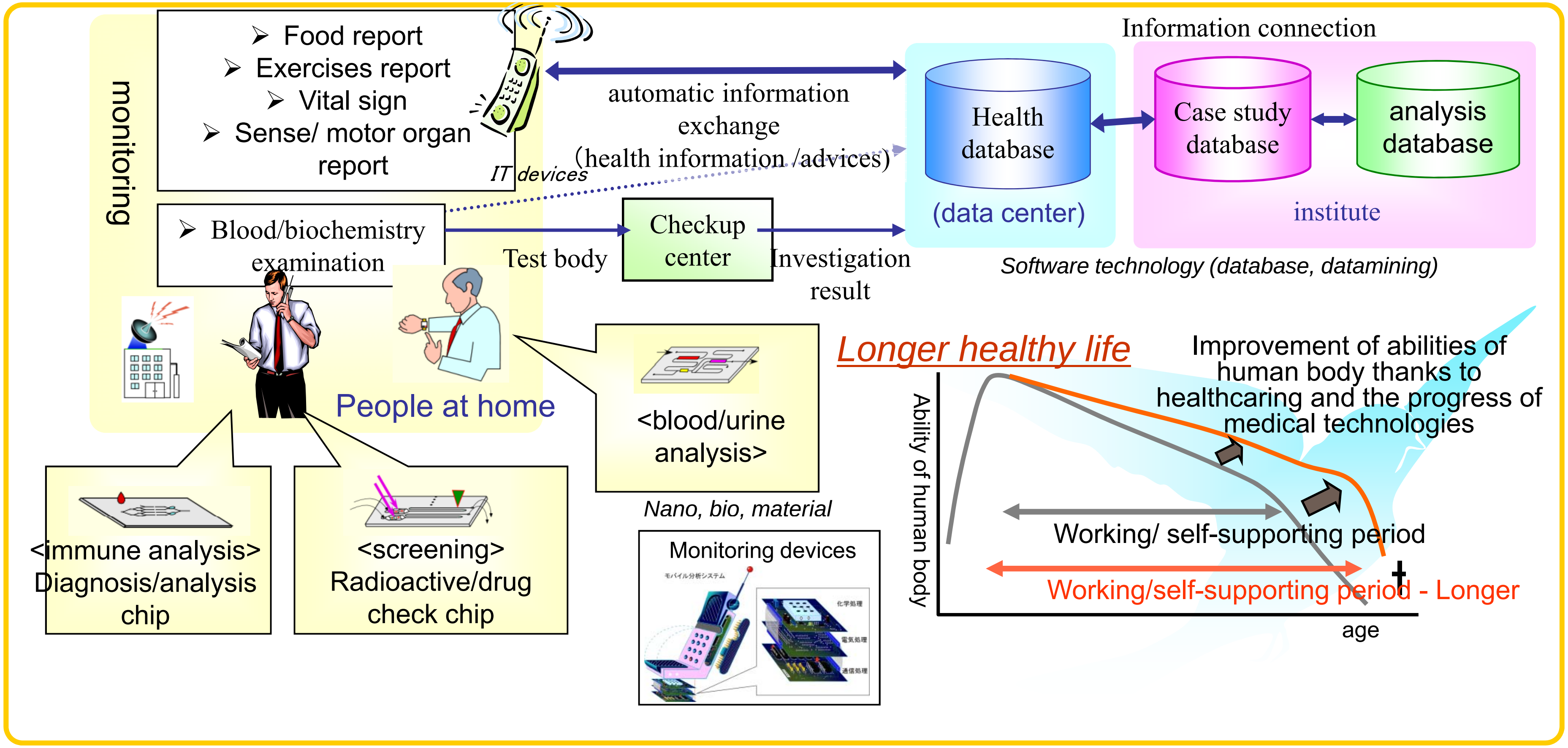
Medical expenses bring about innovating systems



Creation of new industries: Misunderstandings with ¥33 trillion budget

‡

Small earth

Aging society

Smaller demands in advanced countries

Forced demand stimulation

Economic crises

Demand creation according to
new paradigms is important

Japan is in a good position

Segmentalized knowledge

Difficult deductive solution

structurization of knowledge,
Mobilization of knowledge with some goal

Social experiment

Science of materials:
Global Focus on Knowledge