

Clean Coal Day 2024
September 2, 2024

New Thermal Power Plants in Carbon Neutral Society

September 2, 2024

Dr. Shozo Kaneko

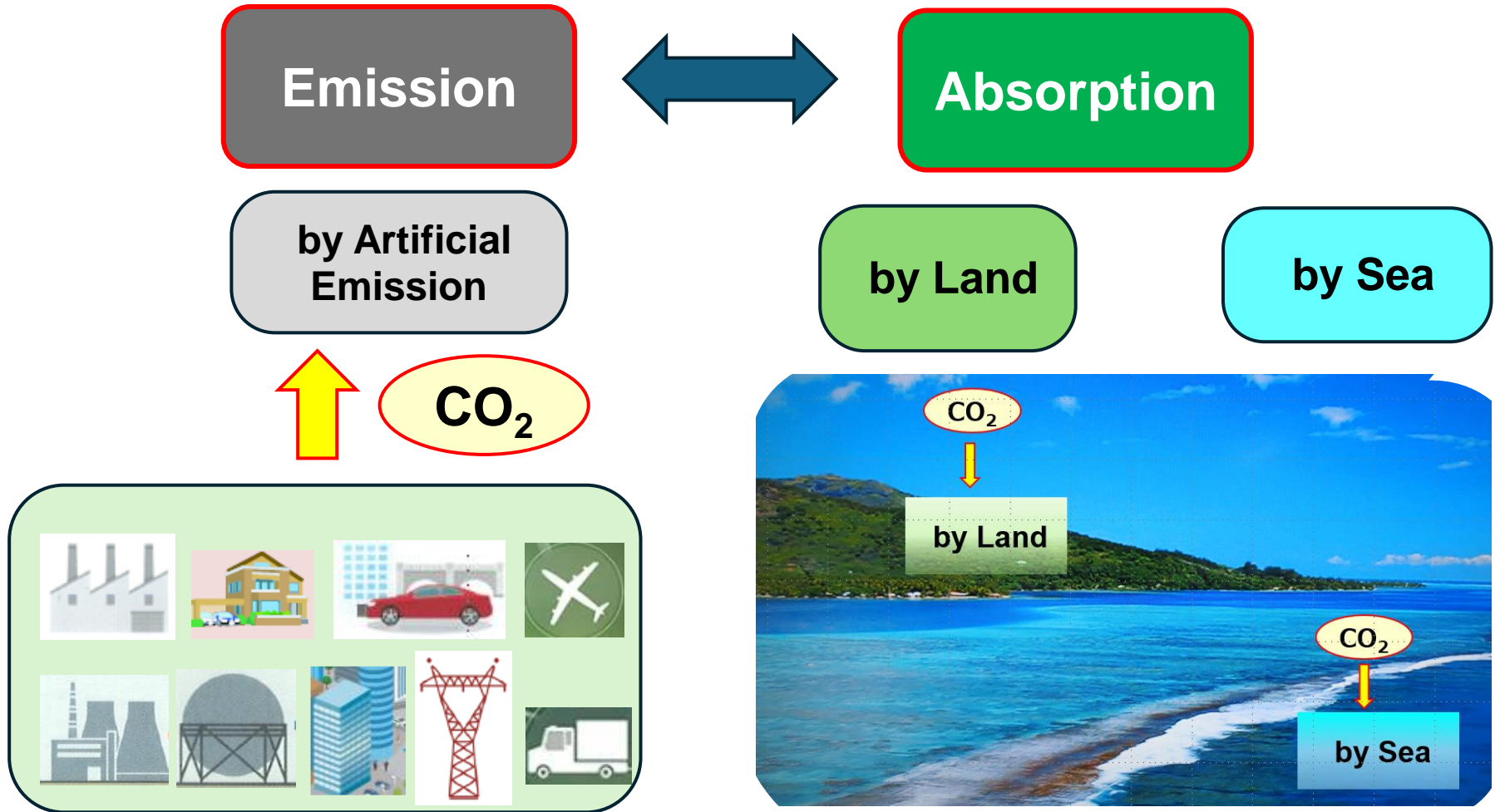
Research Advisor

Institute of Industrial Science

University of Tokyo

Carbon Neutrality

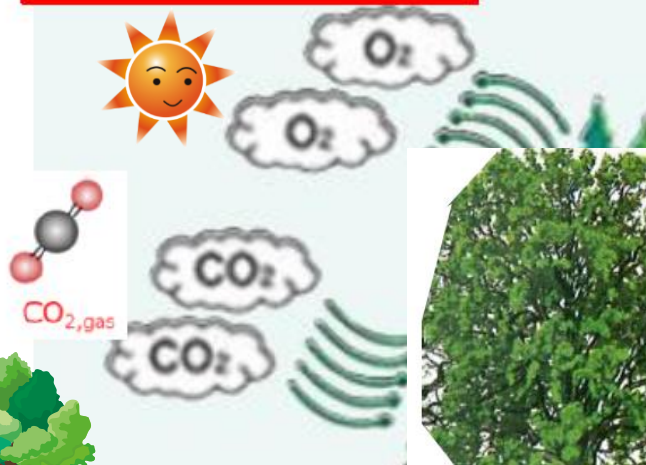
- Carbon Neutral(CN) does not mean “Zero Emission GHG”
- It means balance of “Emission” and “Absorption”



Trees absorb CO₂ while growing up



Photosynthesis



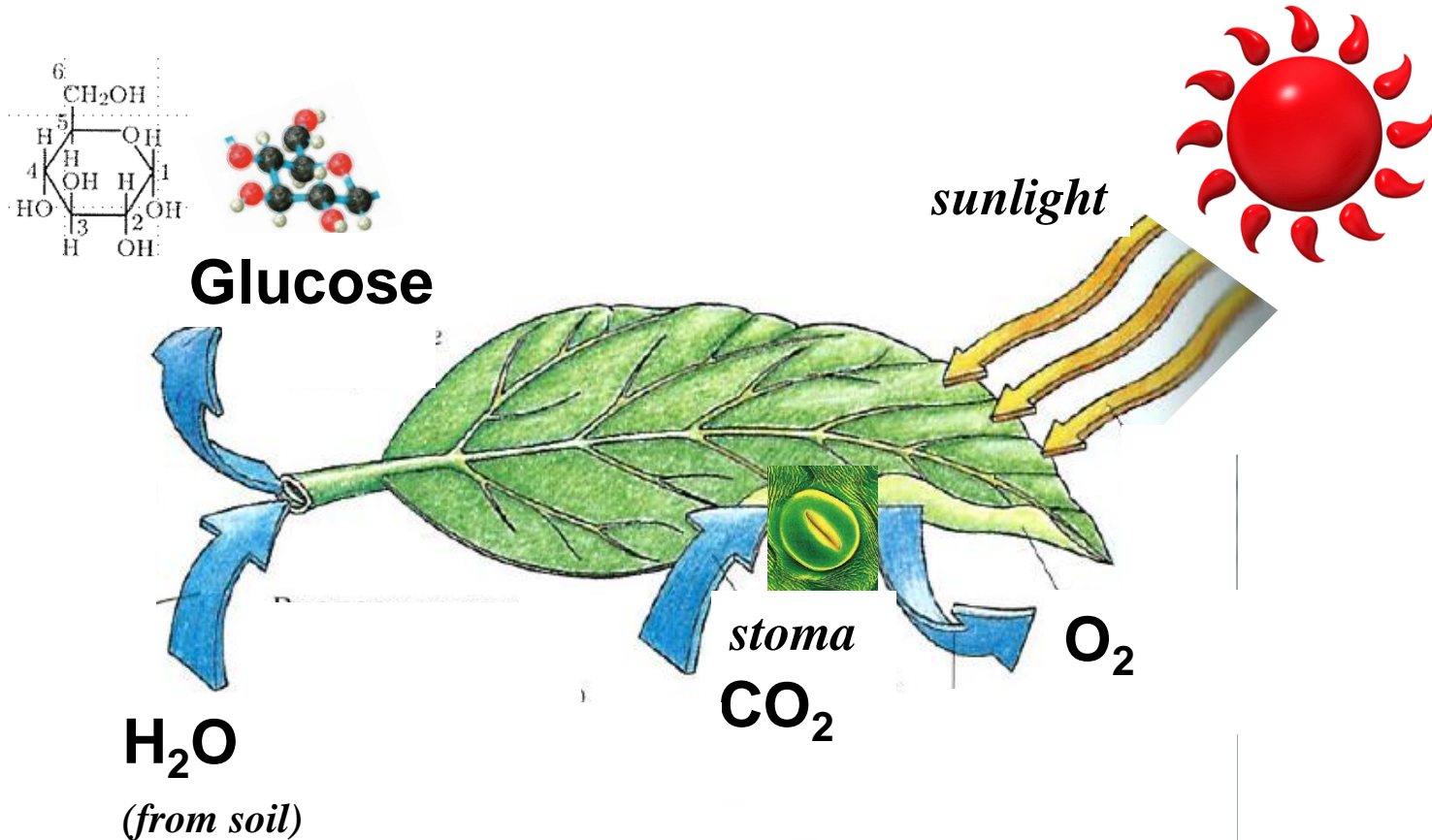
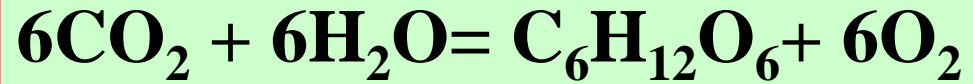
CO₂ in the air is converted to Carbon in wood by Photosynthesis

Required time will be 30 to 40 years

Time Constant \approx 50 years



Photosynthesis



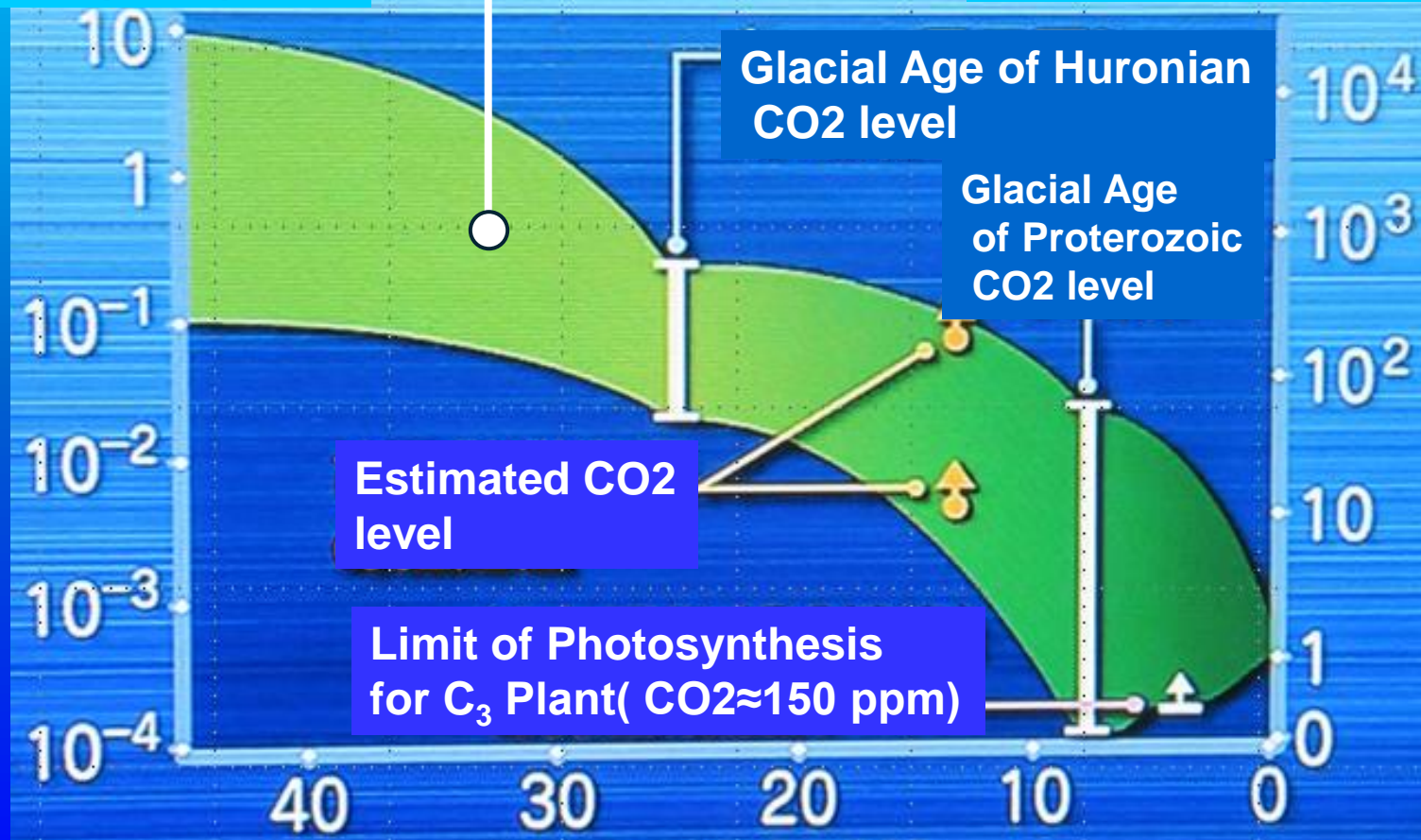
Photosynthesis is one of the most vital phenomena in the history of the earth

Historical Change of CO₂ in the atmosphere

Partial pressure of CO₂ (atm)

Life on earth

Relative ratio of CO₂ (Present Level=1)

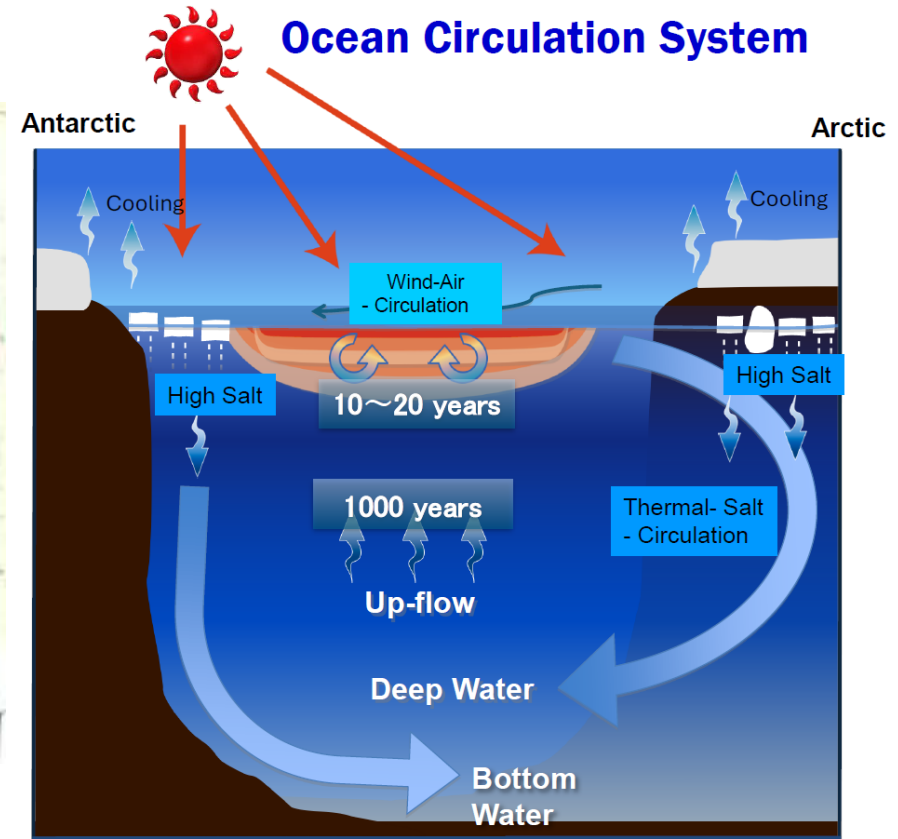
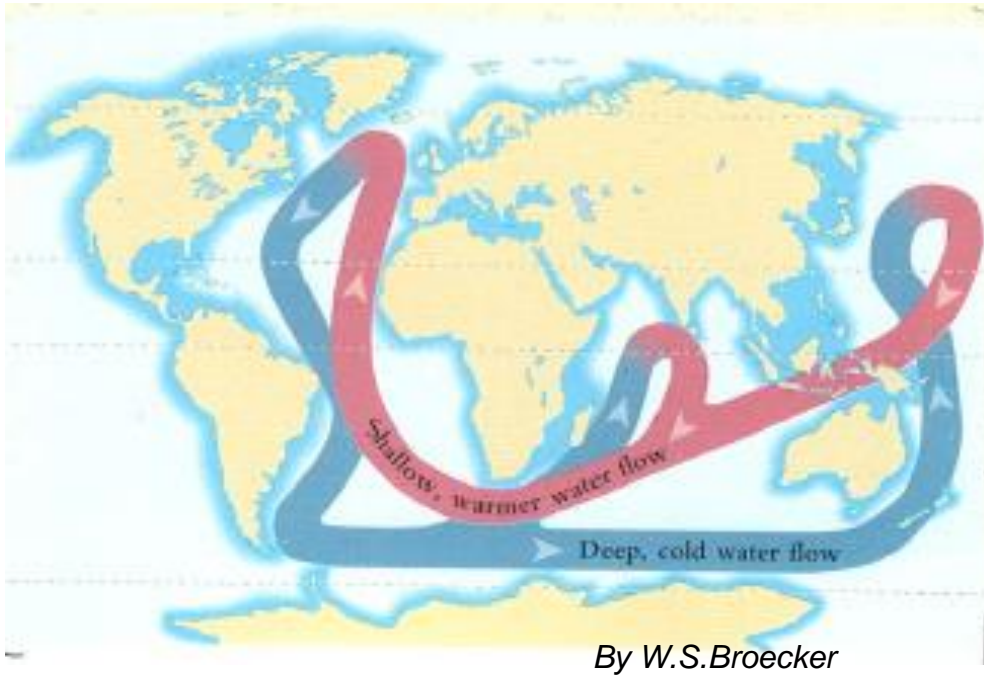


× 100 million years

Source: Casting(1993)

Ocean Circulation System : Ocean Belt

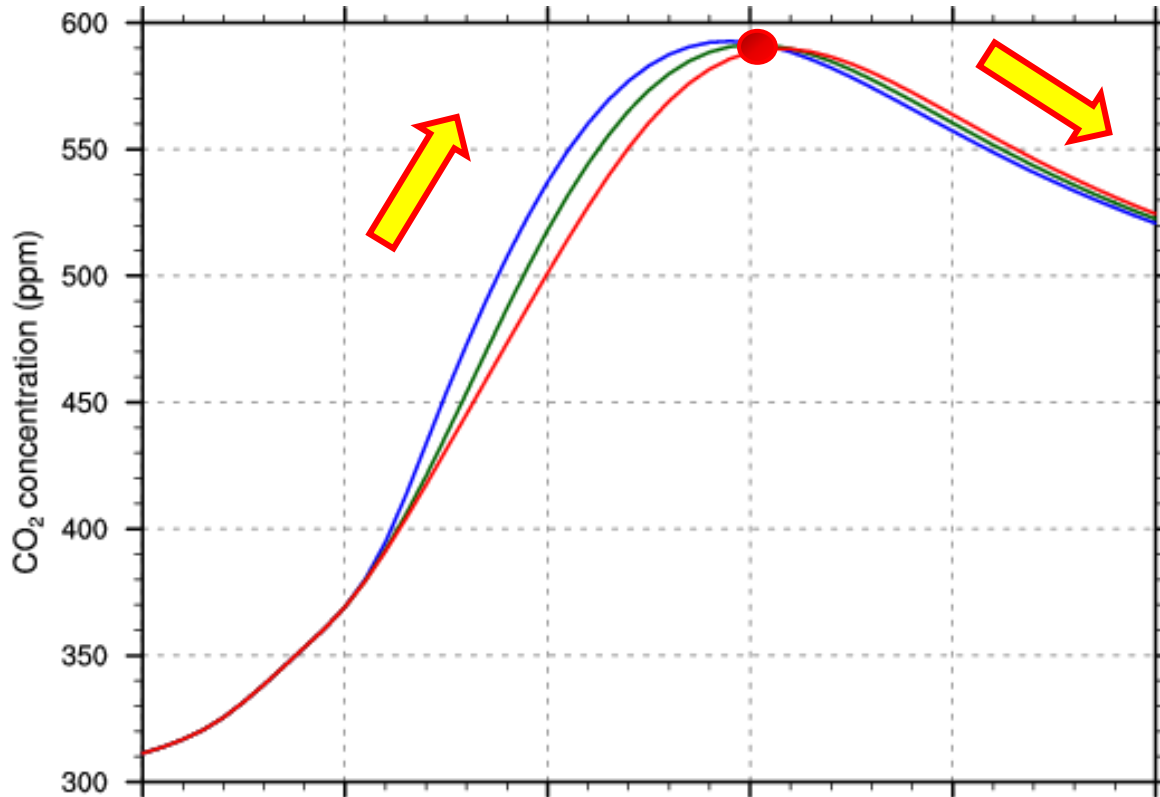
Ocean Belt



Circulates in 700 years

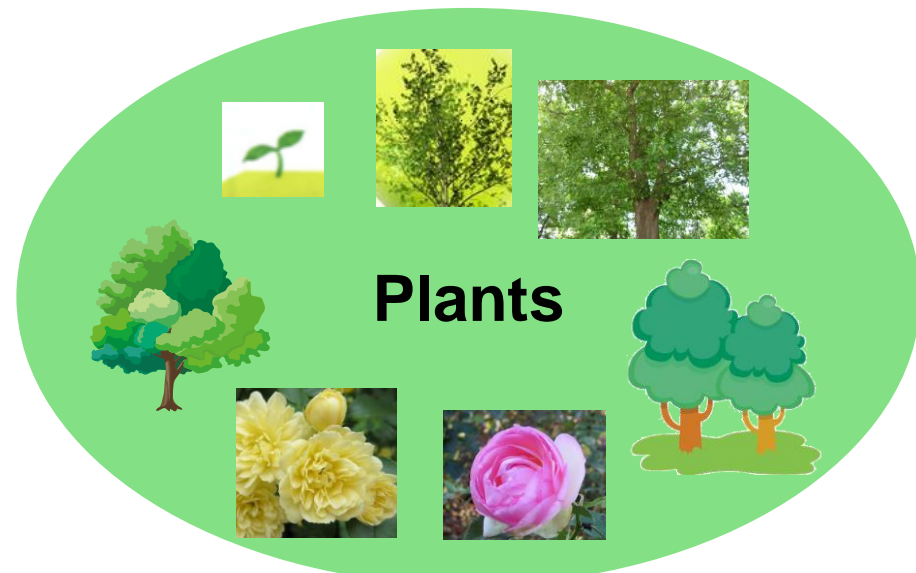
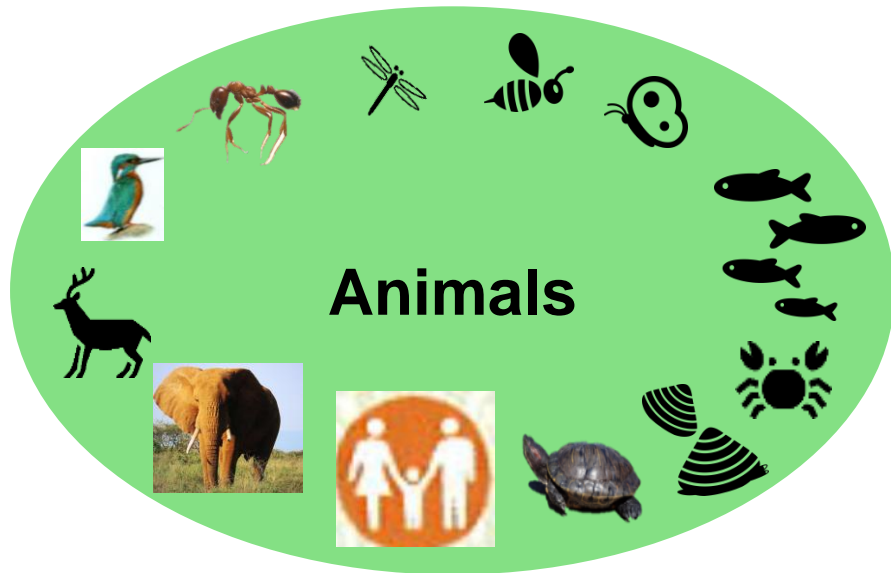
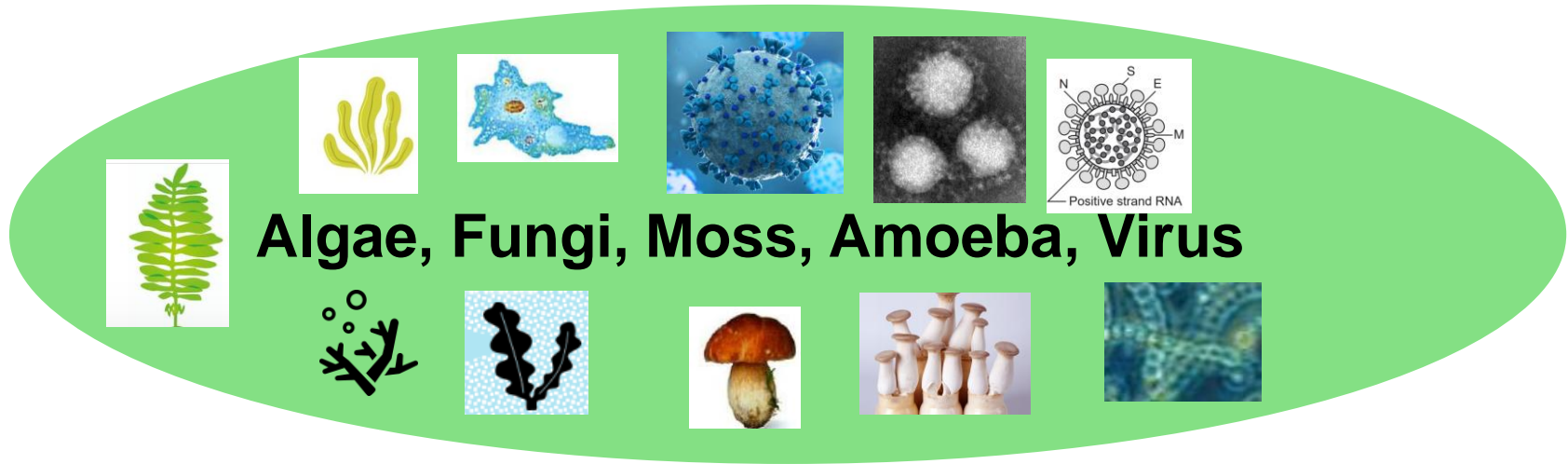
Time Constant \approx 500 years

CO₂ after Carbon Neutrality

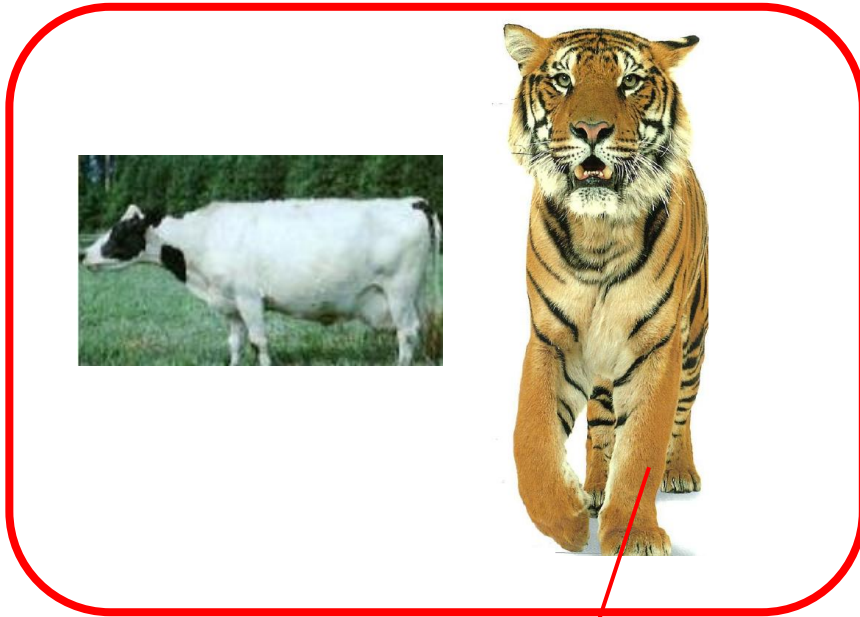


Once emission and absorption reach equilibrium, CO₂ concentration in the air decreases in several hundred years

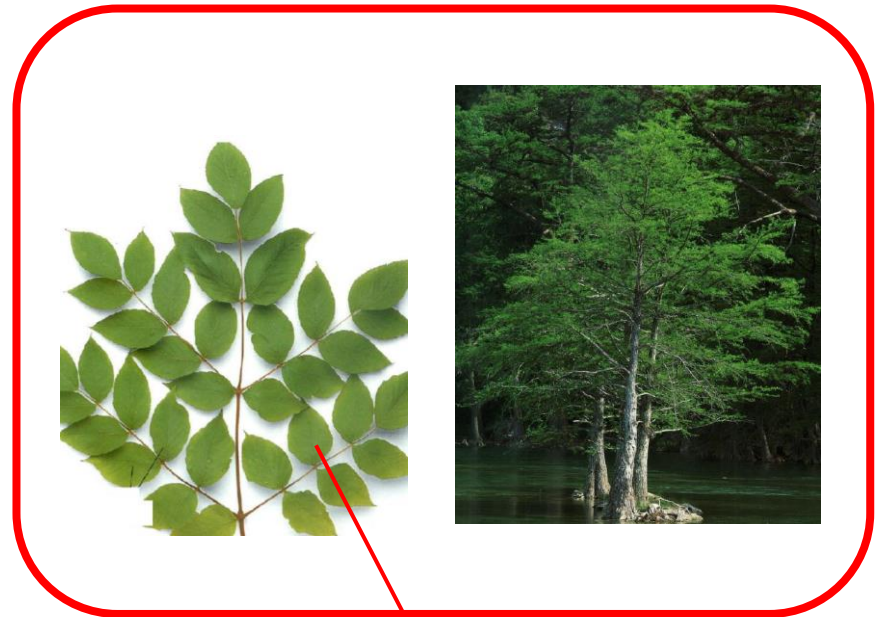
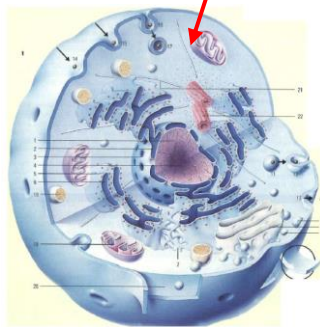
Zero Carbon → No Life



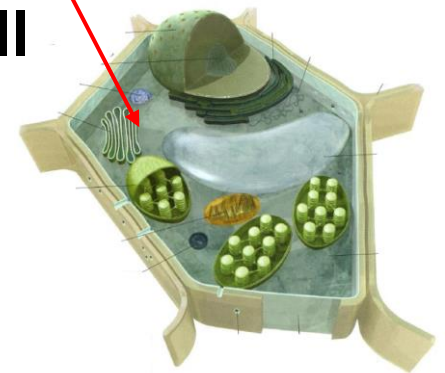
All animals, plants are made of carbon



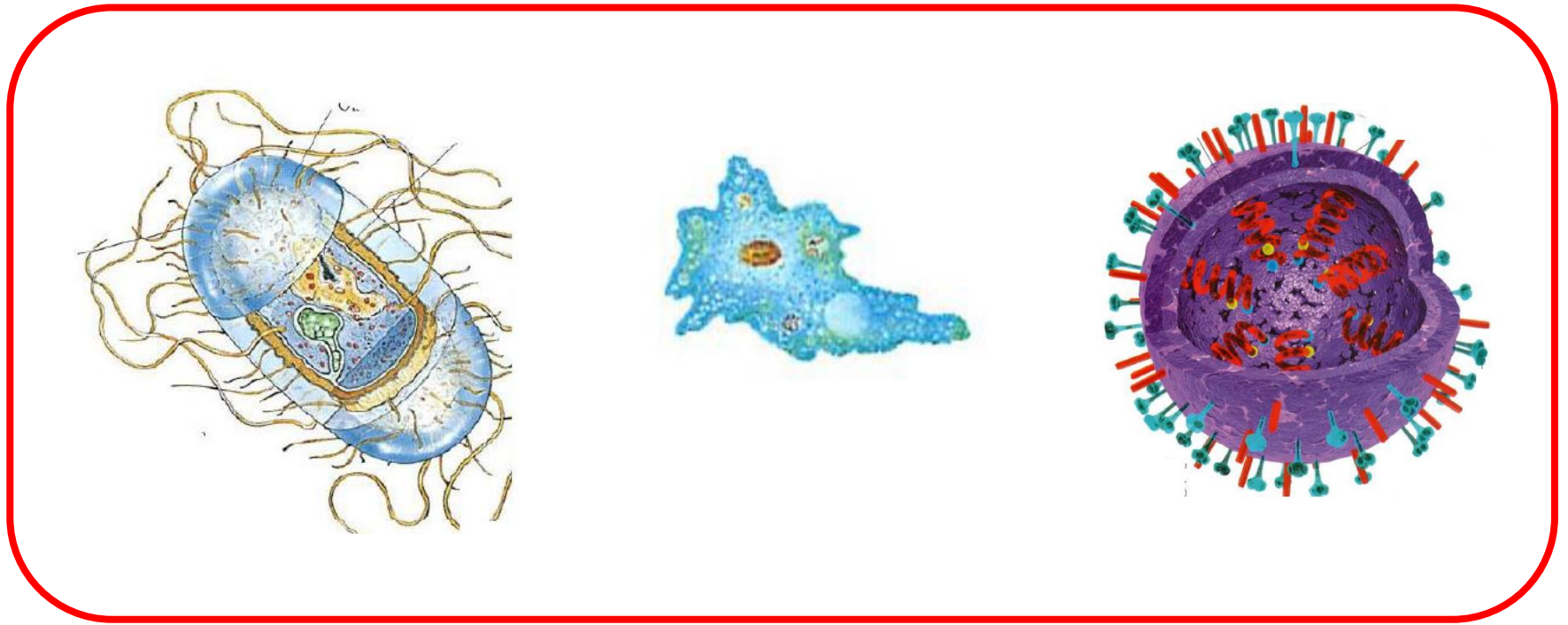
Animal Cell



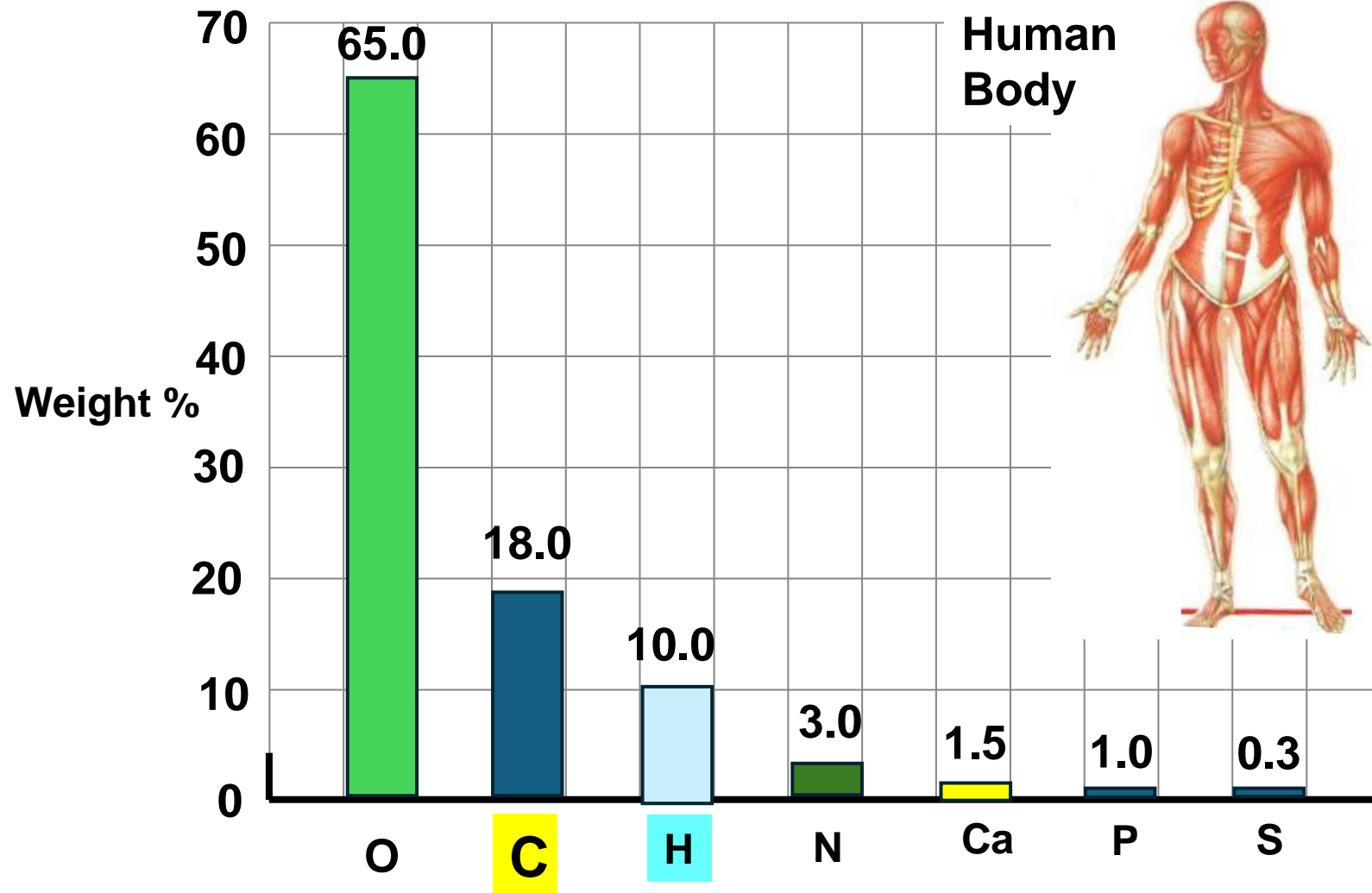
Plant Cell



Even bacteria and virus are made of carbon



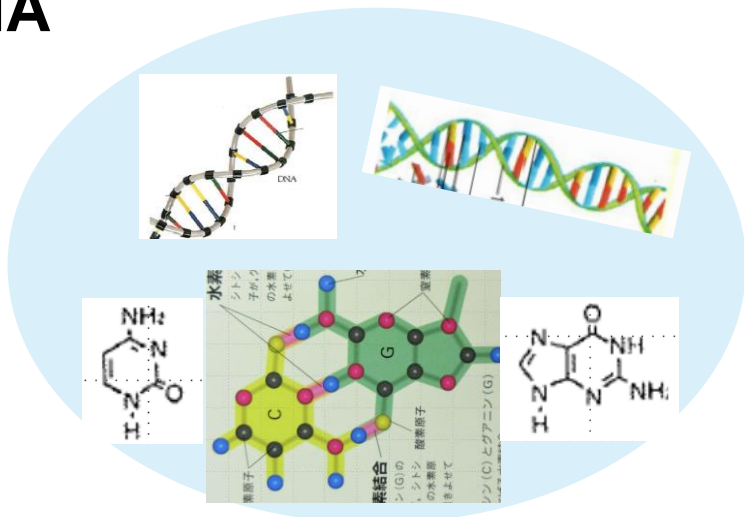
Composition of Human Body



Carbon is the vital element of Human Body!

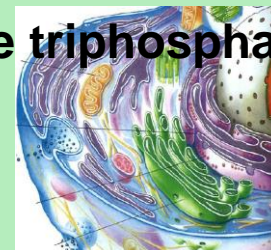
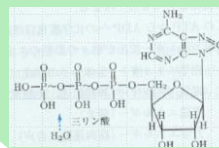
Carbon is the basis of human life

DNA



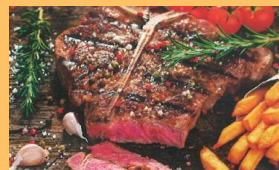
Combustion in the Cell

- Mitochondria
- ATP (Adenosine triphosphate)

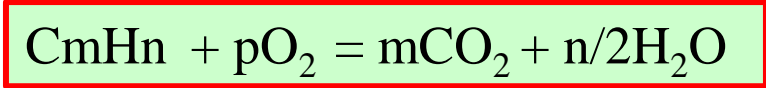
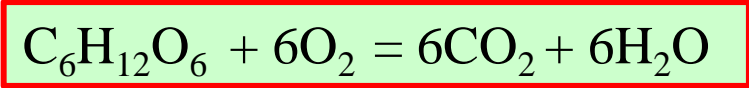
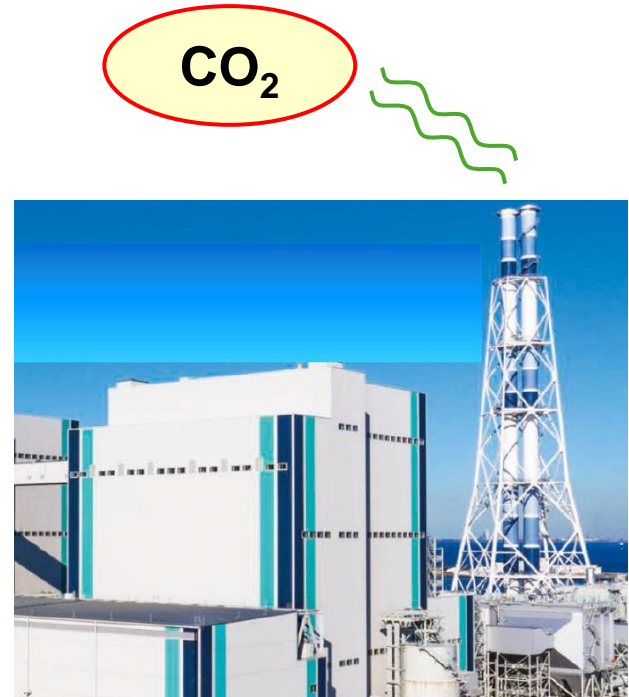
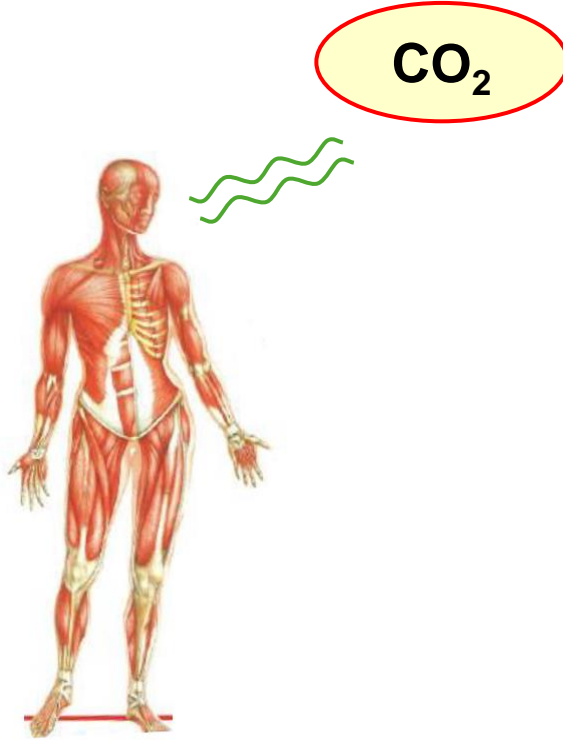


Food

- Protein
- Fat
- Carbohydrate



Human Body and Coal Fired Power Plant



- 2400 kcal/day/person
- 40 g-CO₂/h/person
- 120million Japanese people
≈ 40 million tonnes CO₂ per year

● **This is equivalent to 6GW coal fired power plants**




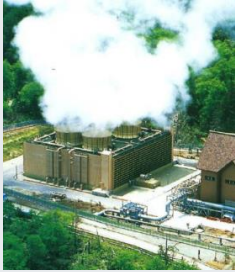

Zero carbon means no life

With carbon , full of life



No carbon , no life

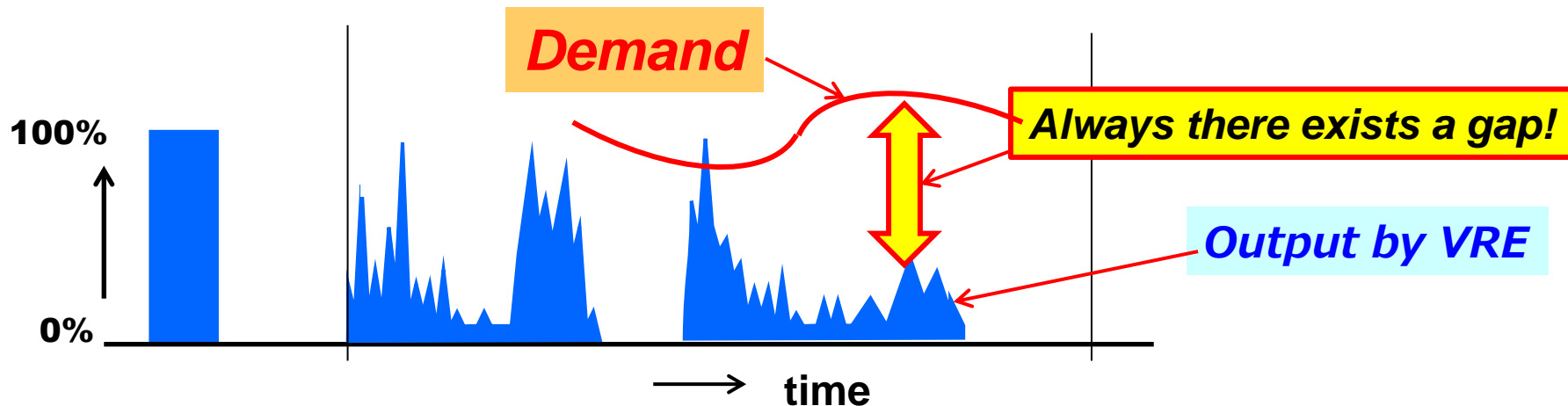
● Types of Renewable Energy

Type	● <u>V</u> ariable <u>R</u> enewable <u>E</u> nergy (VRE)		● <u>S</u> table <u>R</u> enewable <u>E</u> nergy (SRE)		
Load Control	None		Controllable		
Secured Capacity	No (because of unpredictability and intermittency)		Yes		
Conclusion	No contribution to demand-dispatch control		Load can be controlled to match the demand		
Example	PV	Wind	Hydro	Geothermal	Biomass
Features	<ul style="list-style-type: none"> • No generation at night • 1/10 on rainy days 	<ul style="list-style-type: none"> • No wind, no power 	<ul style="list-style-type: none"> • High speed load control 	<ul style="list-style-type: none"> • Same as thermal power 	<ul style="list-style-type: none"> • Same as thermal power
					

➤ VRE needs back-up to compensate!

Defects of VRE

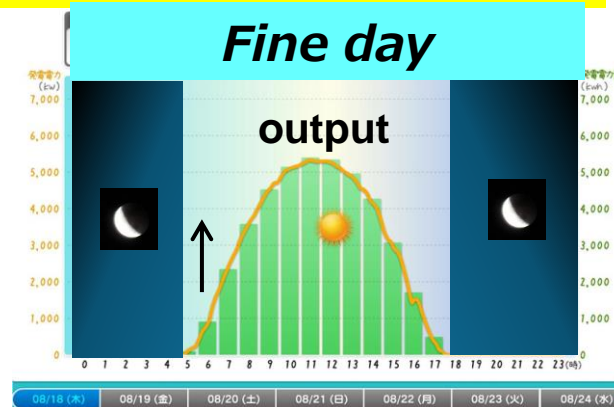
- ① VRE output is intermittent and unpredictable
- ② VRE output does not comply with demand
- ③ The gap must be compensated by back-up



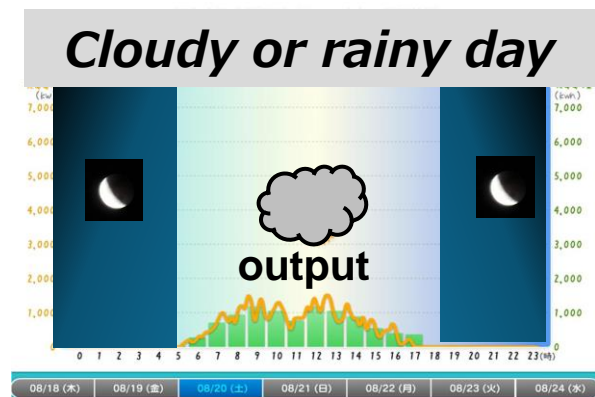
PV



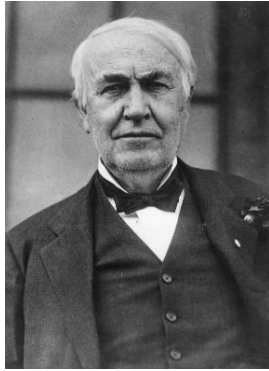
- **No power output at night!**



- **1/10 on rainy days!**



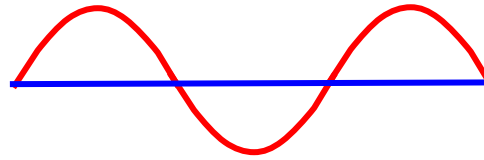
Direct Current vs. Alternating Current



Thomas Alva Edison
(1847-1931)

● Direct Current

- 1883
- New York City
- Pearl Street Station
- Transmission: 1km



● Fight over DC or AC



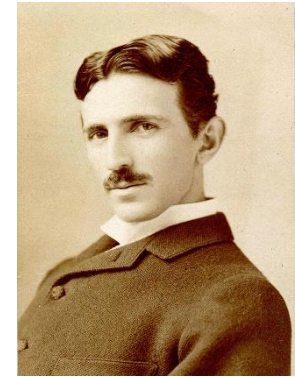
● Free Voltage Control
● Electrical Network



● Finally, AC won and was adopted for electric network worldwide.



● Frequency must be controlled at any time!



Nicola Tesla
(1856-1943)

● Alternate Current

- 1895
- Niagara Falls Hydro
- Transmission: 40km

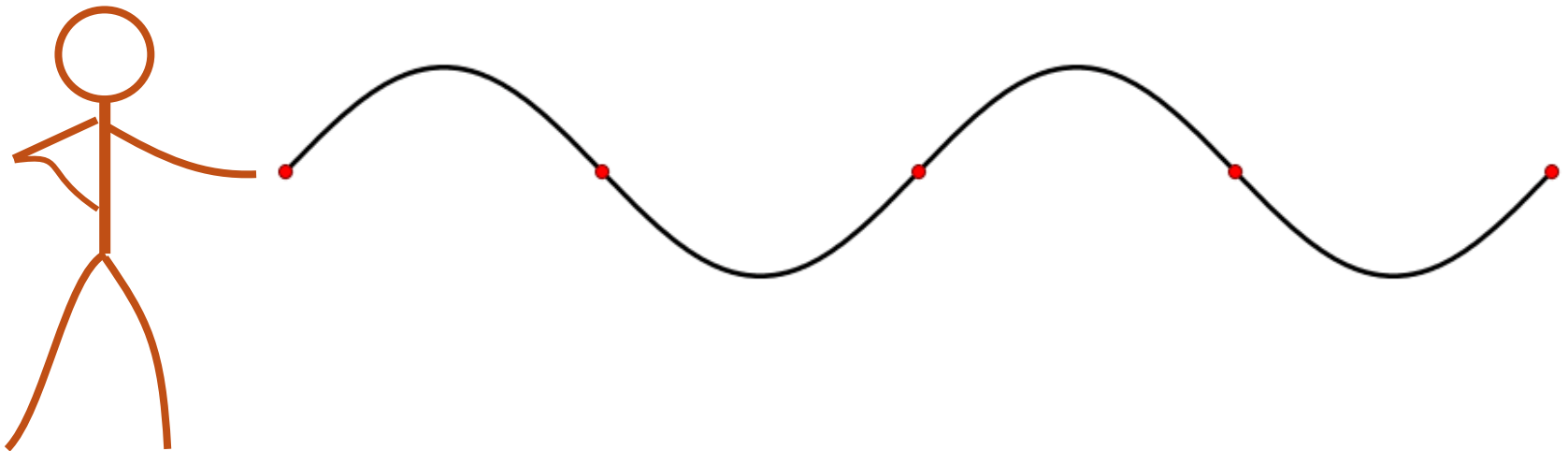
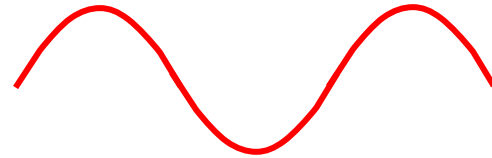


Alternating Current

● Direct Current



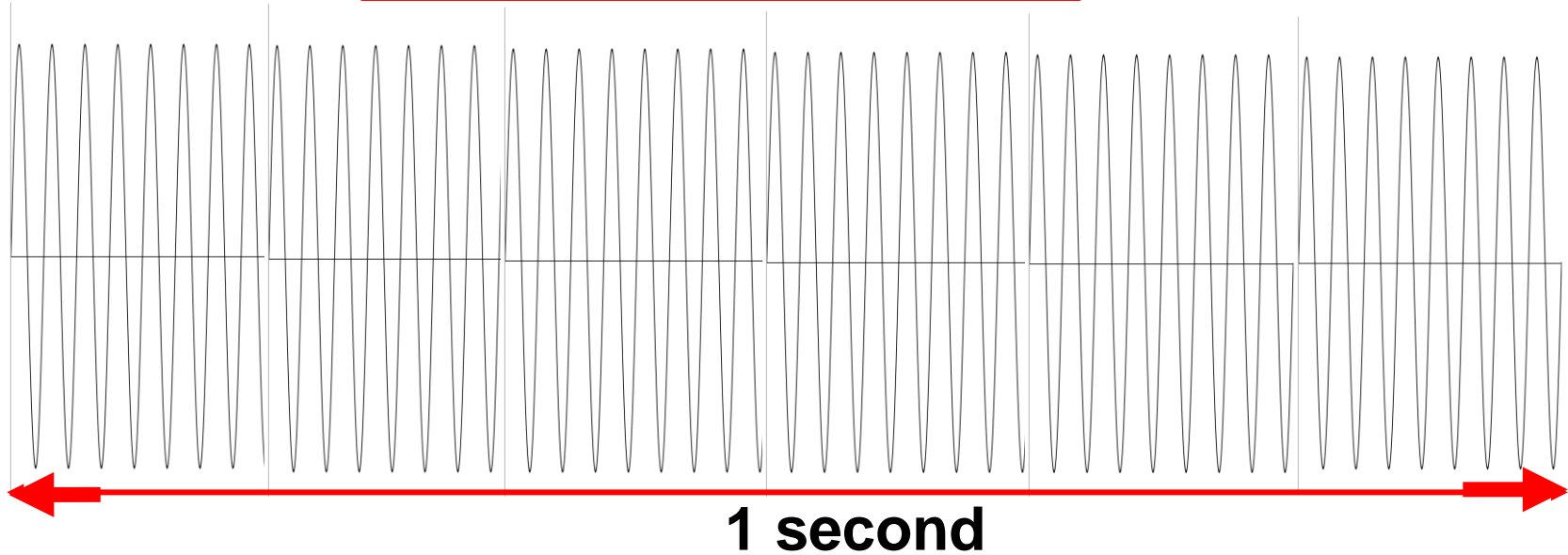
● Alternating Current



50Hz---50 cycles per second

● Alternating Current

● 50 cycles per second



● Alternating Current system is shutdown by 5% deviation!

Alternating Current System

Basic Freq.	50 Hz
Deviation	5%→47.5Hz
Result	Shutdown by UFR

Electric system is far more sensitive!

Human Body

Basic Pulse	50 beat/min
Deviation	5%→47.5pulse($\Delta 3$)
Result	Heart can sustain



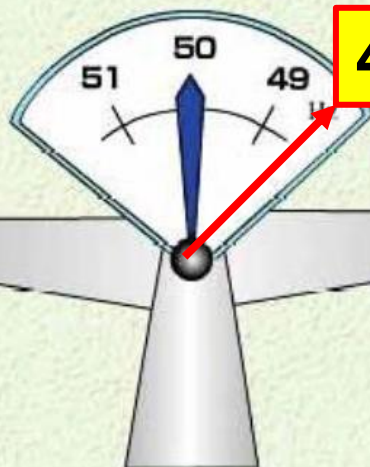
Supply and Demand must meet at any moment!

Japanese standard frequency control range : $\pm 0.2\text{Hz}$

**Supply
(Power Generation)**



Frequency



**Demand
(Consumption)**

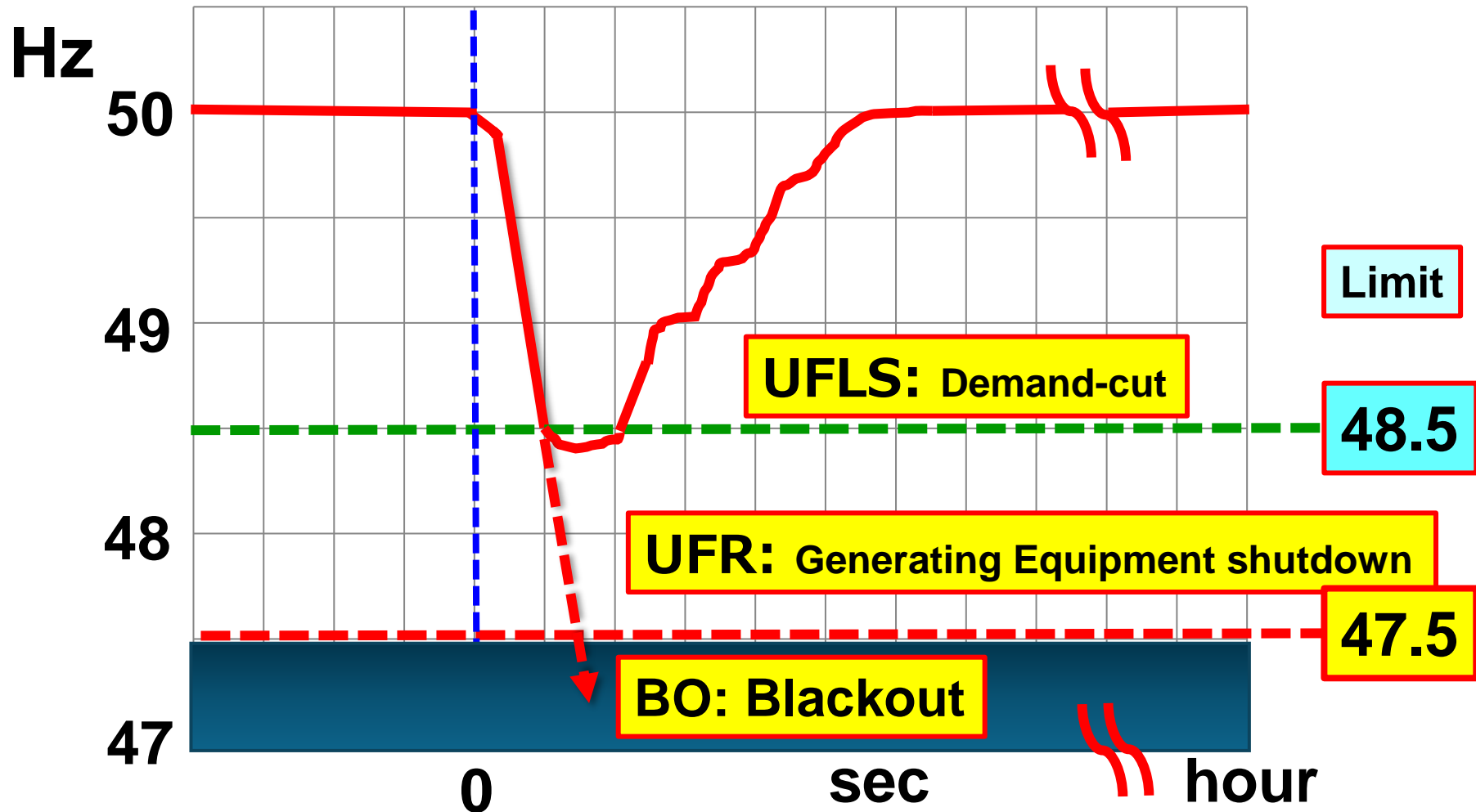


- If the deviation is over 1.5Hz , **UFLS (Under Frequency Load Shedding)** is activated !

- If the deviation is over 2.5Hz , all generating plants go to automatic shutdown -----**Blackout occurs!**

● Two limits against the frequency drop...

UFLS : Under Frequency Load Shedding: Cut demand side
UFR : Under Frequency Relay: Cut generating side

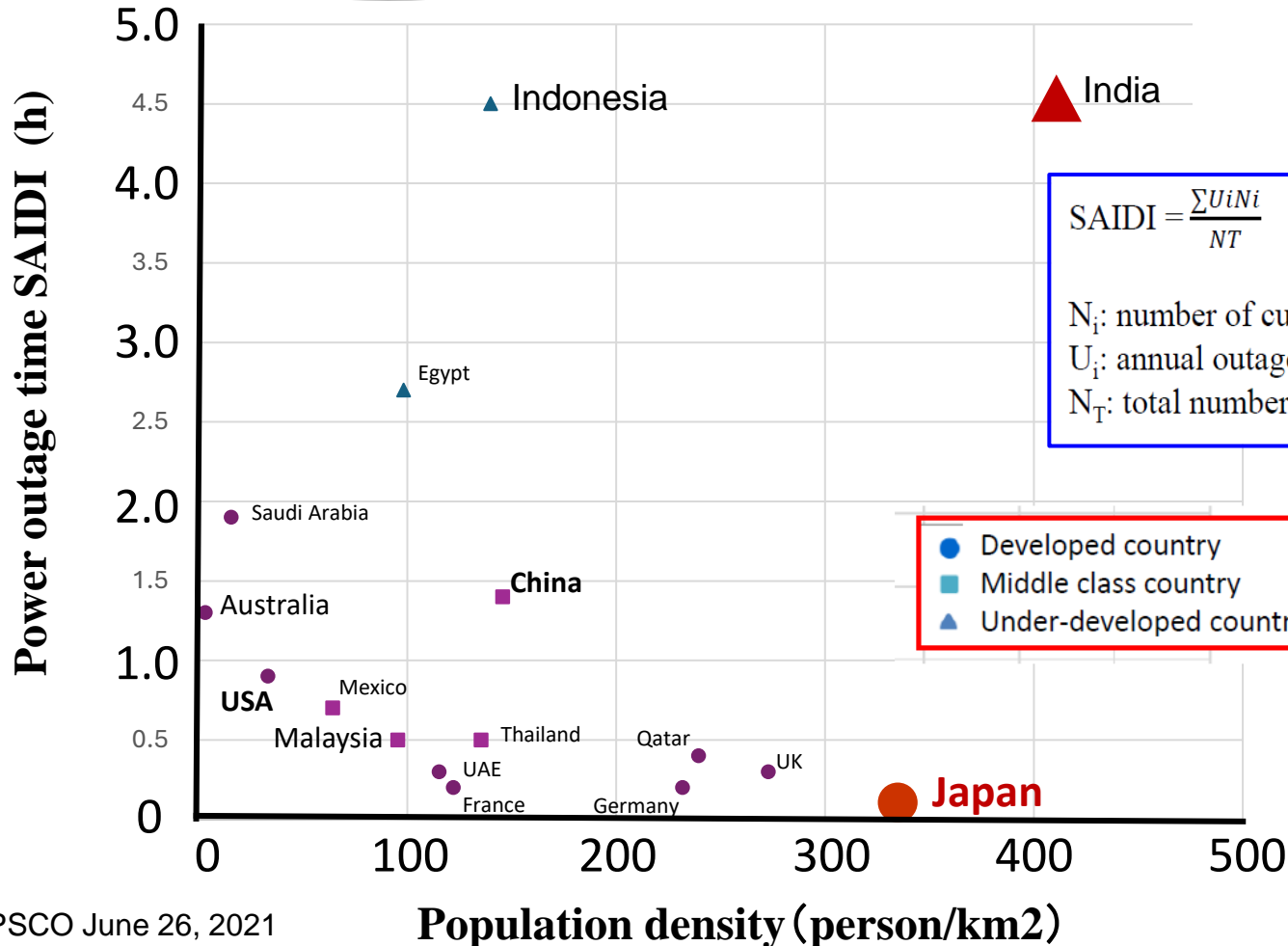




Outages in the World

Mongolia 54.0
 South Africa 44.0
 Brazil 12.6

Bangladesh 64.5 ▲

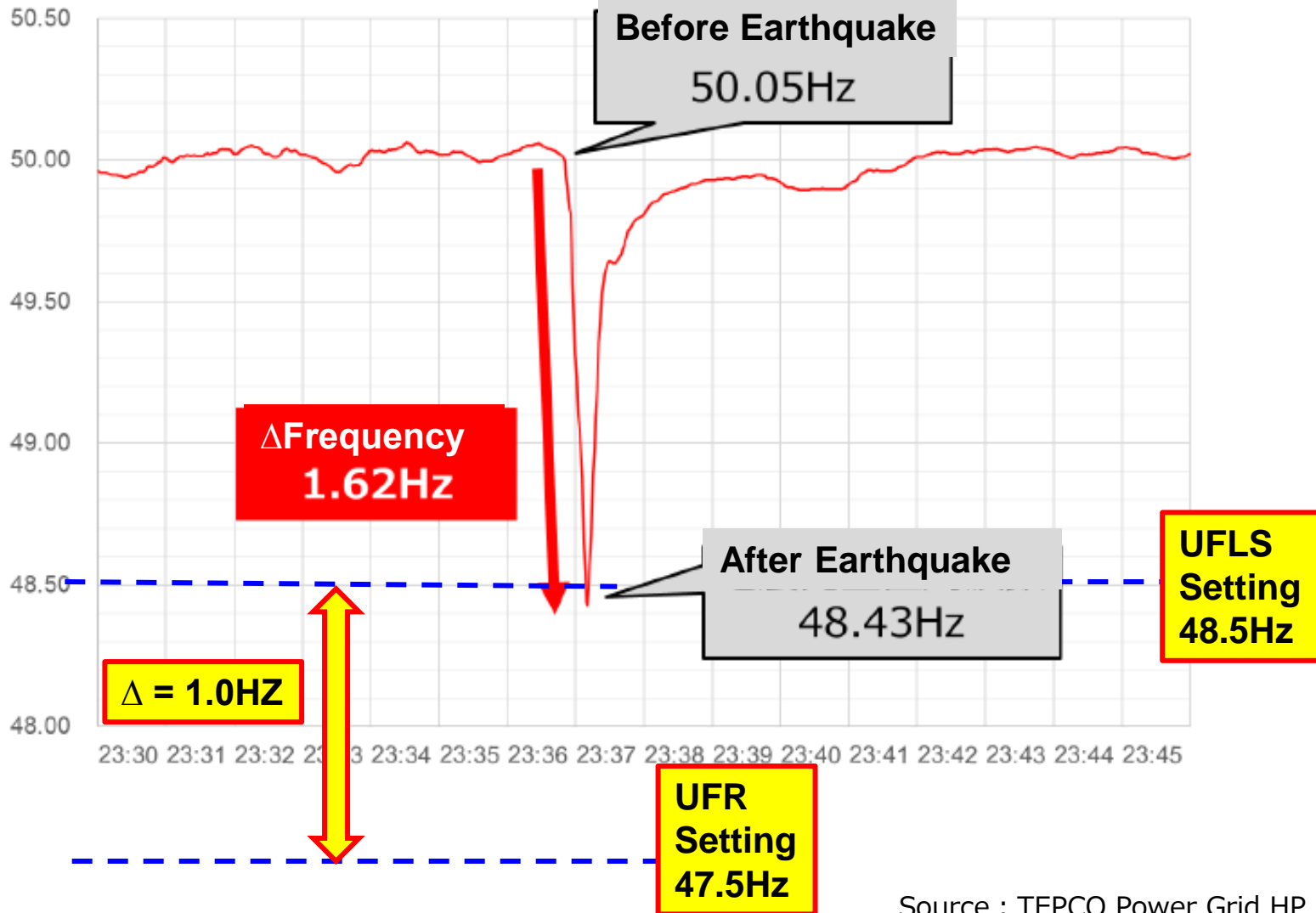


Source: TEPSCO June 26, 2021

Frequency Variation Record on March 16th, 2022

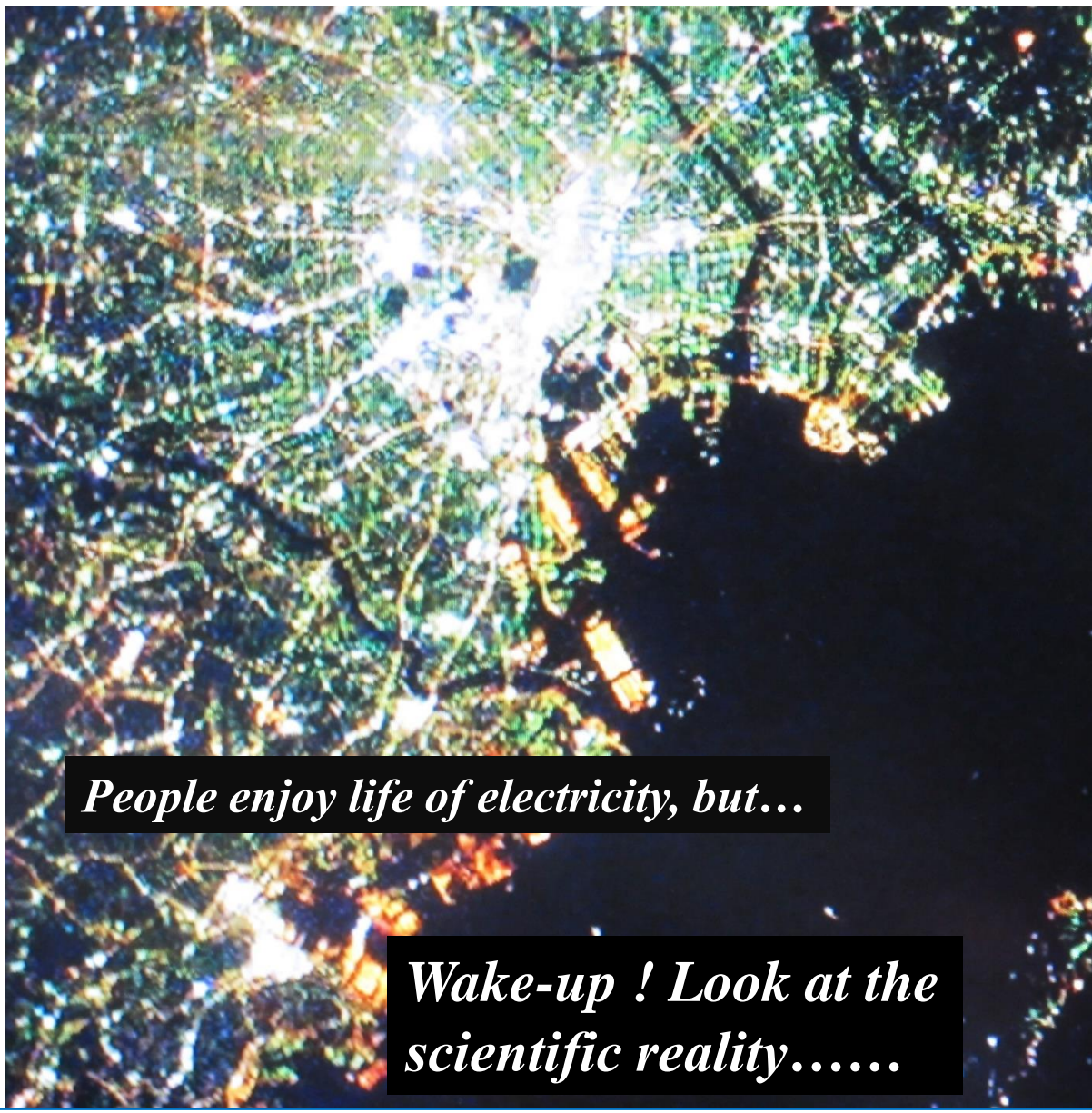
It is a serious problem to prevent blackout in Tokyo

Frequency
in Tokyo
Area



Source : TEPCO Power Grid HP

● Possibility of Blackout in Tokyo



People enjoy life of electricity, but...

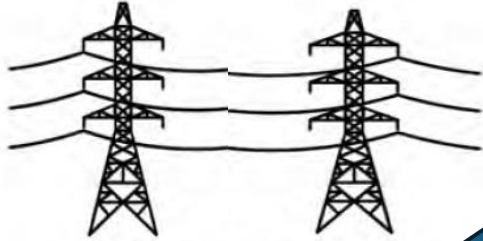
Wake-up ! Look at the scientific reality.....



Damocles sword

AC Electric System vs. Human Body

AC Electric System



Human Body



5% deviation

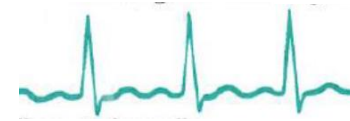
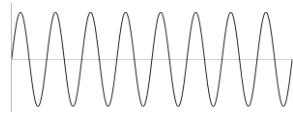
3 Hz out of 60

3 beats out of 60

UFR and Shutdown

Blackout!

Healthy and Normal



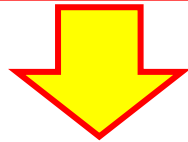
- *AC Electric System is much more delicate and sensitive compared to Human Body!*

VRE vs. SRE

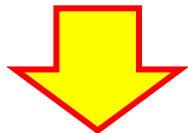
Solar and Wind



Variable Renewable Energy

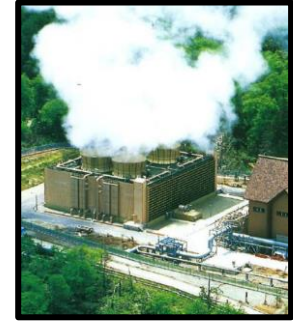


Intermittent and unpredictable

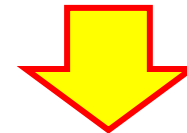


Sacrifice System Stability

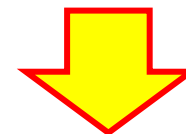
Hydro and Geothermal



Stable Renewable Energy

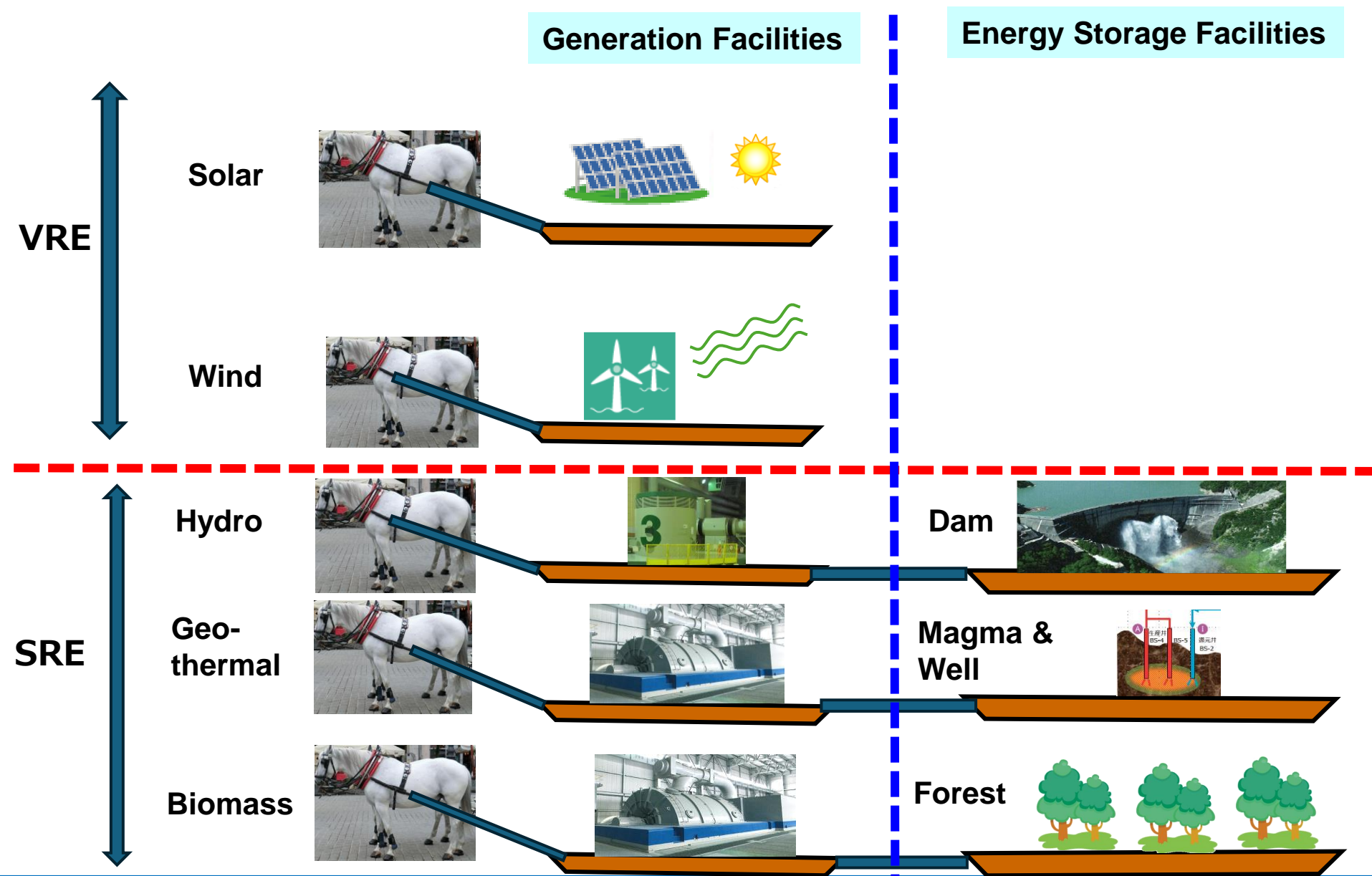


Stable and Controllable

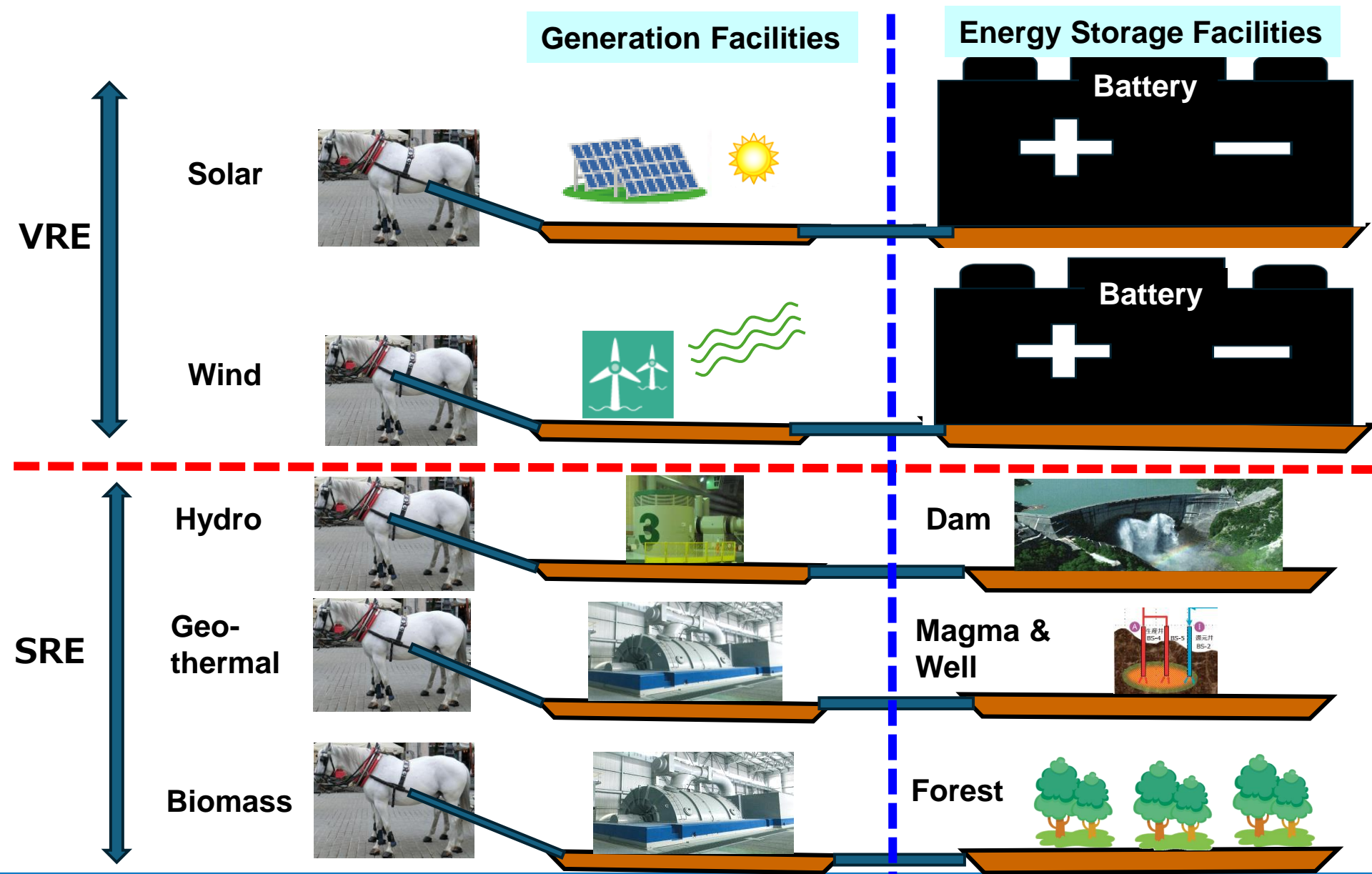


Harmonize with AC System

Solar and wind are cheap and economical?

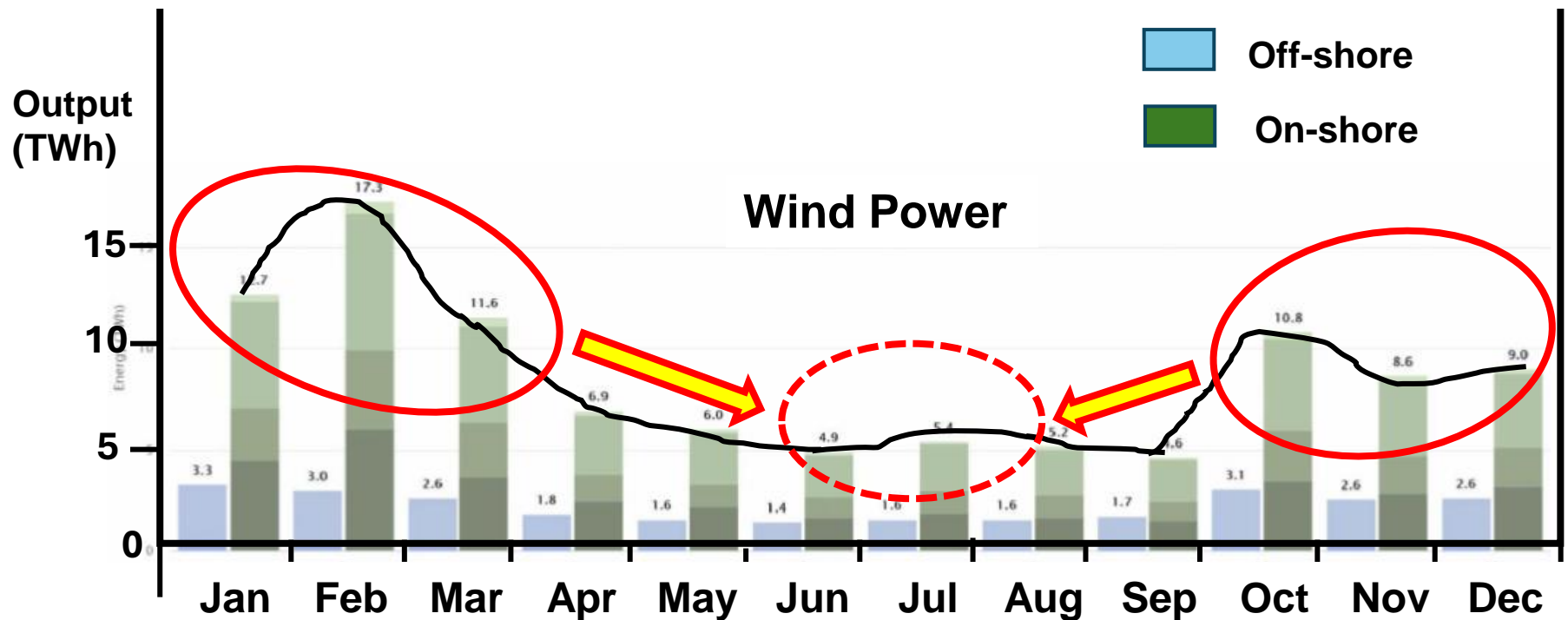


Reality for electric system stability



● Seasonal Time Shift

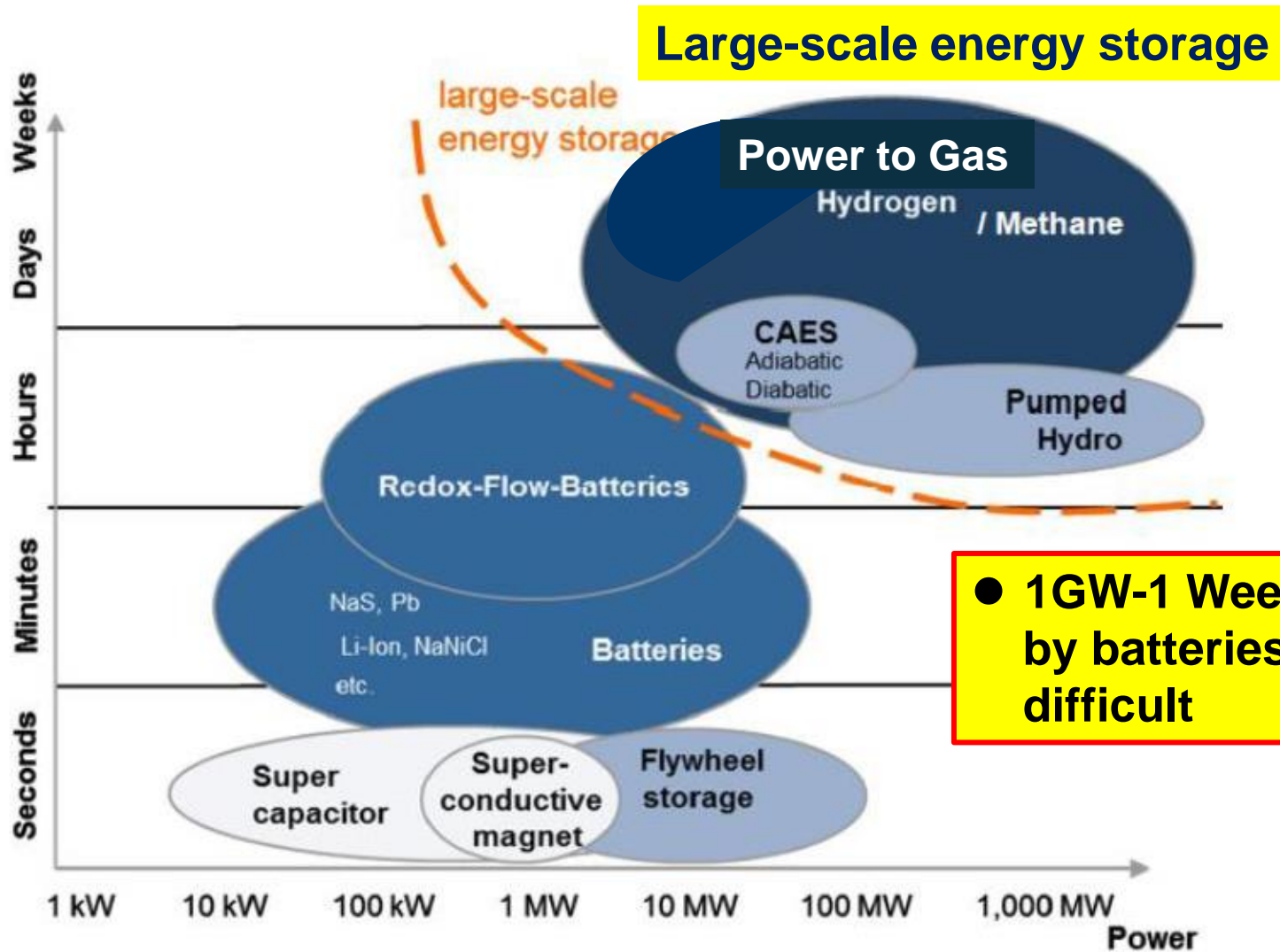
- Wind power generation is greater in winter than in summer !
→ Seasonal power shift is necessary when wind percentage is high!



Monthly Power Generation by Wind in Germany(2020)

Source: Net Public Electricity Generation in Germany in 2020, Fraunhofer

Energy Storage

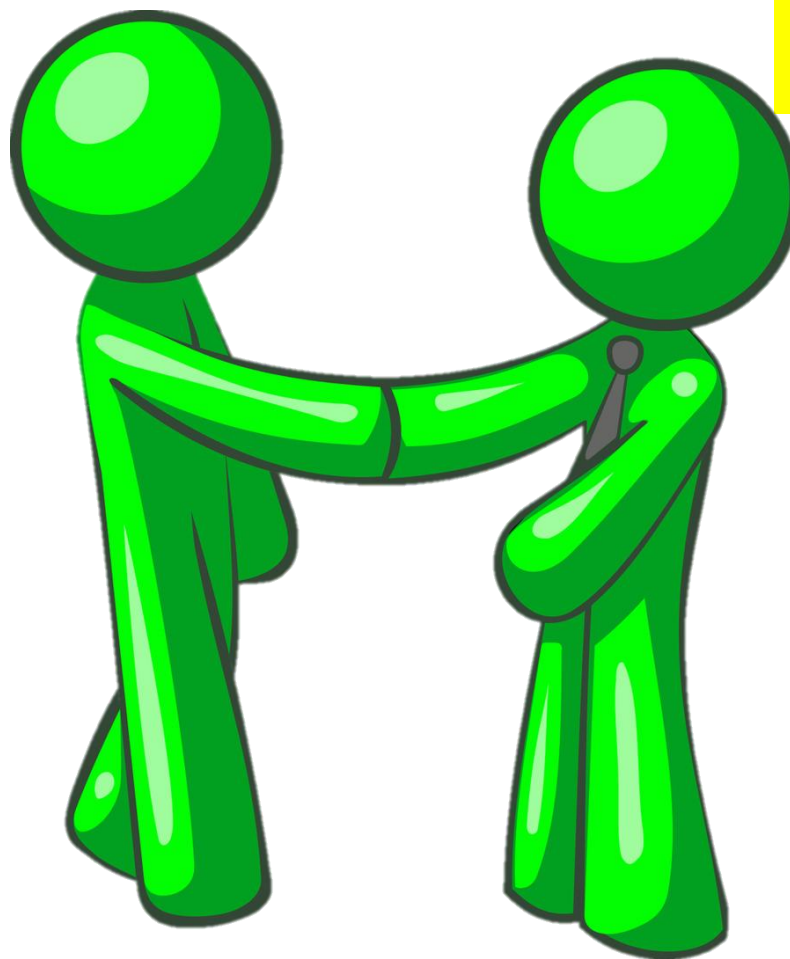


Source: "Development and applications for MW-scale electrolyzer systems" (SIEMENS, 2016)

Renewable Energy needs Thermal Power !

***Thermal
Power***

***Renewable
Energy***



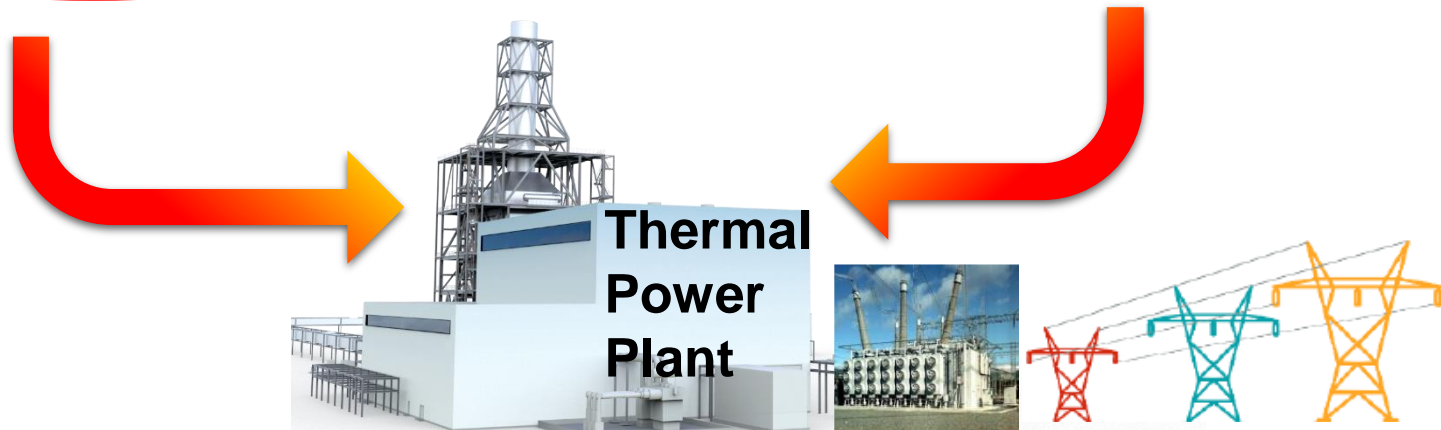
Thermal Power Plants in the future

- *Thermal Power never die, only fossil fuels are switched to synthetic fuels!*

Surplus Renewable Energy

Fossil Fuels
(Coal · Nat. Gas)

Synthetic Fuels
($H_2 \cdot NH_3 \cdot CH_4$)



2020

2030

2040

2050

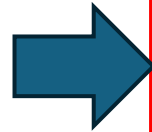
Requirements for new thermal power plants

Fuel Versatility
Multiple Fuel Capability



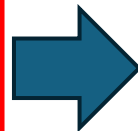
- **Energy Security**
- **Lowest cost fuel, either fossil or synthetic**

Quick Load Change



- **To coexist with AC Current network**
- **Prevention of Blackout**

Minimum Construction



- **To minimize construction and time**

● Outline of FlexPower System

New Thermal Power Plants in Carbon Neutral Society



FlexPower System

		Flex-USC		Flex-GTCC	
System Configuration		B-ST-G		GT-HRSG-ST-G	
Fuels	Fossil	Coal/Oil/Natural Gas/Residue		Natural Gas/Light Oil	
	CN Fuels	H ₂ /NH ₃ /Biomass		H ₂ /NH ₃ /e-methane	
Construction		Small Modular		Small Modular	
High Efficiency (Inlet Temp.)		ST : 650°C		GT: 1650°C ST: 650°C	
Stage		Step1	Step2	Step1	Step2
Load Change Rate(%/min)		5	15	5	15
Minimum Load (%)		15	5	15	5
Heat Storage		w/o	w	w/o	w

Don't put all your eggs in one basket!



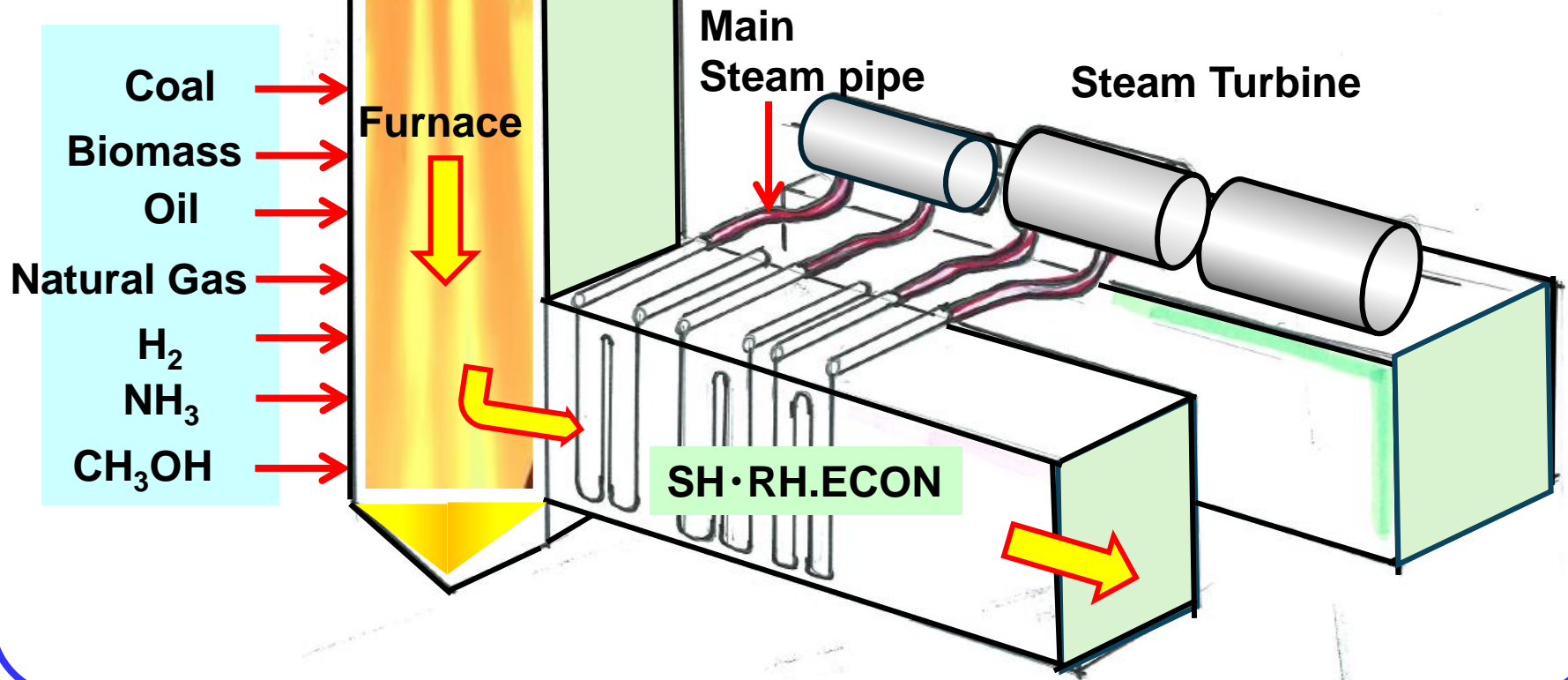
- **Risk hedge**
- **Risk distribution**
- **Multiple options**

● *If you don't have options,
you cannot negotiate.*

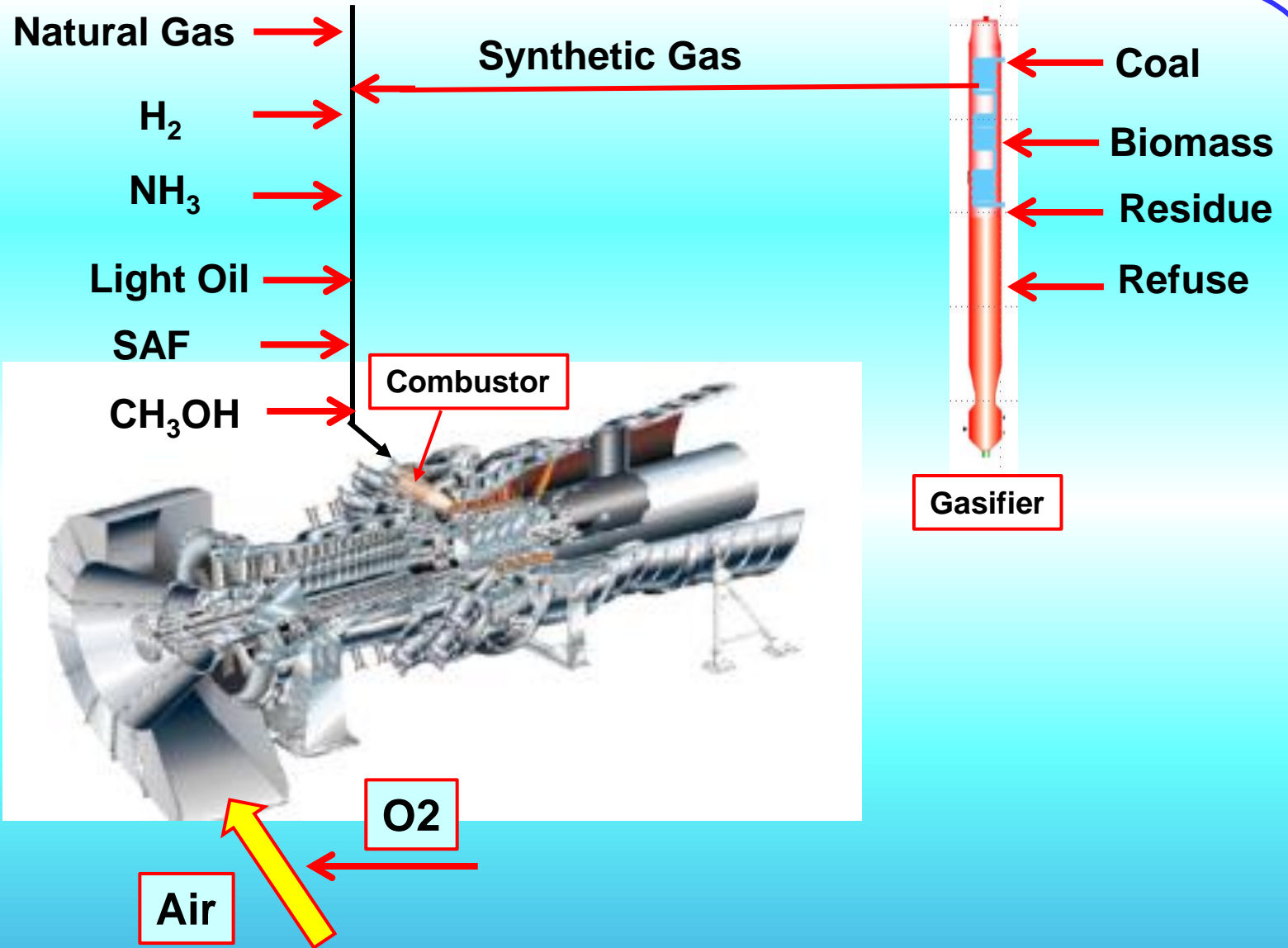
Flex-USC ANGEL BOILER



- Any Fuels can be used
- Inverted Furnace
- SH & RH Modules in Horizontal Passage
- Minimum Length of SH & RH piping
- Small Modular Construction

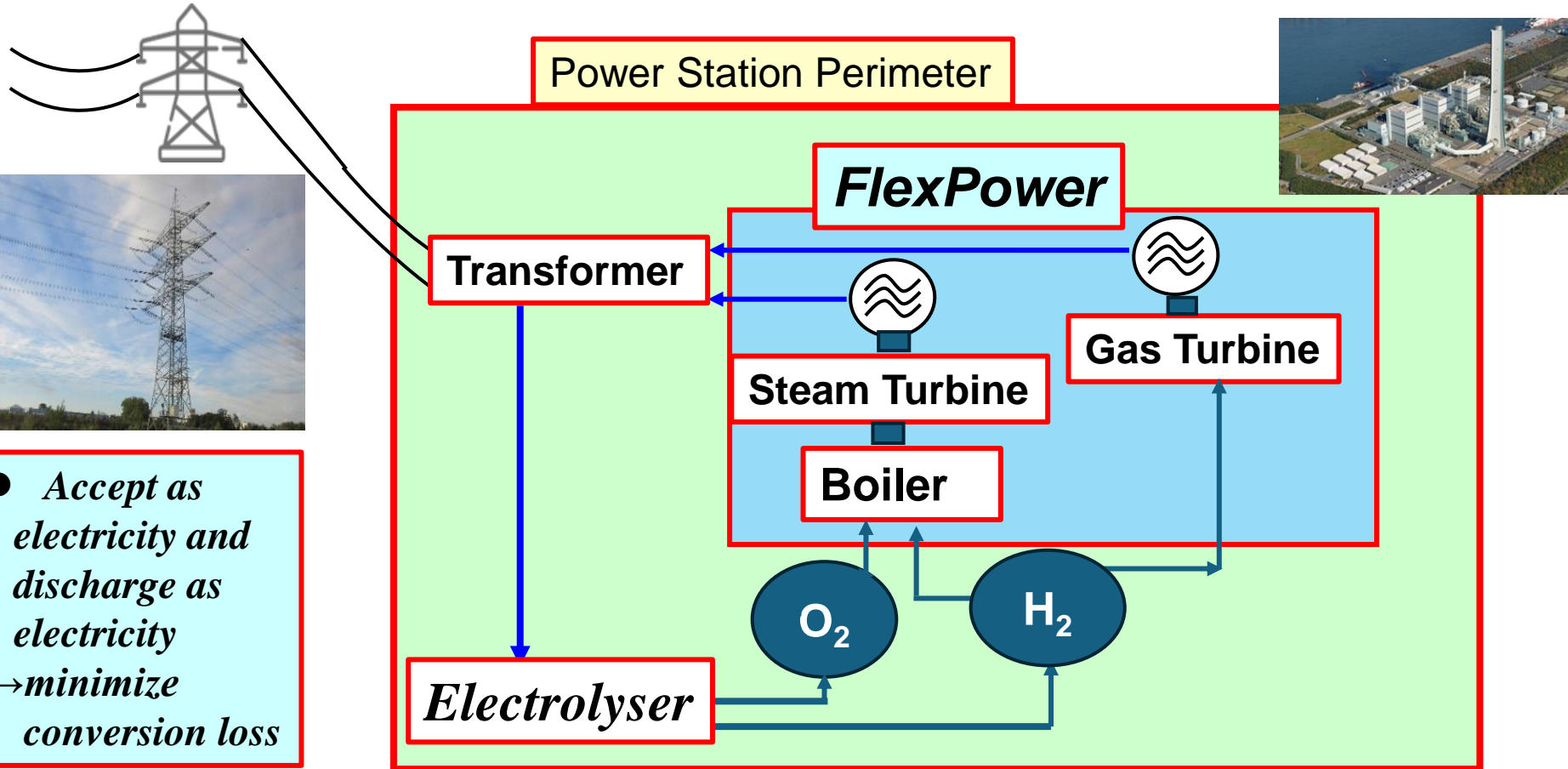


Flex-GTCC



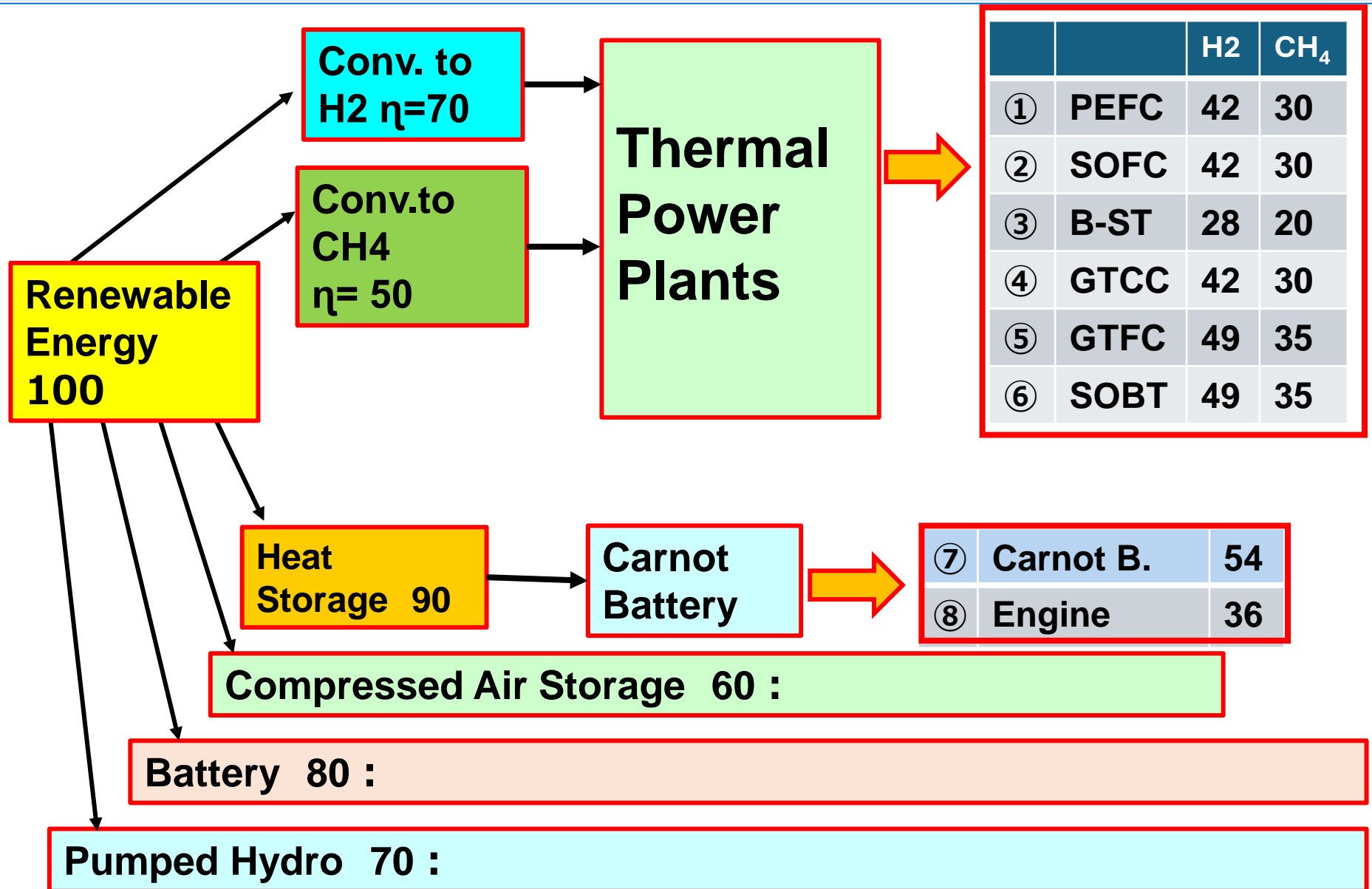
● Optimum Thermal Power Plant in CN Society

● Conversion will be done within the Boundary



Hydrogen and Oxygen are used on the spot!

● Synthetic Fuels and Overall Efficiency



The future is bright...

The End