International Institute for Carbon-Neutral Energy Research

"Hydrogen" an Energy Vector for the Sustainable Society

Winton Physics Symposium
9th Nov. 2017

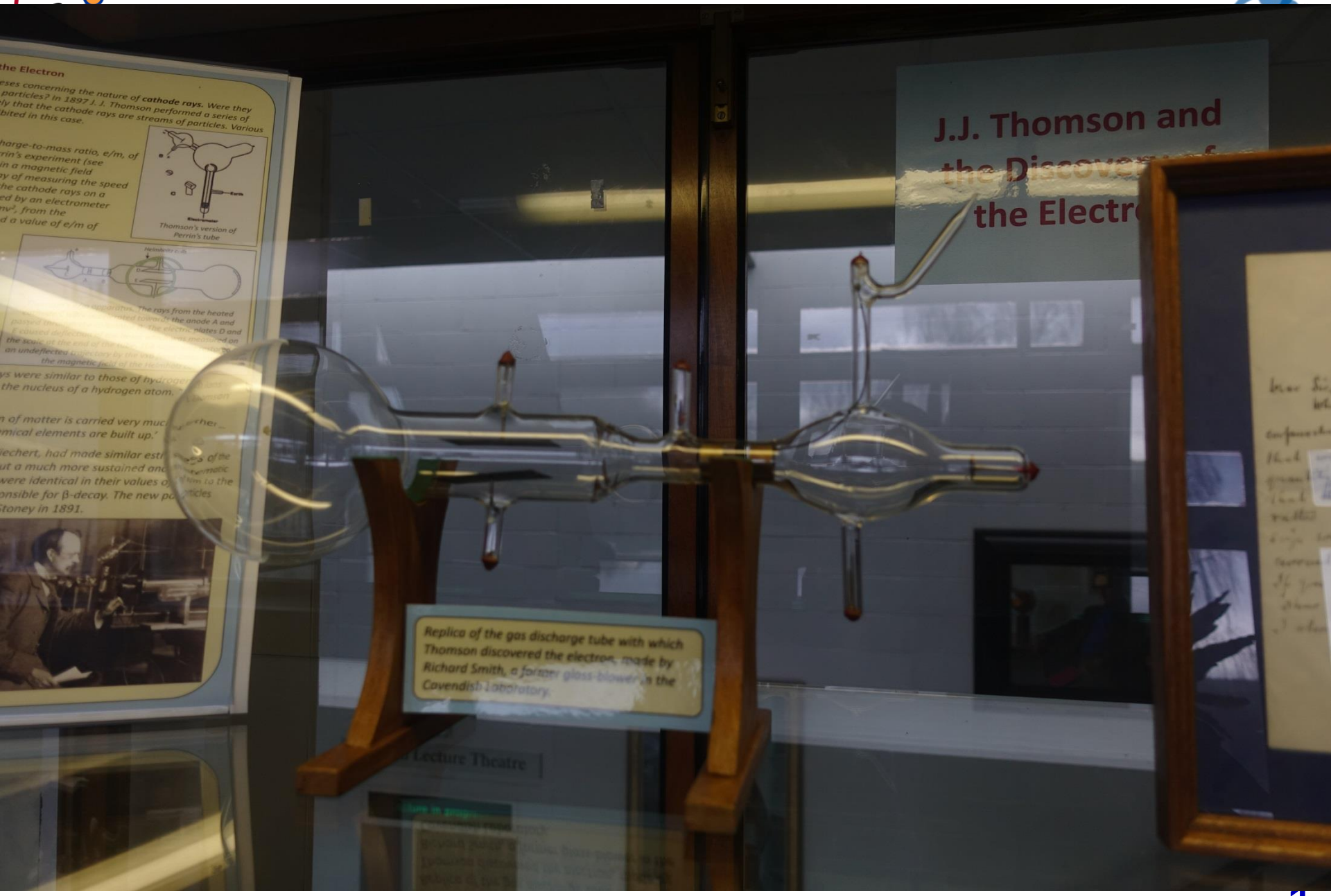
Kyushu University WPI Visiting Professor

Katsuhiko Hirose

KYUSHU UNIVERSITY

wpi World Premier International Research Center Initiative

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN


J.J. Thomson and
the Electr
Replica of the gas discharge tube with which
Thomson discovered the electron, made by
Richard Smith, a former glass-blower in the
Cavendish Laboratory.
Lecture Theatre

I am a lucky physicist/engineer to have been observed and been involved two big innovations of automotive technology

Status update for Fuel Cell Vehicles

- Today's Theme

Electrons and Protons for economy

Physics for Economy

- **We cannot change physics**

- **Physics can change the world**

- Economics
  - Observing the economy and find the basic rules behind the phenomena
  - Apply for the stimulating the economy to improve and better economy

- Physics
  - Observing the nature and find the rule behind the phenomena
  - Apply the theory to the experiment to understand more about nature
  - But not trying to change the world

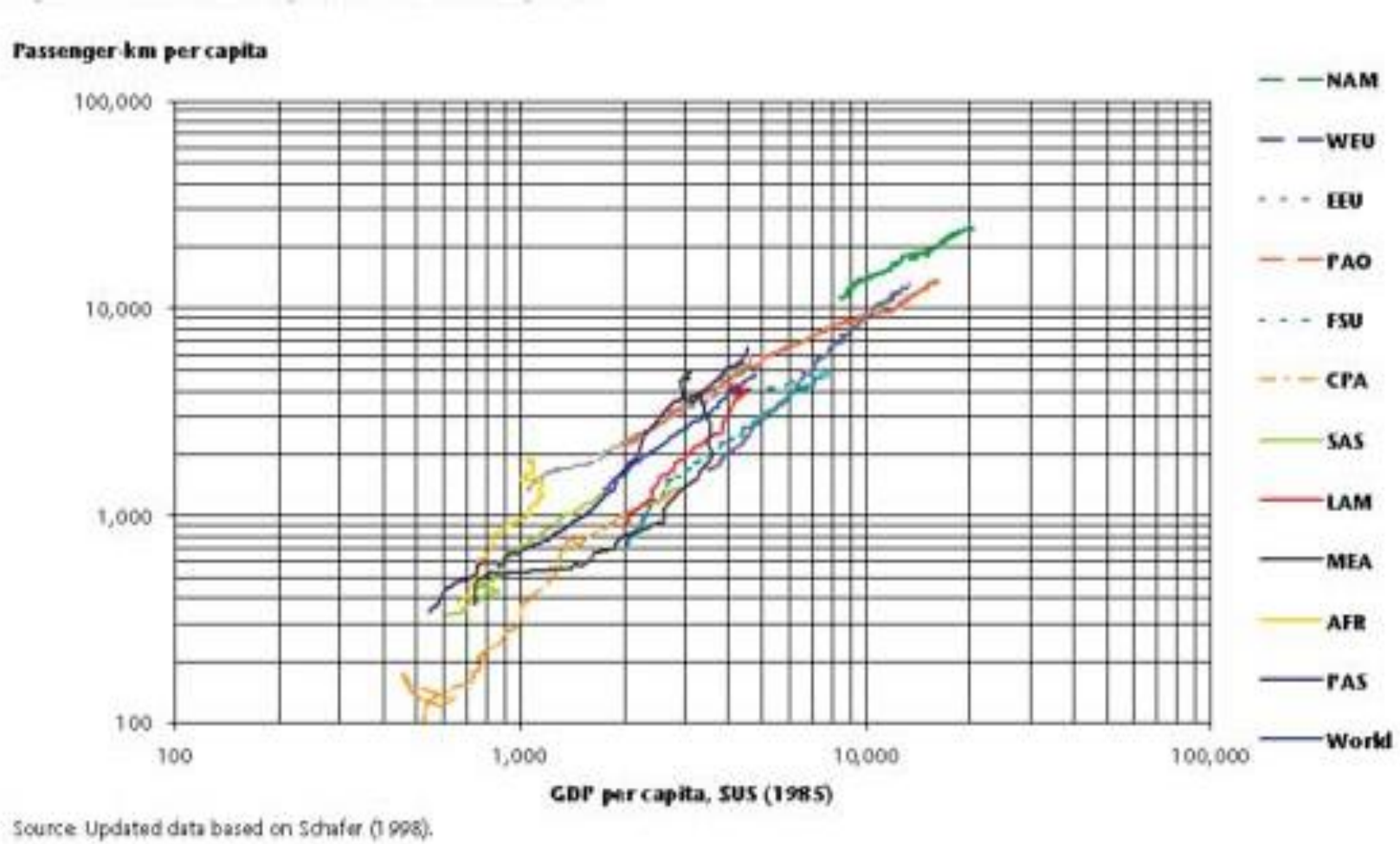
What we are facing

- Global Warming due to the use of Fossil Fuel
- As an Energy

- People seeking better life
  - What happens everybody seek the same life as US or European life style

- In the past
  - North and South, rich and poor
  - Due to the posses and not possess
  - Cash flow from people not posses to people to posess
  - Enhance and accelerate the economical gap

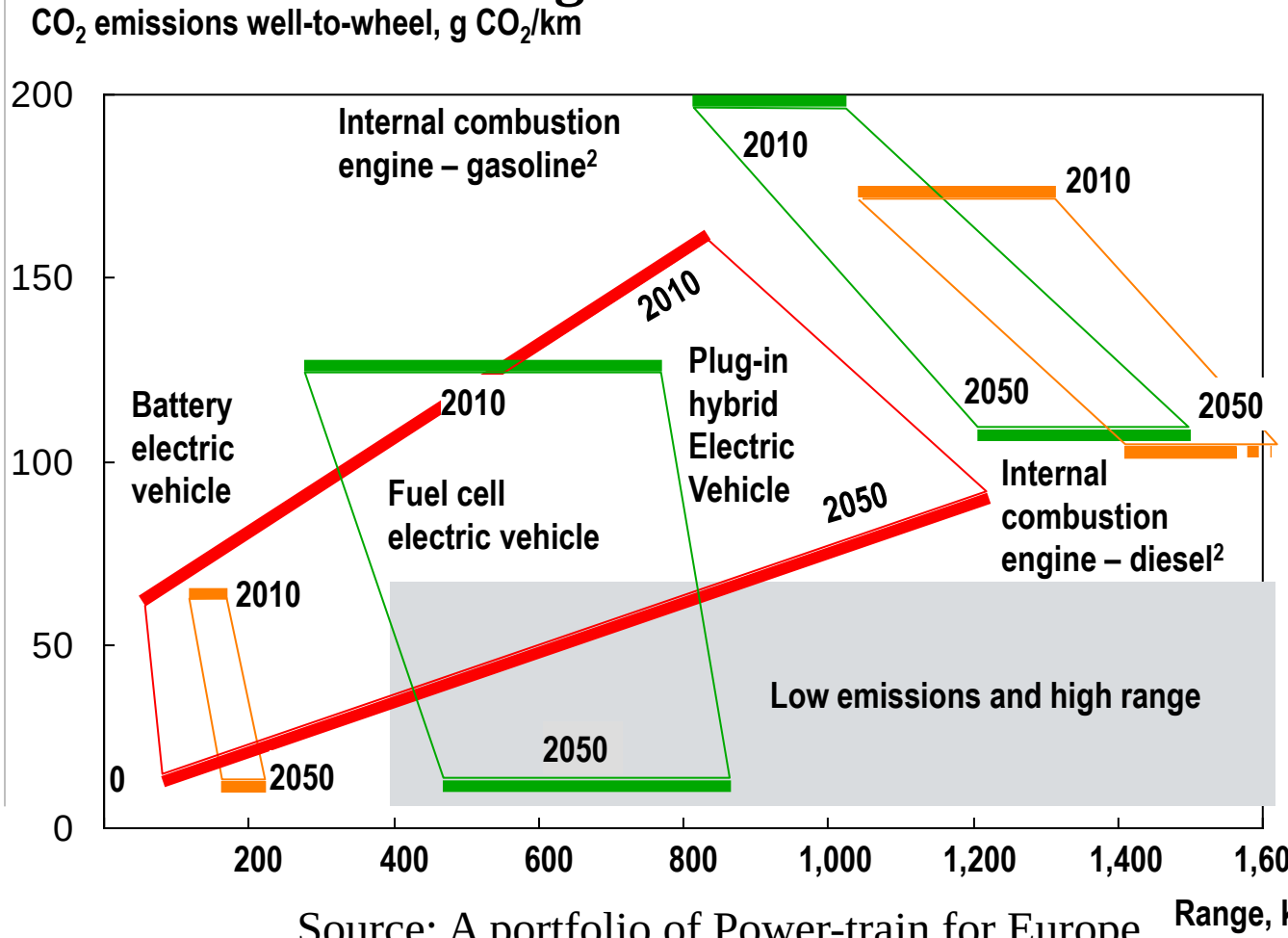
Mobility is the basic desire everywhere



Source WBCSD Mobility 2001

Potential of eclectic propulsion technologies

- **Electric propulsion system has big potential**
- **FCV covers wider customer usage**

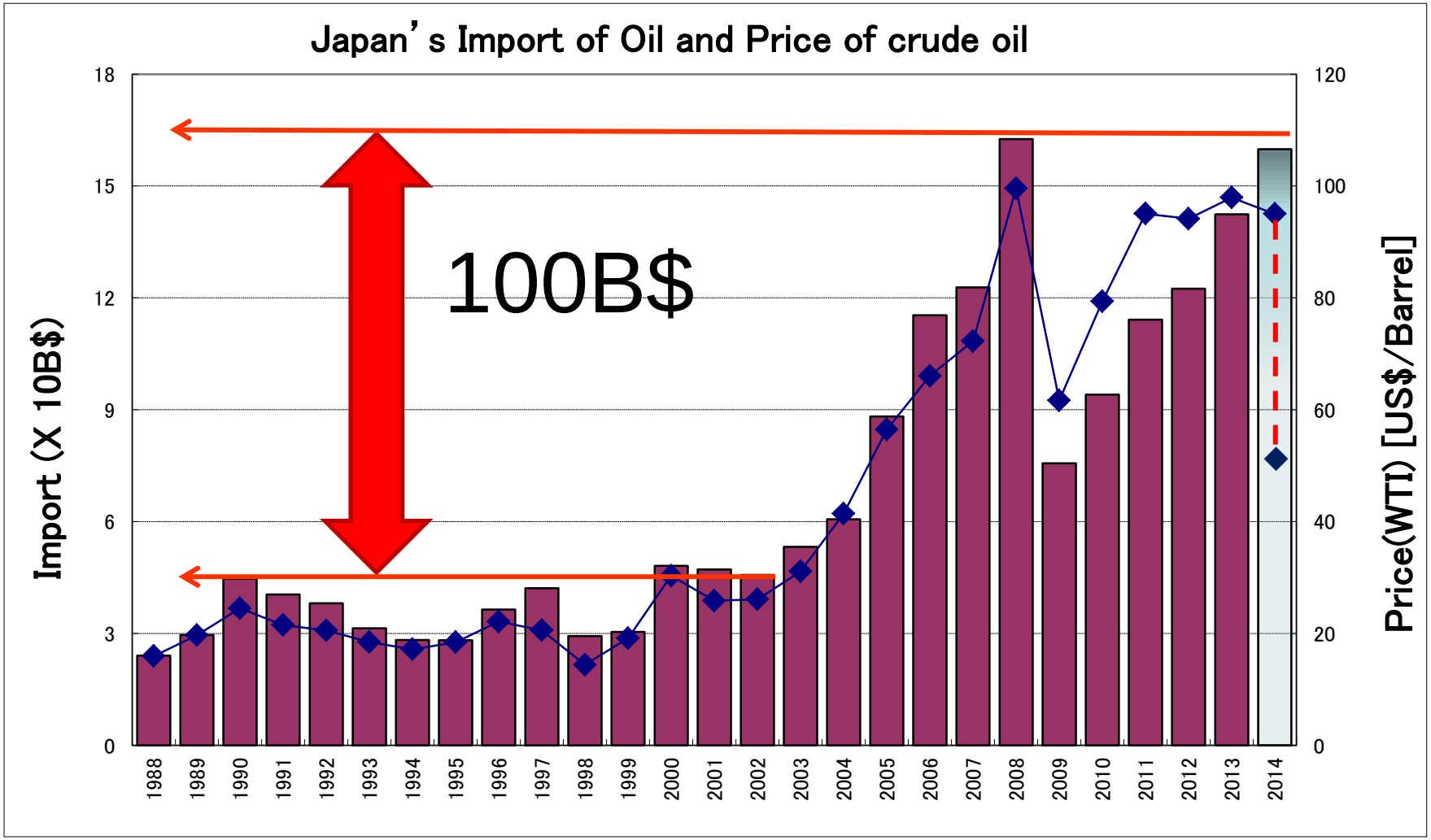


Source; A portfolio of Power-train for Europe

1 According to the Integrated Energy and Climate Program; 21% compared to 1990
2 Range for 2050 based on fuel-economy improvement (constant tank size assumed); assumed 6% CO_2 reduction due to biofuels by 2020, 24% by 2050

Cost of importing crude oil to Japan

From Japanese Gov trade statics



Huge amount of cash out of country increased drastically in recent years

European Commission

The EU Energy System

53%
of EU energy imported in 2014

€400 billion
spent on energy imports in 2014

6
Member States depend on a single external supplier for their entire gas imports

75%
of EU housing stock is energy inefficient

94%
of EU transport relies on oil products (of which 90% imported)

30%
EU wholesale electricity prices higher than US

4.4%
rise in EU household electricity prices 2012-2013

€1 trillion
investments into the EU energy sector needed by 2020

€120 billion
per year spent on energy subsidies (directly or indirectly)

€129 billion
annual turnover of EU renewable energy businesses

Source: EU Commission Communication on "A framework Strategy for a Resilient Energy Union with Forward-Looking Climate Change Policy", 25 February 2015.

CLIMATE POLICY OBSERVER
monitoring climate policies

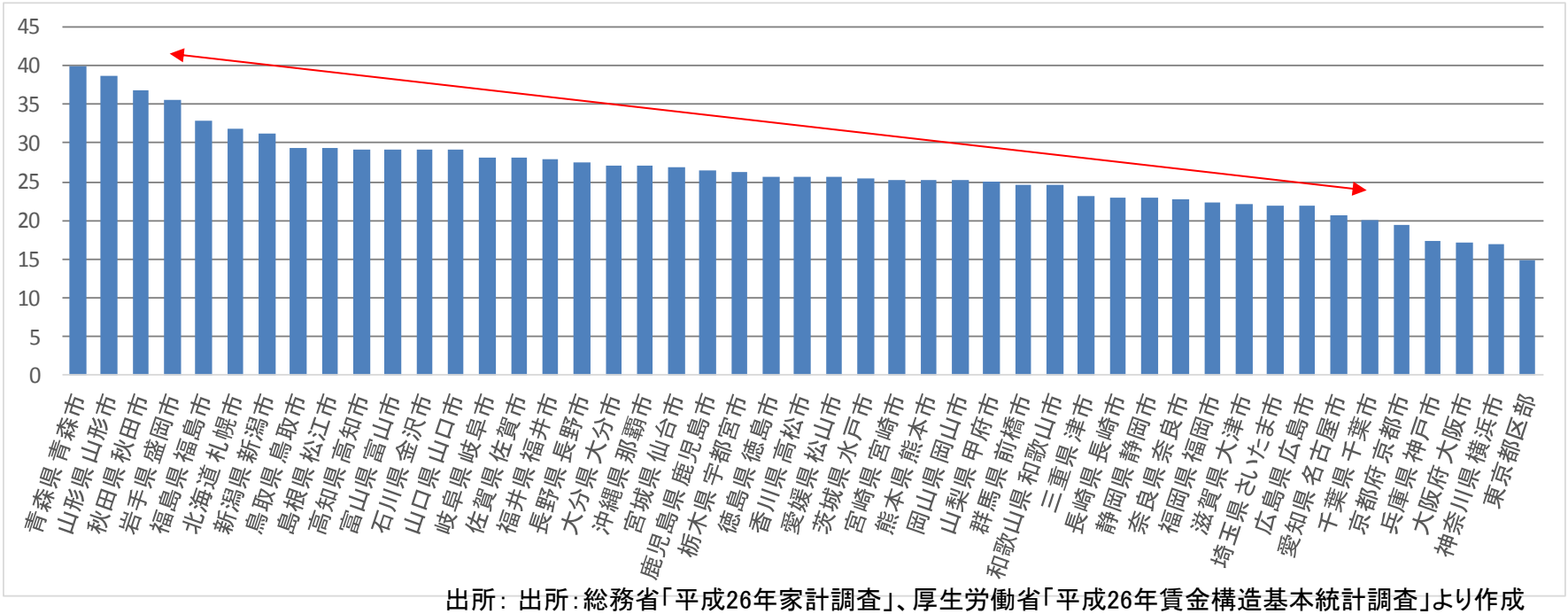
Research and Innovation

Redistribution of value to the local economy

Recognition of reality

- **Rise of energy cost for local economy**
- **Cash out by the energy expense damage the regional economy since the small economyy since the energy has small value chain for locals**

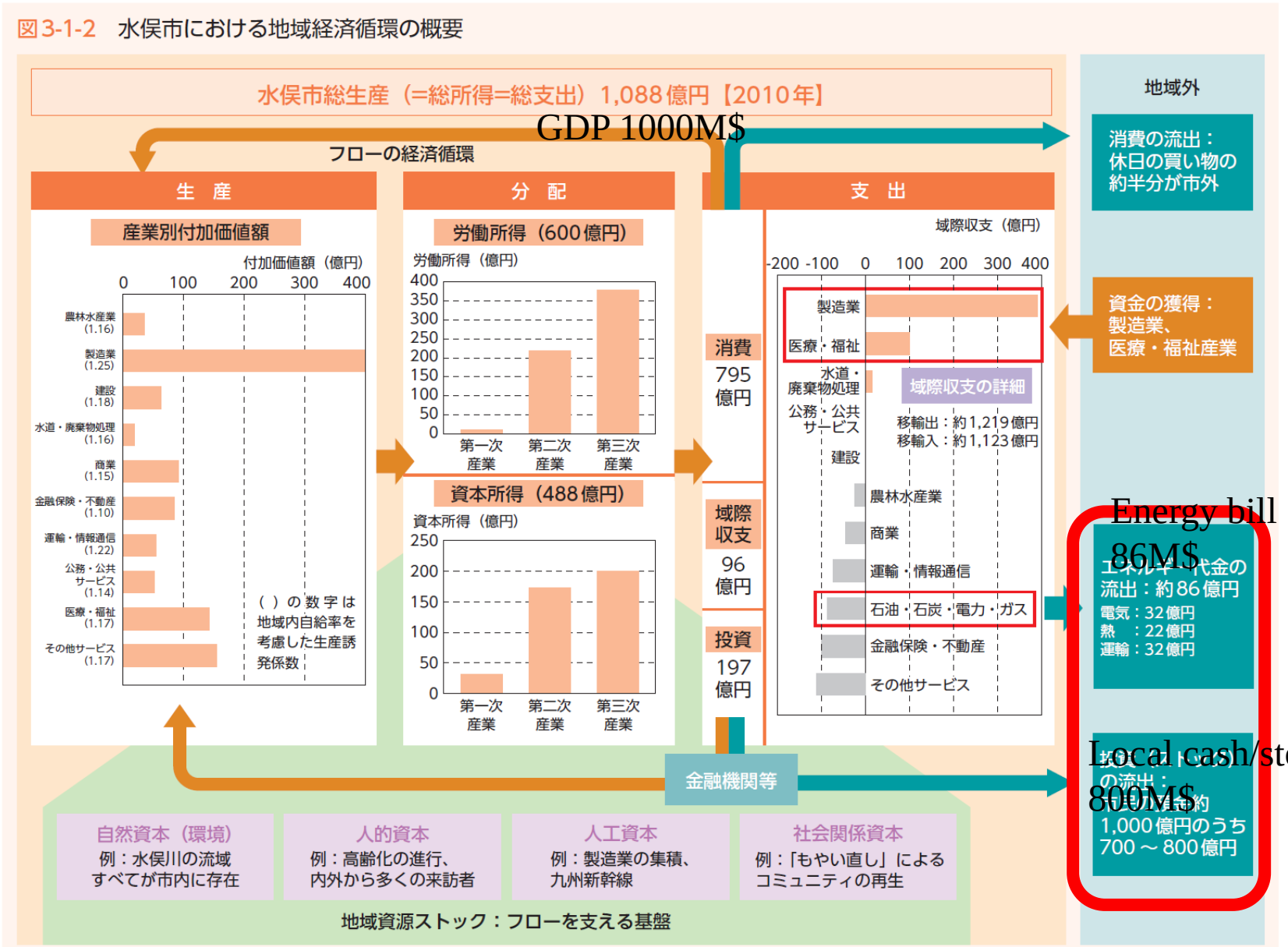
Number of days to pay for energy bill
Petrol/Heating/Electricity)



出所：出所：総務省「平成26年家計調査」、厚生労働省「平成26年賃金構造基本統計調査」より作成

Source HyGrid study group based on Gov. statics

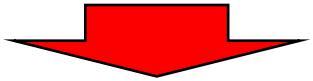
Local economy 地方の経済構造



資料：熊本県水俣市「平成23年度水俣市環境まちづくり概要報告書」、環境省「循環共生型の地域づくりに向けた検討会中間取りまとめ」より作成

Target of study
Internal economies the energy

- Method of energy cost into internal economy
- Electricity can be localized through PV, Wind and Bio energy
- Petrol, Heating are issues

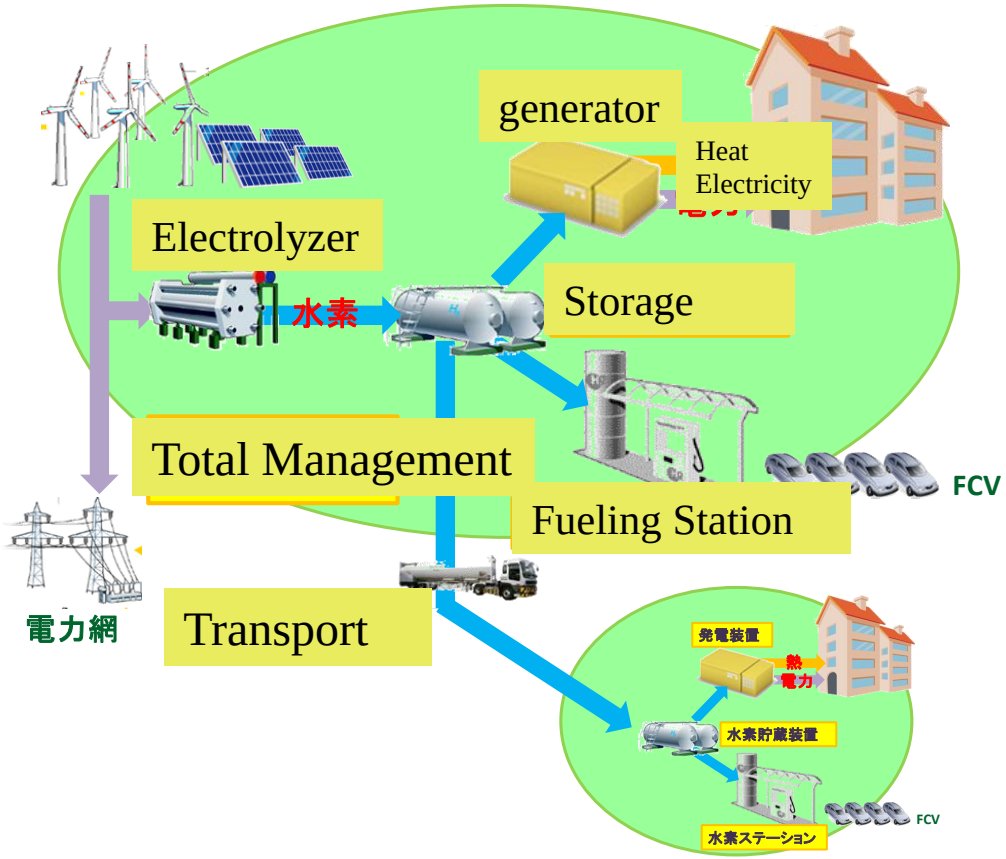


- Hydrogen from renewable electricity enables cost of fuel into internal economy
- Business of hydrogen is a biggest issue

- Business feasibility and balance sheet of society can be studied
- Clarify the issue and make a roadmap

HyGrid system

- **Combination of Established technologies**



Study result

Lower FIT price
Hydrogen with reduced Capex can make more profit than selling electricity

Electricity

(a)

CAPEX	100%	100%	100%
売電価格	25 円/kWh	25 円/kWh	15 円/kWh
IRR	14.02 %	-	3.78 %
NPV	200,208 万円	-	12,700 万円

Sell Hydrogen priority

(b)

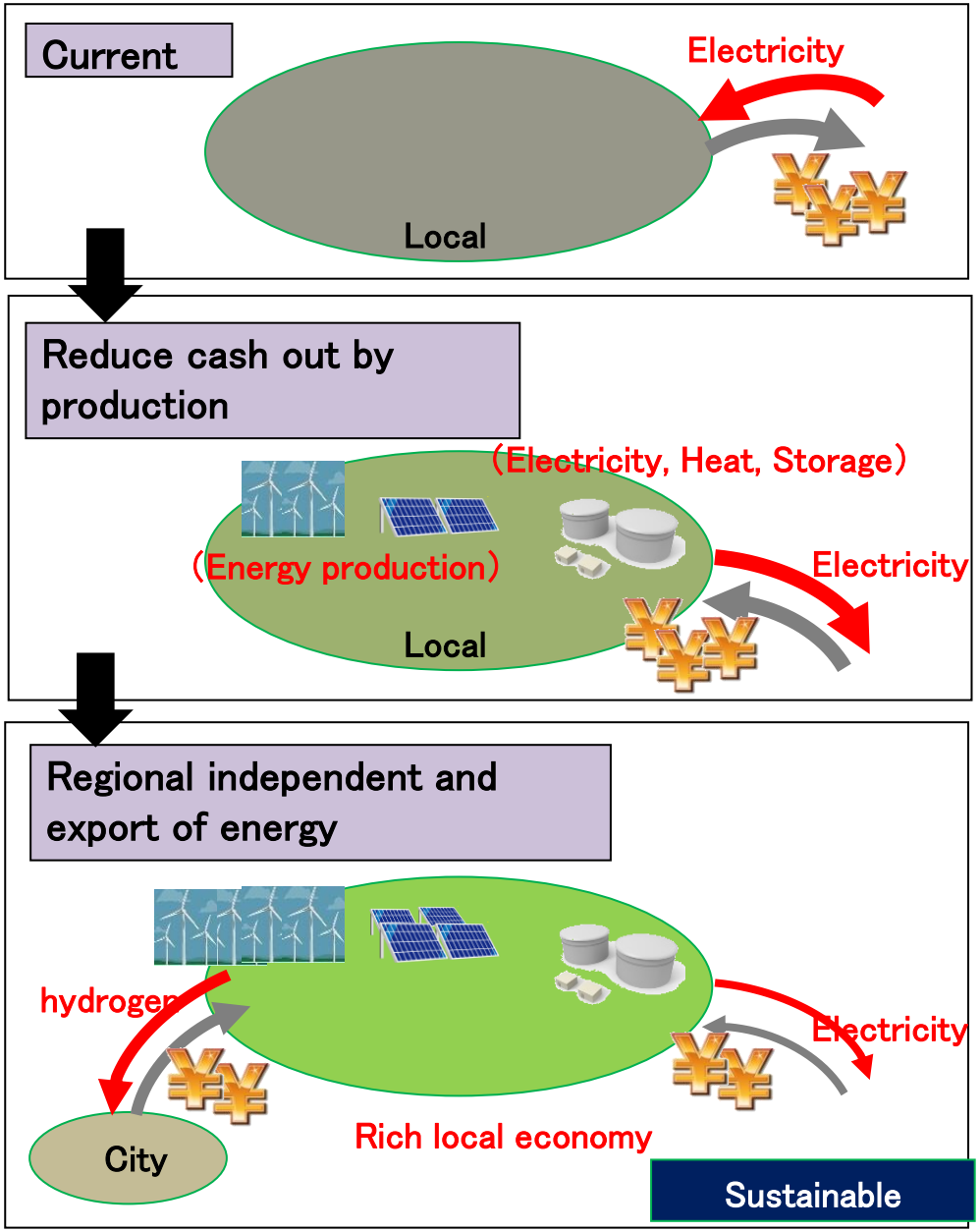
CAPEX	100%	50%	50%
売電価格	25 円/kWh	25 円/kWh	15 円/kWh
IRR	1.04 %	5.37 %	4.17 %
NPV	-62,978 万円	63,195 万円	30,465 万円

Sell Electricity prioirity

(c)

CAPEX	100%	50%	50%
売電価格	25 円/kWh	25 円/kWh	15 円/kWh
IRR	2.70 %	6.72 %	-0.84 %
NPV	-9594 万円	98,591 万円	-88,917 万円

Exit of colony to independence

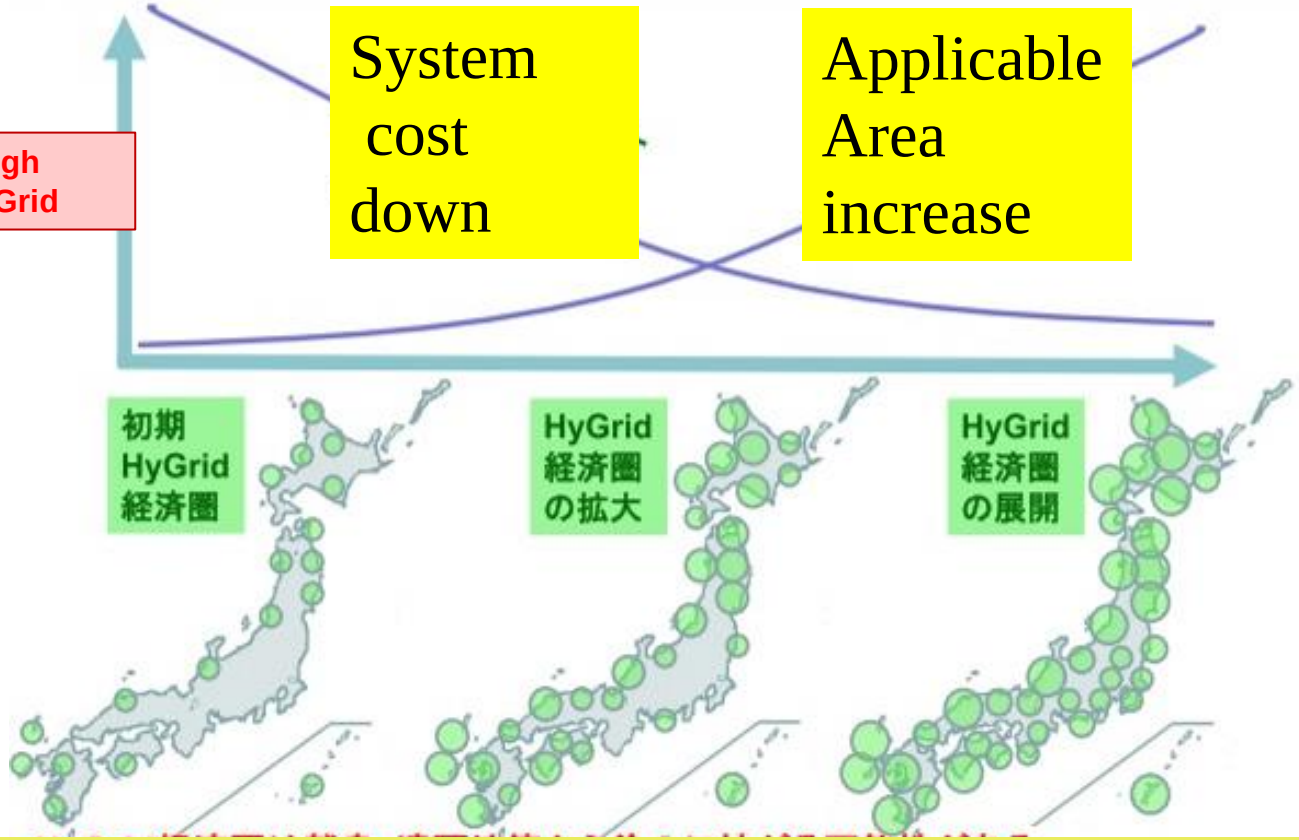


De-carbonation from local economy

Cost down through expansion of HyGrid

System cost down

Applicable Area increase



HyGrid economic system initiated from remote areas/islands and expand to bigger economy

Potential of renewable energy cost for the society

Toward sustainable mobility

- **Electric propulsion is very important for the future**
  - **Battery and Fuel Cell Vehicles play major role for low carbon mobility**
  - **Large OEM are preparing both BEV and FCV**

- **Infrastructures are also being build US, Japan, Europe**

  However

- **FCV has more societal benefits than individual**
  - **FCV energy diversification**
  - **HV direct fuel saving**

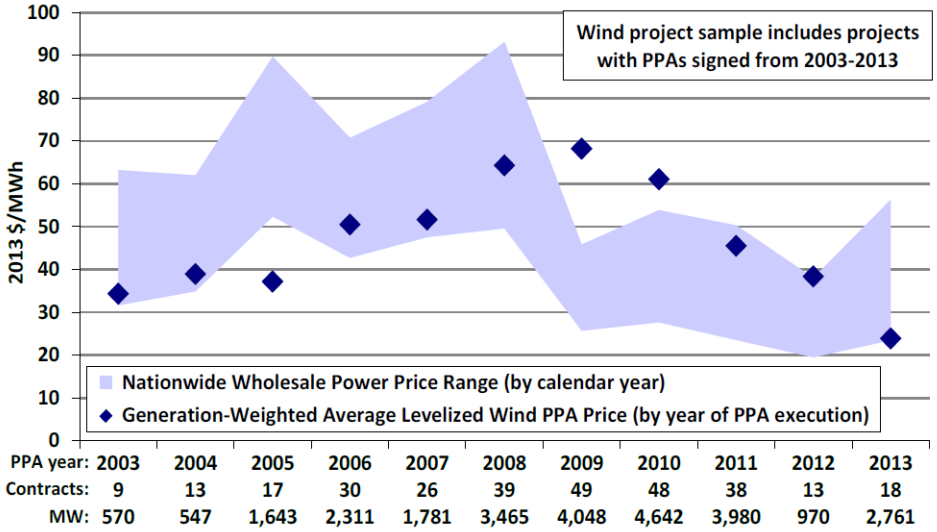
  - **Benefits of energy diversification and sustainable ecosystem must be clarified and transfer to individuals to encourage the transition to sustainable mobility/society**

Potential of renewable energy cost for the society

WIND AND WATER POWER PROGRAM

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Relative Competitiveness of Wind Improved in 2013: Comparison to Wholesale Prices



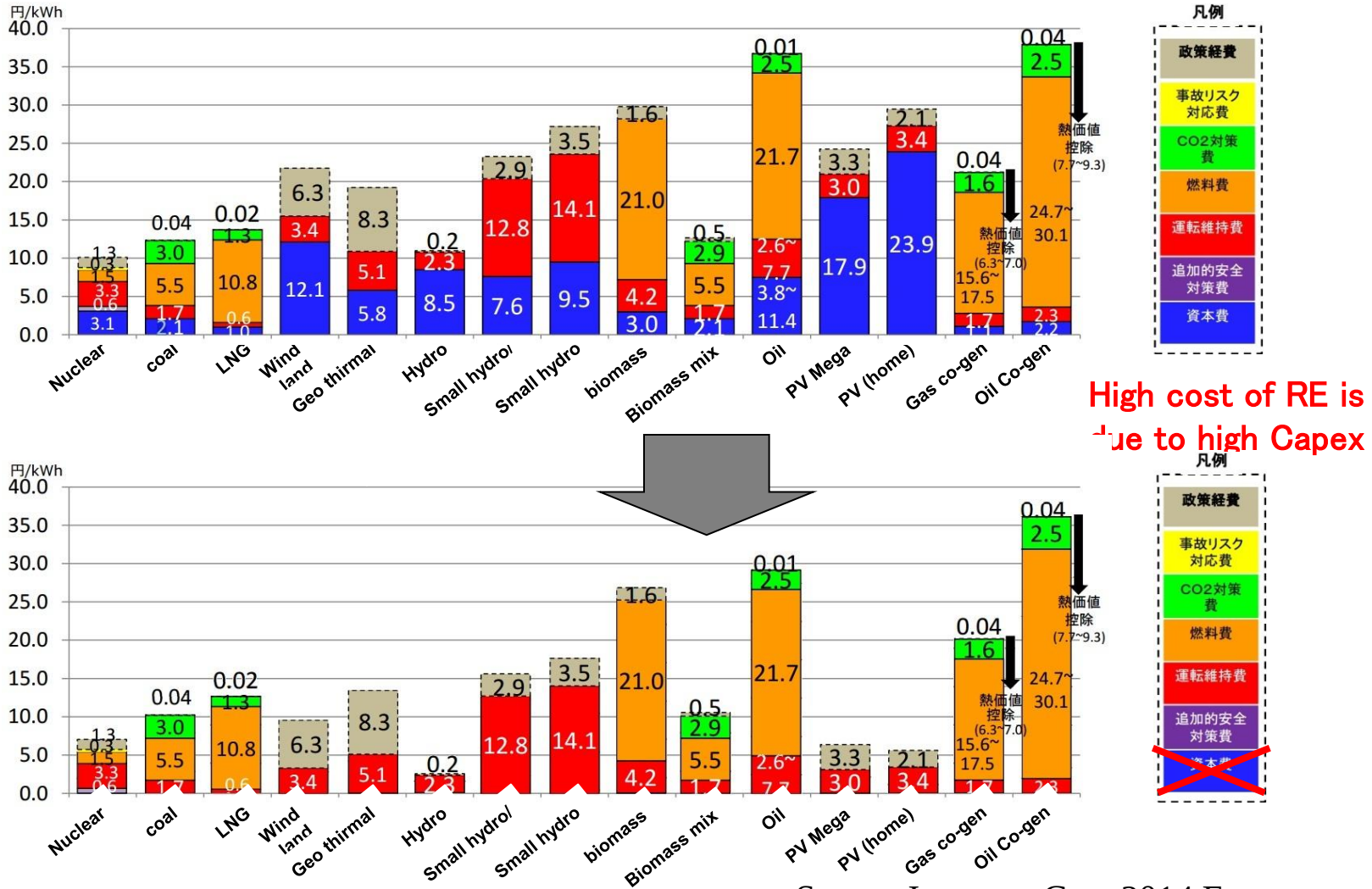
PPA year:	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Contracts:	9	13	17	30	26	39	49	48	38	13	18
MW:	570	547	1,643	2,311	1,781	3,465	4,048	4,642	3,980	970	2,761

- Wholesale price range reflects flat block of power across 23 pricing nodes across the U.S.
- Recent wholesale prices reflect low natural gas prices, driven by weak economy and shale gas
- Price comparison shown here is far from perfect – ***see full report for caveats***

52

Source from DOE EERE report wind power

Cost comparison of various generation Japan 2030



High cost of RE is due to high Capex

Source Japanese Gov. 2014 Energy committee report

出所：総合資源エネルギー調査会 発電コスト検証ワーキンググループ（第6回会合）「長期エネルギー需給見通し小委員会に対する 発電コスト等の検証に関する報告（案）」平成27年 4月 発電コストワーキンググループ「2014年モデルプラント試算結果概要、並びに感度分析の概要」を修正

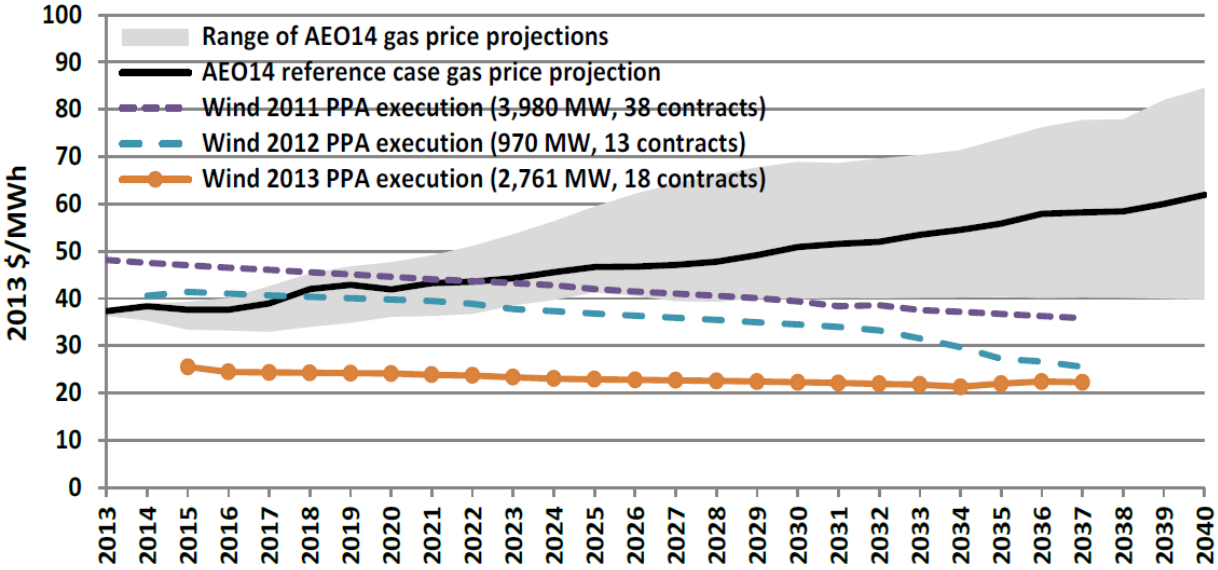
RE become cheap after depletion, enhancing life of facility is key to reduce cost

ReRecoginition of current status

WIND AND WATER POWER PROGRAM

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

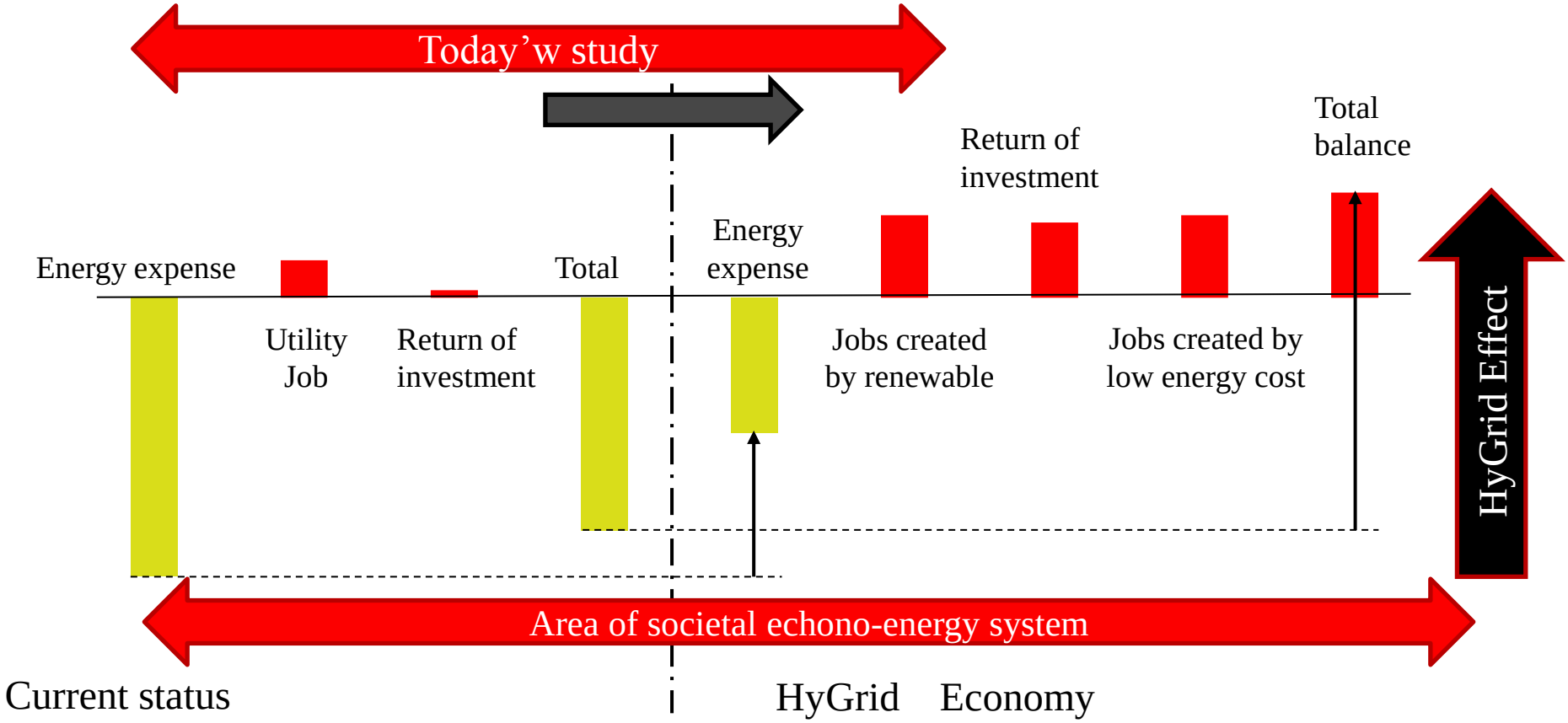
Recent Wind Prices Are Hard to Beat: Competitive with Expected Future Cost of Burning Fuel in Natural Gas Plants



Price comparison shown here is far from perfect – ***see full report for caveats***

Source from DOE EERE report wind power [5]

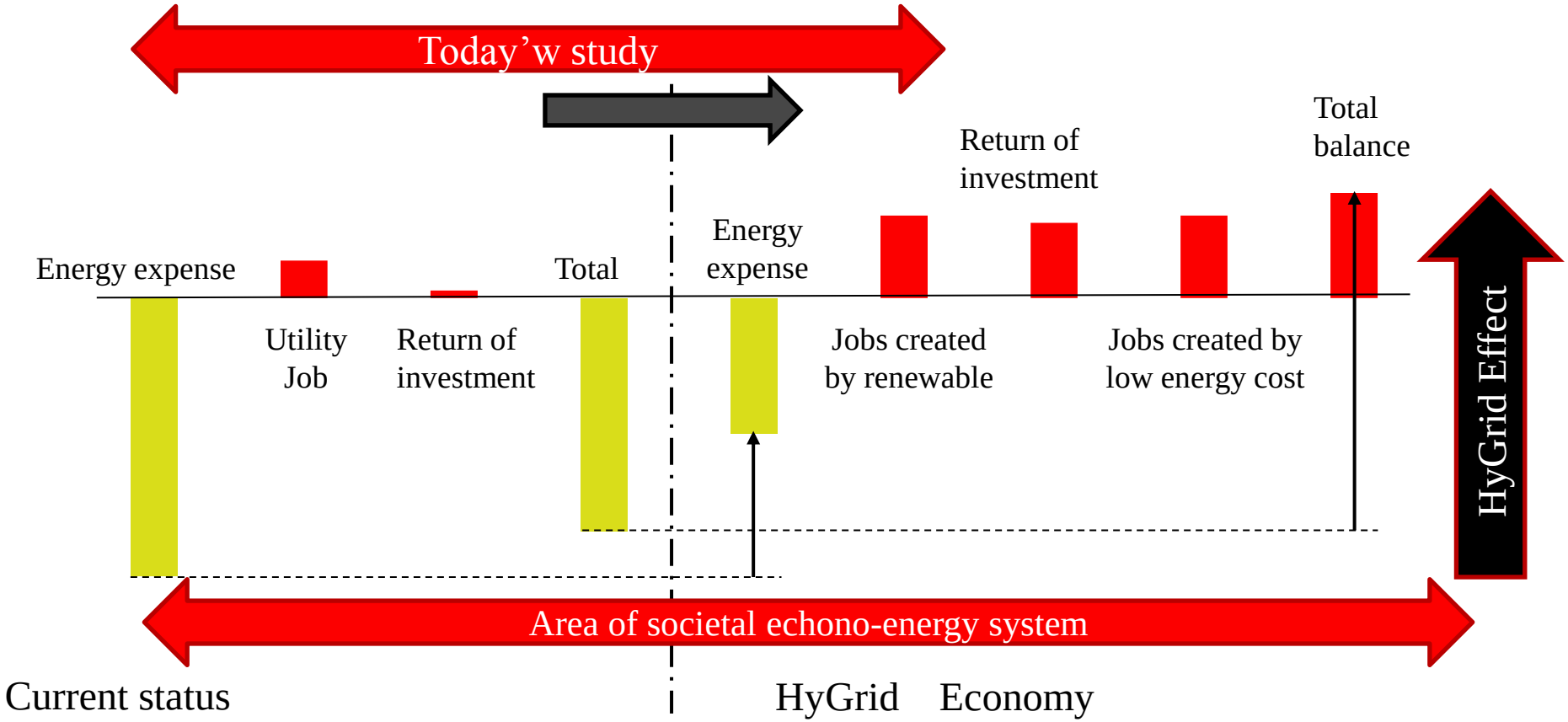
HyGrid Model



Shrink of local economy
Colony of local economy to the big city

Minimize cash out from the society by creating the job and internal cash flow

Conclusion



- **If cheap renewable energy can be used in the local system, local energy/ echono-system can be made economical and sustainable**

When Hydrogen society will come?

CITY OF WESTMINSTER

GAS LIGHT &
COKE COMPANY
1813 - 1937

SITE OF A GASWORKS
WHICH PROVIDED THE FIRST
PUBLIC SUPPLY OF GAS
IN THE WORLD

World has been lighted by hydrogen before electricity

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Hydrogen Council

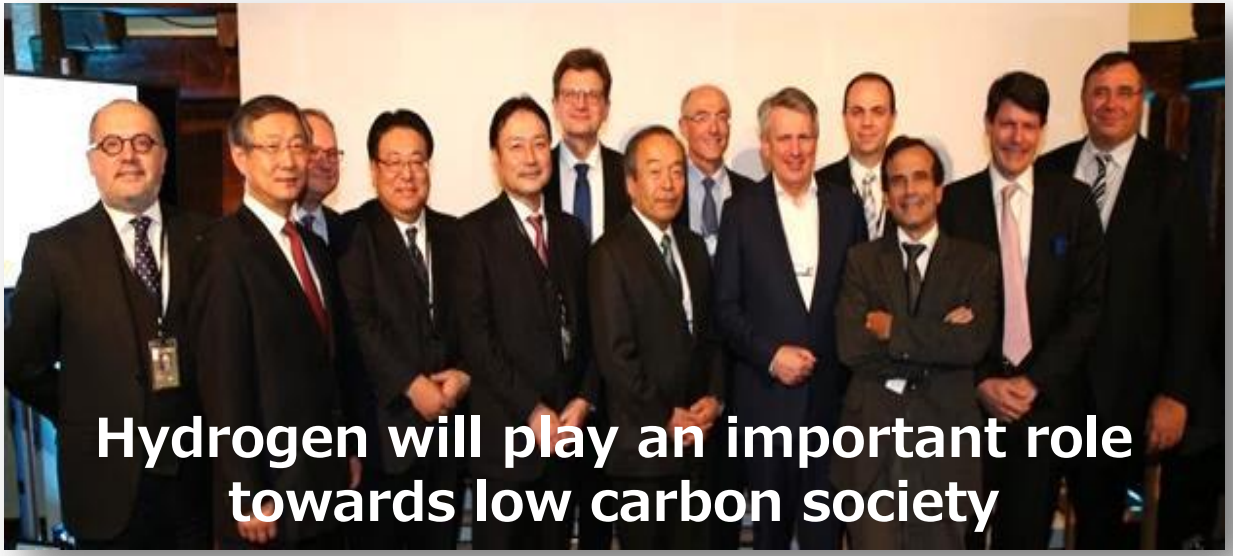
How hydrogen empowers the energy transition

Supported by Hydrogen Europe & FCHEA.

Hydrogen Council

Original members:

Established on January 18, 2017

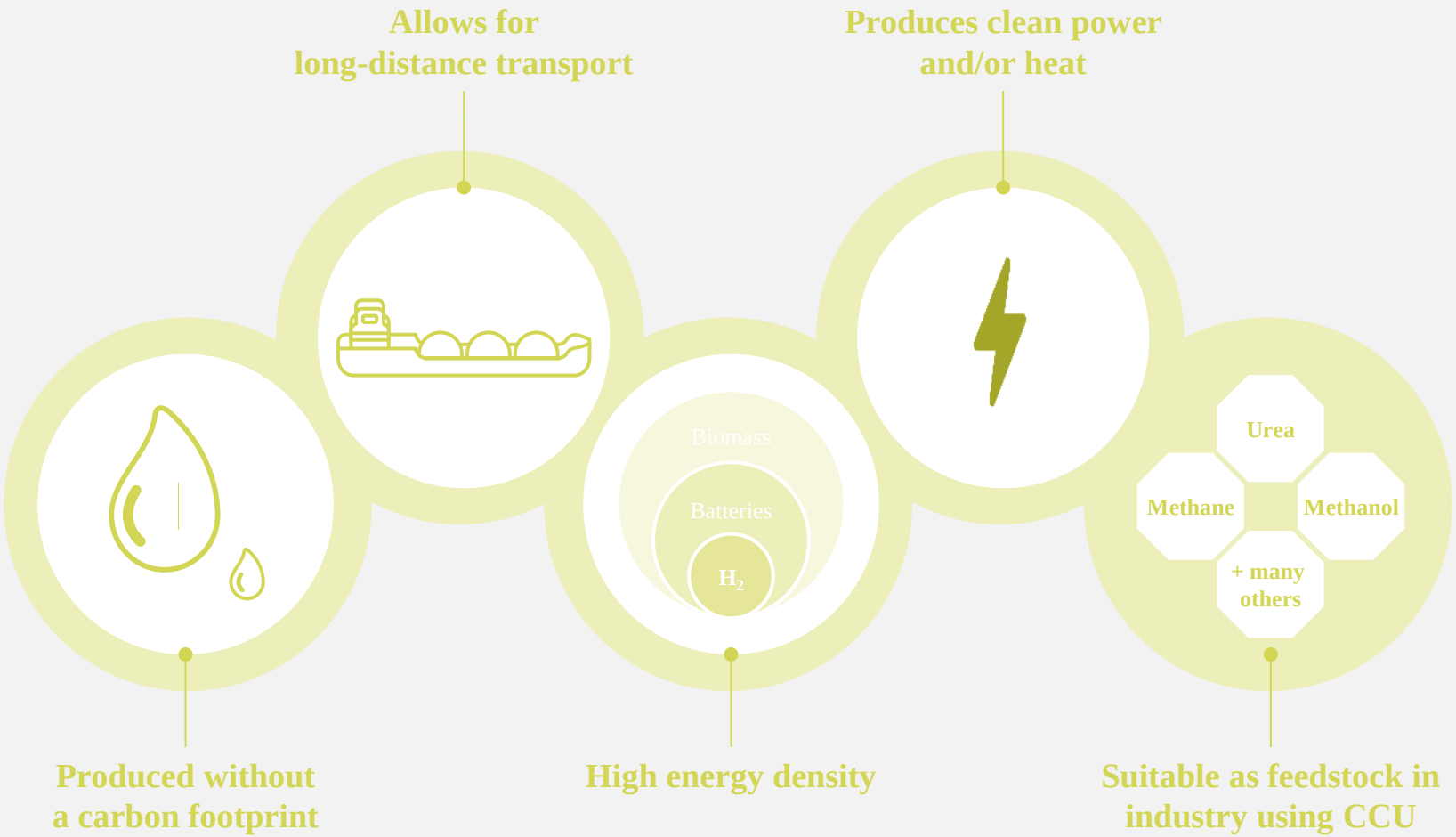


New members:

Supporting members:


Hydrogen Council
Hydrogen Council
1-NVX-123

Hydrogen is a versatile, zero-emission energy carrier with many benefits to the energy transition



Source: Hydrogen Council

Hydrogen helps to overcome the challenges of the energy transition

SOURCES OF ENERGY › **BACKBONE OF ENERGY SYSTEM** › **END USES**

Increasing renewables share leading to imbalances of power supply & demand

Infrastructure needs to go through a major transformation

Global buffering capacity based on mostly fossil sources

Some energy uses are hard to electrify via the grid or with batteries:

- Transport
- Industry
- Residential heating

Carbon needs to be reused to decarbonize feedstock

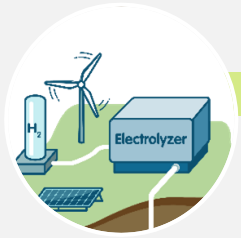
Energy vectors

- Electricity
- Hydrogen
- Today
- Future

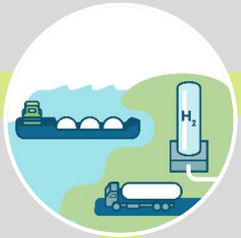
Source: Hydrogen Council

Hence, hydrogen has seven roles in the energy transition

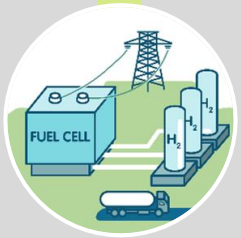
SOURCES OF ENERGY | **BACKBONE OF ENERGY SYSTEM** | **END USES**



1. Enable large-scale, efficient renewable energy integration

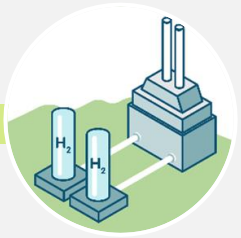


2. Distribute energy across sectors and regions

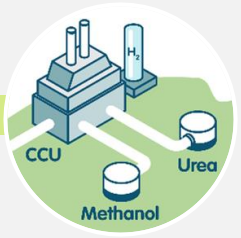


3. Act as a **buffer** to increase system resilience

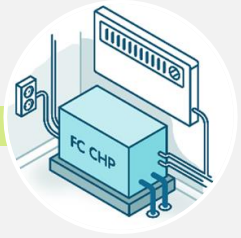
4. Decarbonize transport



5. Decarbonize **industry energy** use



6. Serve as **feedstock** using captured carbon



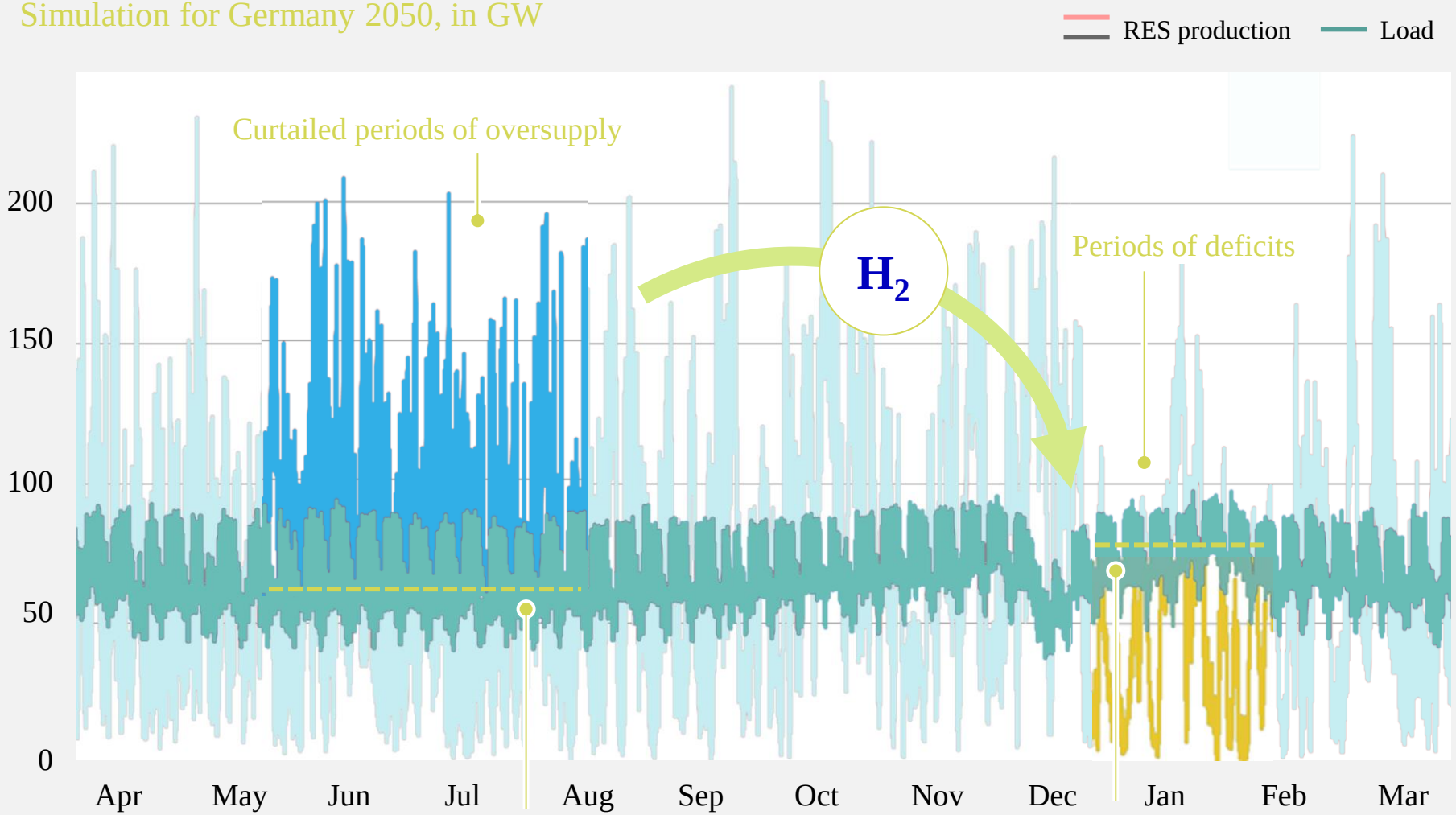
7. Help decarbonize **building heating**

Energy vectors
Hydrogen

Source: Hydrogen Council

1. Hydrogen enables seasonal storage avoiding massive curtailment

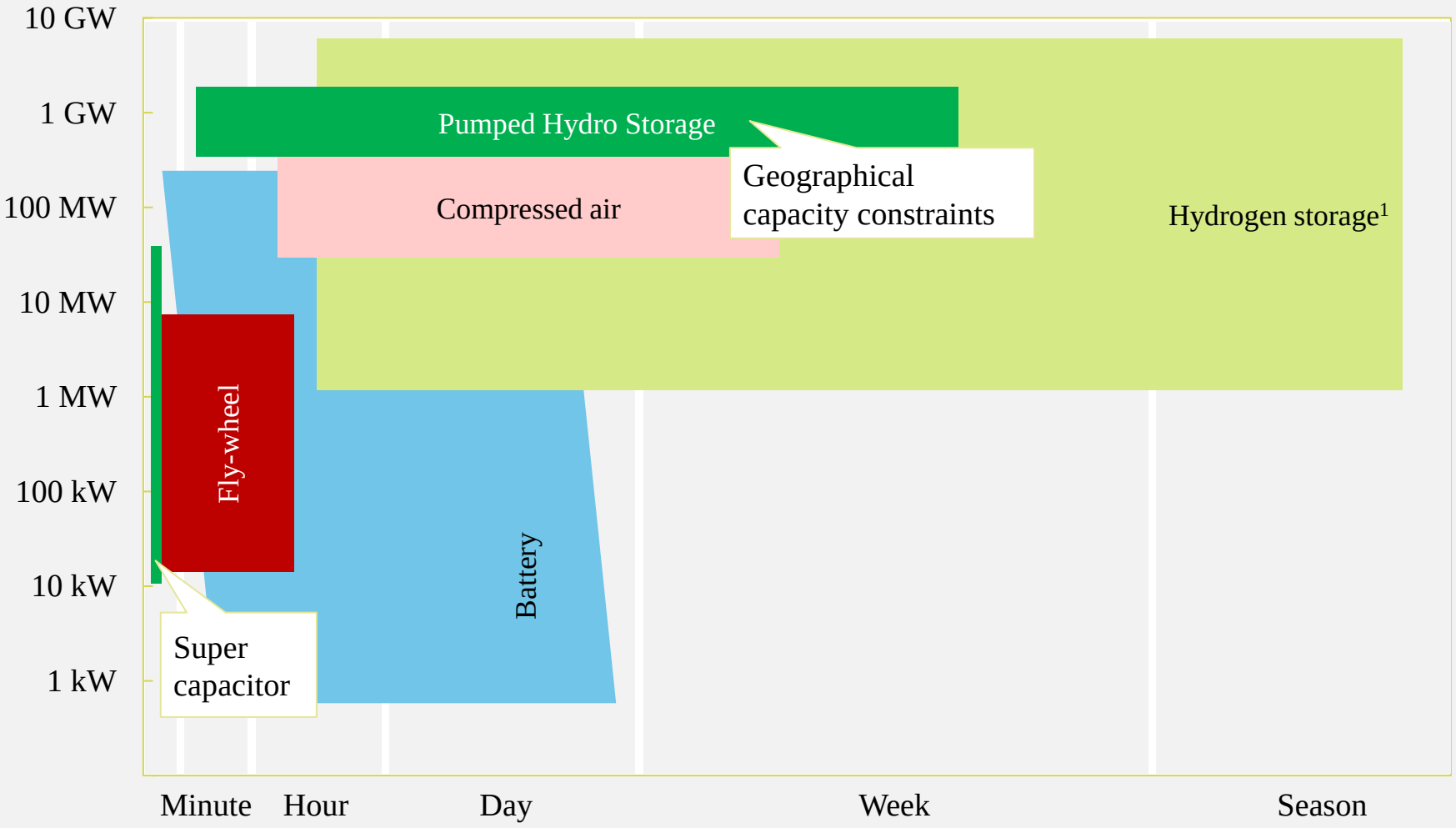
Simulation for Germany 2050, in GW



Source: EC 2050 scenario, McKinsey analysis

1. Hydrogen for long-term carbon-free energy storage

Technology overview of carbon-free energy storage technologies

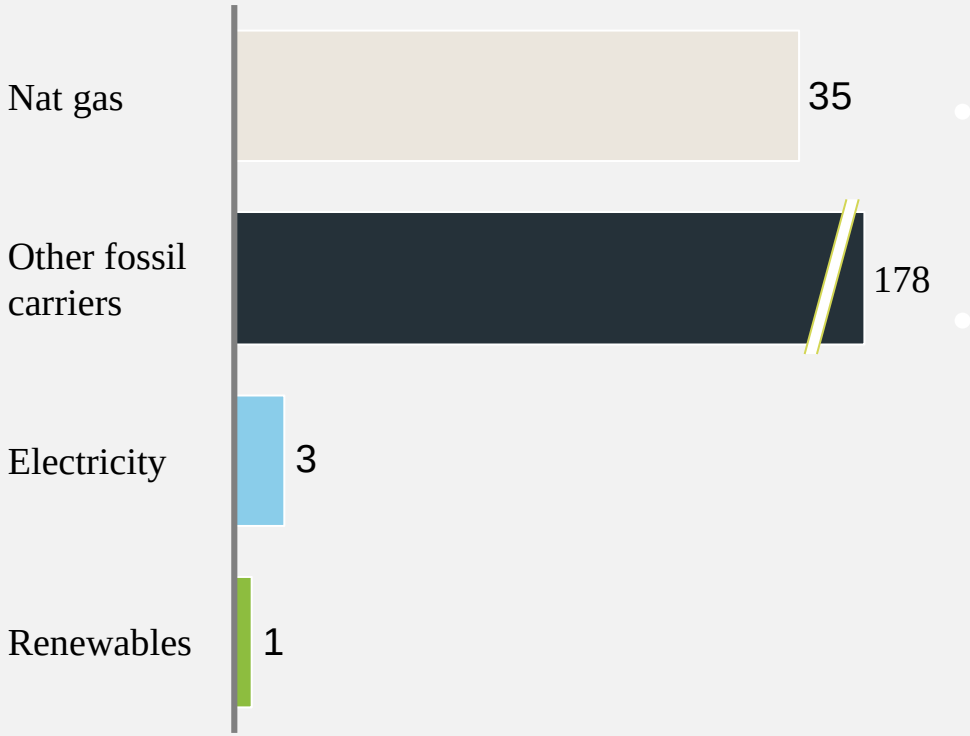


1 IEA data updated due to recent developments in building numerous 1MW hydrogen storage tanks

Source: IEA Energy Technology Roadmap Hydrogen and Fuel Cells, JRC Scientific and Policy Report 2013

The energy transfer between countries (~220 EJ), accounting for local mismatches of demand and supply, almost exclusively relies on fossil vectors

Energy transfer between countries
EJ



Western and Central European[1] nat. gas grid:

- ~145,000 km main pipelines
- ~24,000 GWh/d cross-border capacity

By ship (capacity per year)

- ~100 mn cbm LNG or LPG
- ~200 mn dwt coal
- ~500 mn dwt oil

} 40% of world's fleet tonnage

but also by train & trucks

Hydrogen can provide a cost effective, clean alternative infrastructure to help ensure security of energy supply and continued trading

1 EGIG/ENTSOG

SOURCE: McKinsey, expert interviews, cedigaz; IGU wrld LNG report, DoE Global energy storage database, CIA

1-3. Hydrogen is a carbon neutral energy carrier which is easily stored and distributed

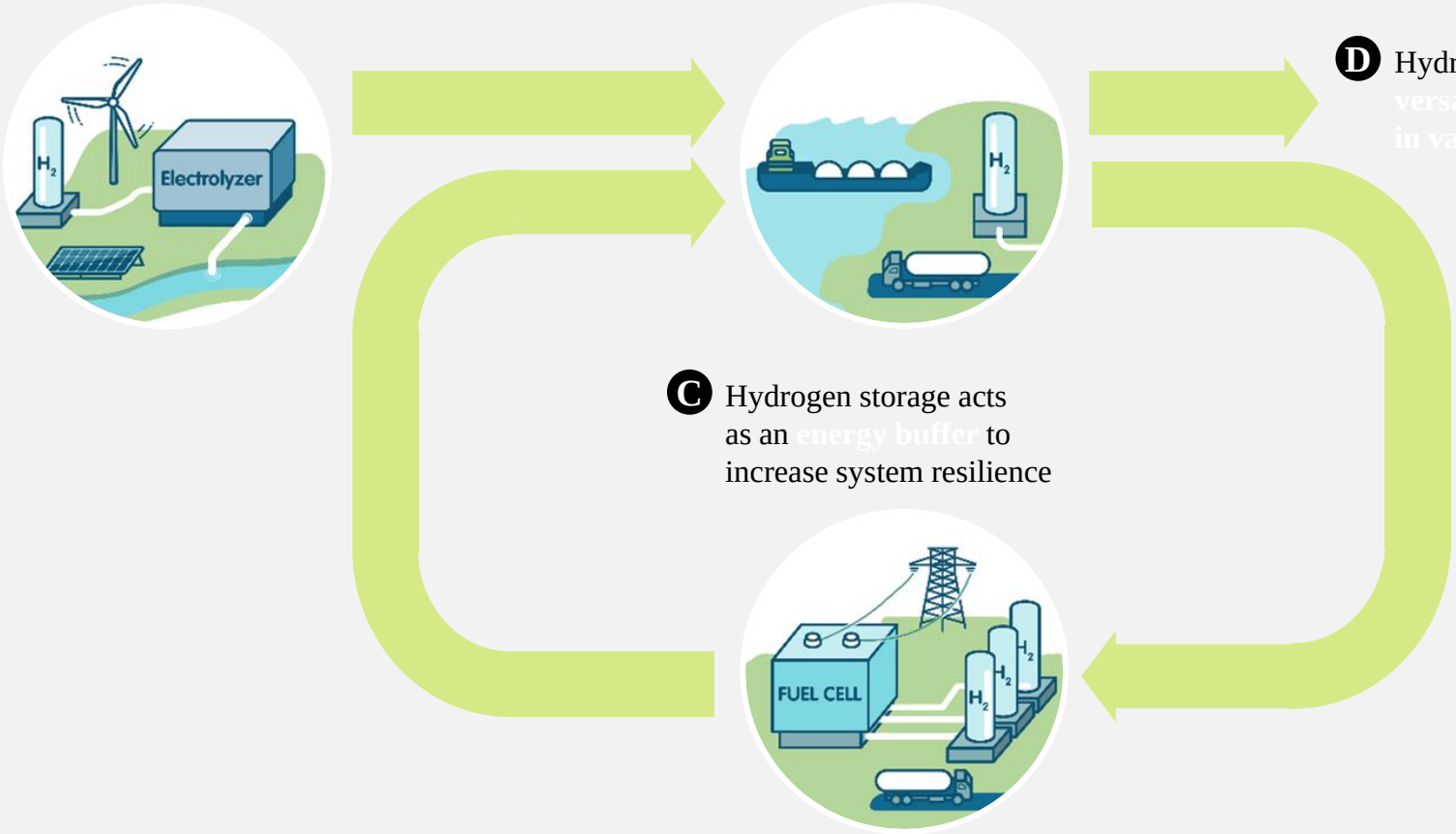
Energy vectors
Hydrogen

A Hydrogen production is **carbon neutral and provides seasonal storage**

B High energy density supports **efficient energy distribution** across sectors and regions

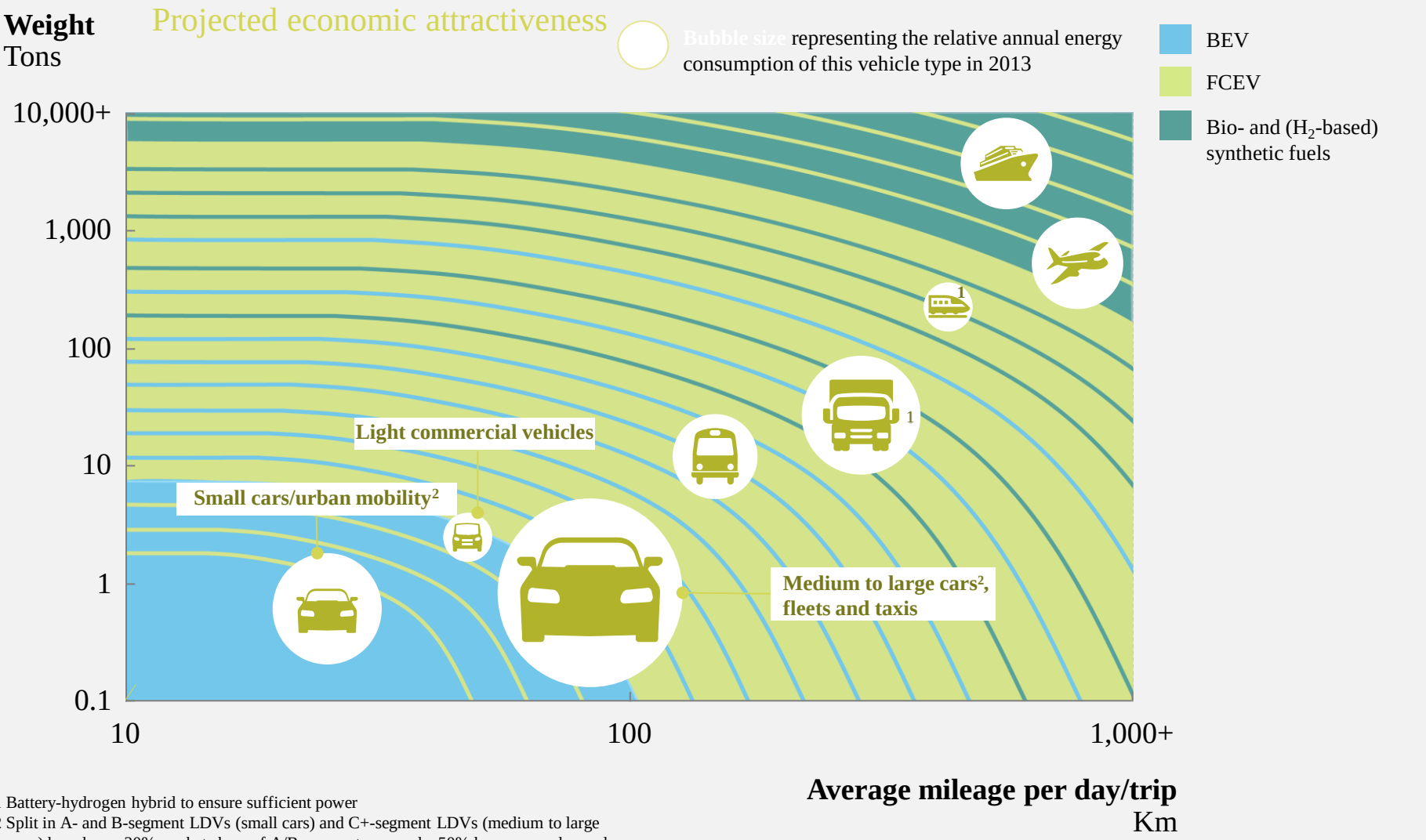
C Hydrogen storage acts as an **energy buffer** to increase system resilience

D Hydrogen to be used as a **versatile energy carrier in various end uses**



Source: Hydrogen Council

4. FCEVs will play an essential role in decarbonizing transport



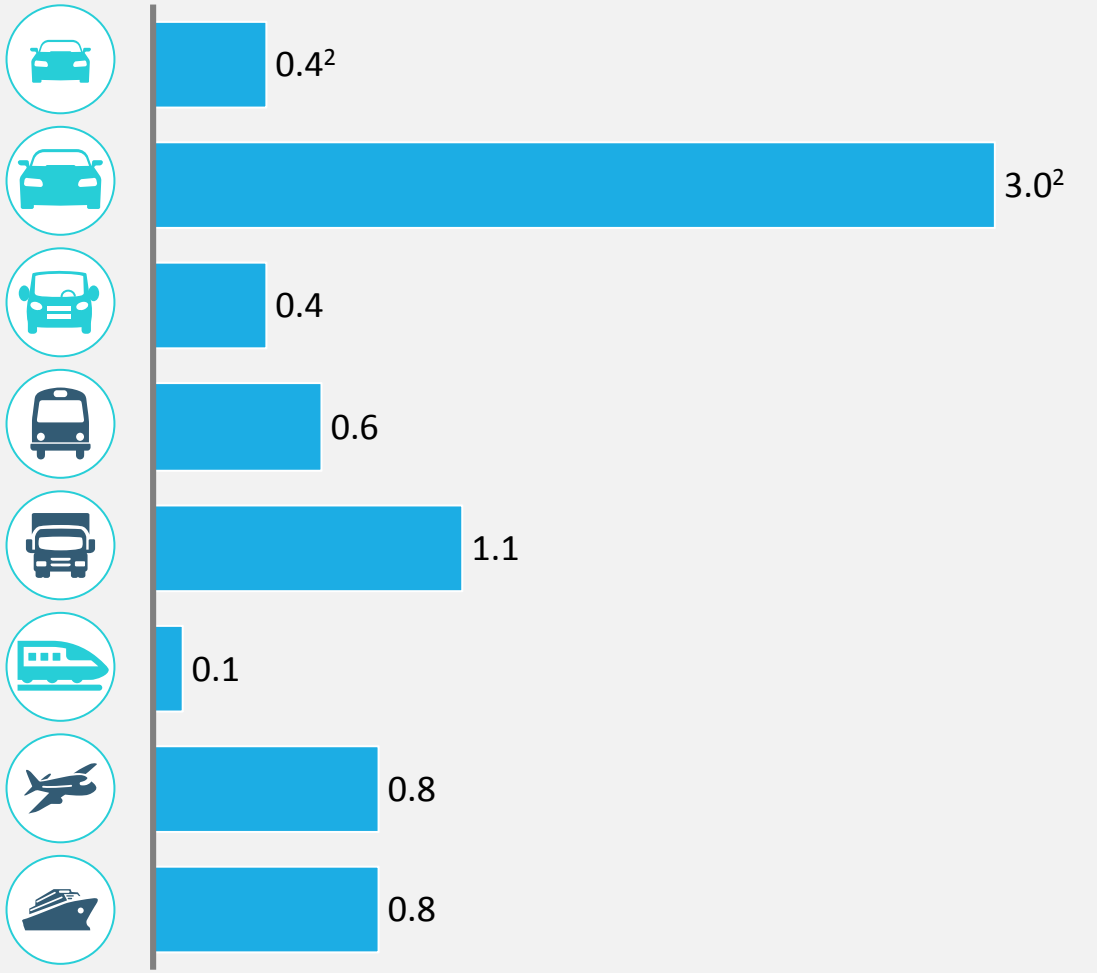
1 Battery-hydrogen hybrid to ensure sufficient power
2 Split in A- and B-segment LDVs (small cars) and C+-segment LDVs (medium to large cars) based on a 30% market share of A/B-segment cars and a 50% less energy demand

Source: Toyota, Hyundai, Daimler

BACKUP

4. Transport causes 20% of the total energy-related carbon emissions

GHG emissions in the transport sector, 2013, Gt CO_2



- **Transport sector emits 7.2 Gt of CO_2**
  - 20% of total energy-related CO_2 emissions[1])
- **Three complementary options for transport decarbonization exist:**
  - Battery electric vehicles (BEVs)
  - Fuel cell electric vehicles (FCEVs)
  - Bio- and (hydrogen-based) synthetic fuels

1 The global amount of energy-related CO2 emissions in 2013 was 34 Gt
2 Split in A- and B-segment LDV's (small cars) and C+-segment LDV's (medium-to-large cars) based on a 30% market share of A/B-segment cars and a 50% less energy demand

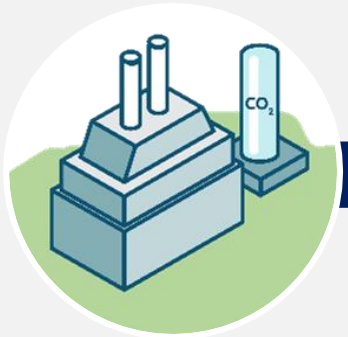
Source: ICCT, IPCC, IEA ETP 2016

HyFly Flying by hydrogen

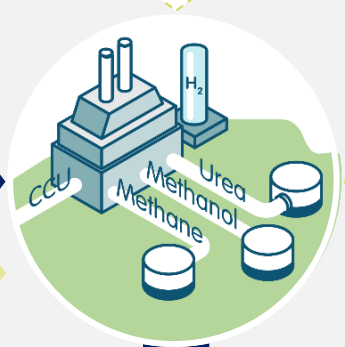

Deutsches Zentrum
für Luft- und Raumfahrt
German Aerospace Center
Institute of Engineering Thermodynamics
DLR
H_2
ENERGIZING
AMATERSKO IZDELANO LETALO
DLR
Fuel Cell Hybrid - Powered by DLR
TOYOTA
TOYOTA

6. Hydrogen complements chemical feedstock to decarbonize industry

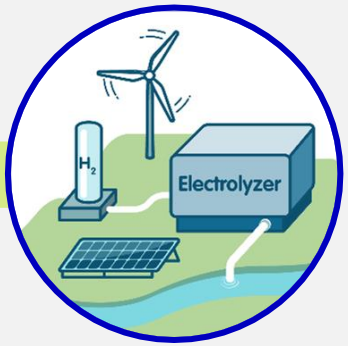
Conventional feedstock (oil derivatives)



Carbon



Hydrogen



A Hard to decarbonize industry applying carbon capture

Carbon-hydrates

A Hydrogen is produced carbon-free (e.g., via RES electrolysis

Carbon

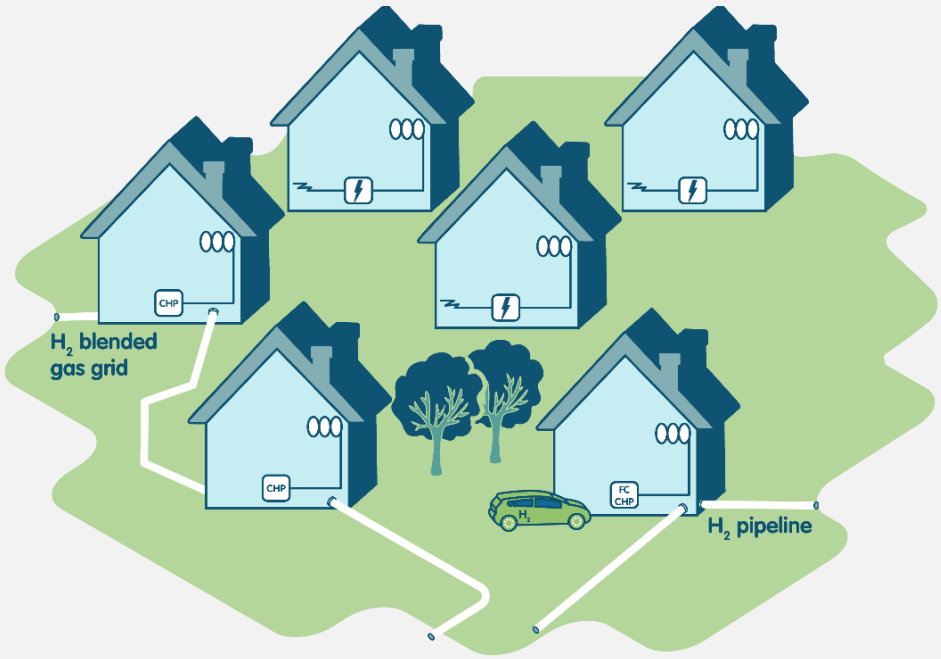
C Carbon capture of the end of lifecycle

e.g. carbon2chem project planned by ThyssenKrupp

B Production of Methanol (as used for plastics), Ammonia

Source: Hydrogen Council

7. Building heating can use hydrogen as a fuel or leverage hydrogen technologies



Already 190,000 buildings are heated with hydrogen-based fuel cell micro CHPs

- **Hydrogen is part of a portfolio of solutions for decarbonizing building heating** (choice depending on local conditions)
- Hydrogen through the gas grid[1] can fuel heating technology

Leeds planning to convert natural gas grid in hydrogen grid by 2026

Plan to ban oil and natural gas for heating purposes in Germany by 2030

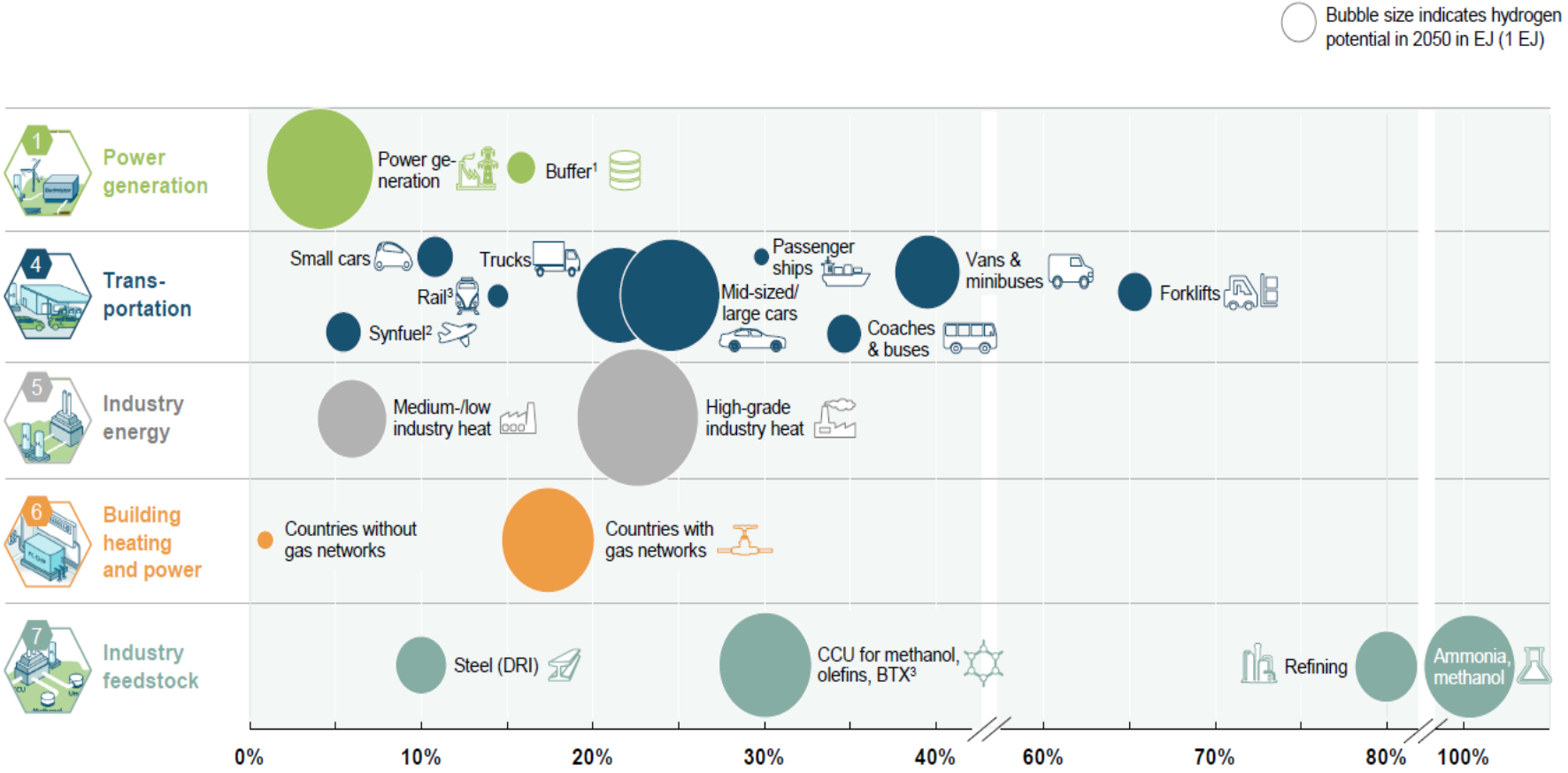
- Hydrogen technologies can serve as energy converter

Japan is expanding to 5.3 million micro CHP-based households by 2030.

1 pure or blended to the gas grid

Source: Hydrogen Council

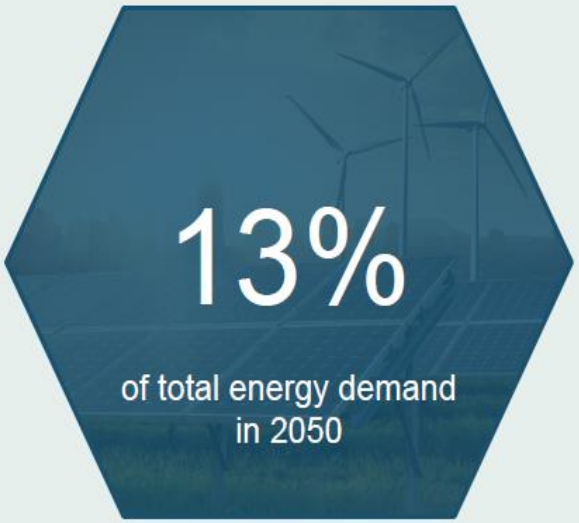
Hydrogen has significant potential across all applications



1 Percent of total annual growth in hydrogen and variable revewable power demand
2 For aviation and freight ships
3 Trains and tramways
3 Percent of total methanol, olefin, BTX production using olefins and captured carbon

SOURCE: Hydrogen Council

Hydrogen benefits energy systems, environment and business



SOURCE: Hydrogen Council, IEA ETP Hydrogen and Fuel Cells CBS, National Energy Outlook 2016"

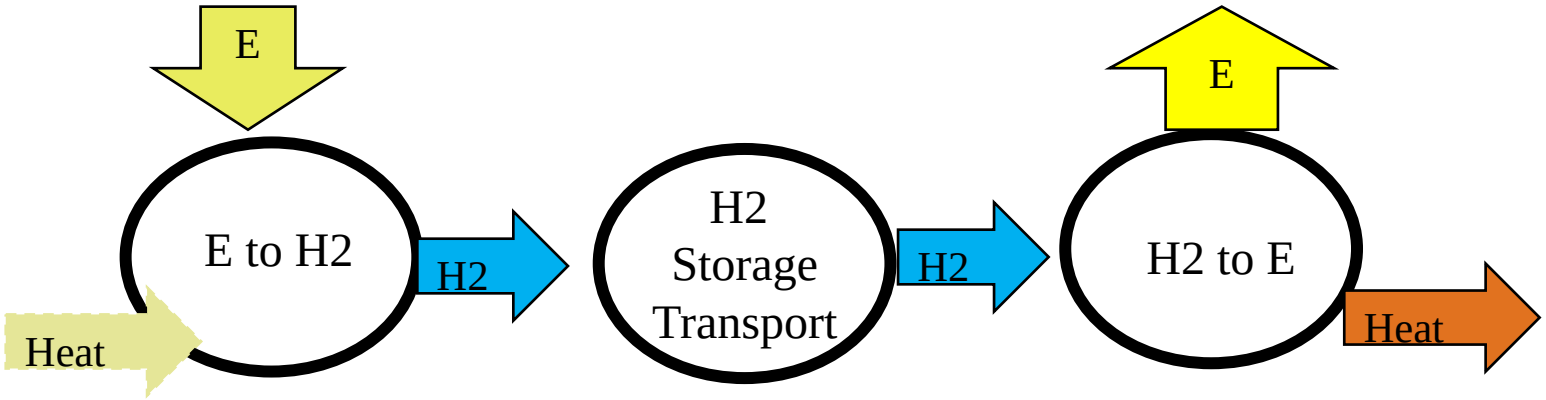
One of the example of hydrogen value into the economy
and
Helping society sustainable

Hydrogen as electricity storage

E in >>> E Out

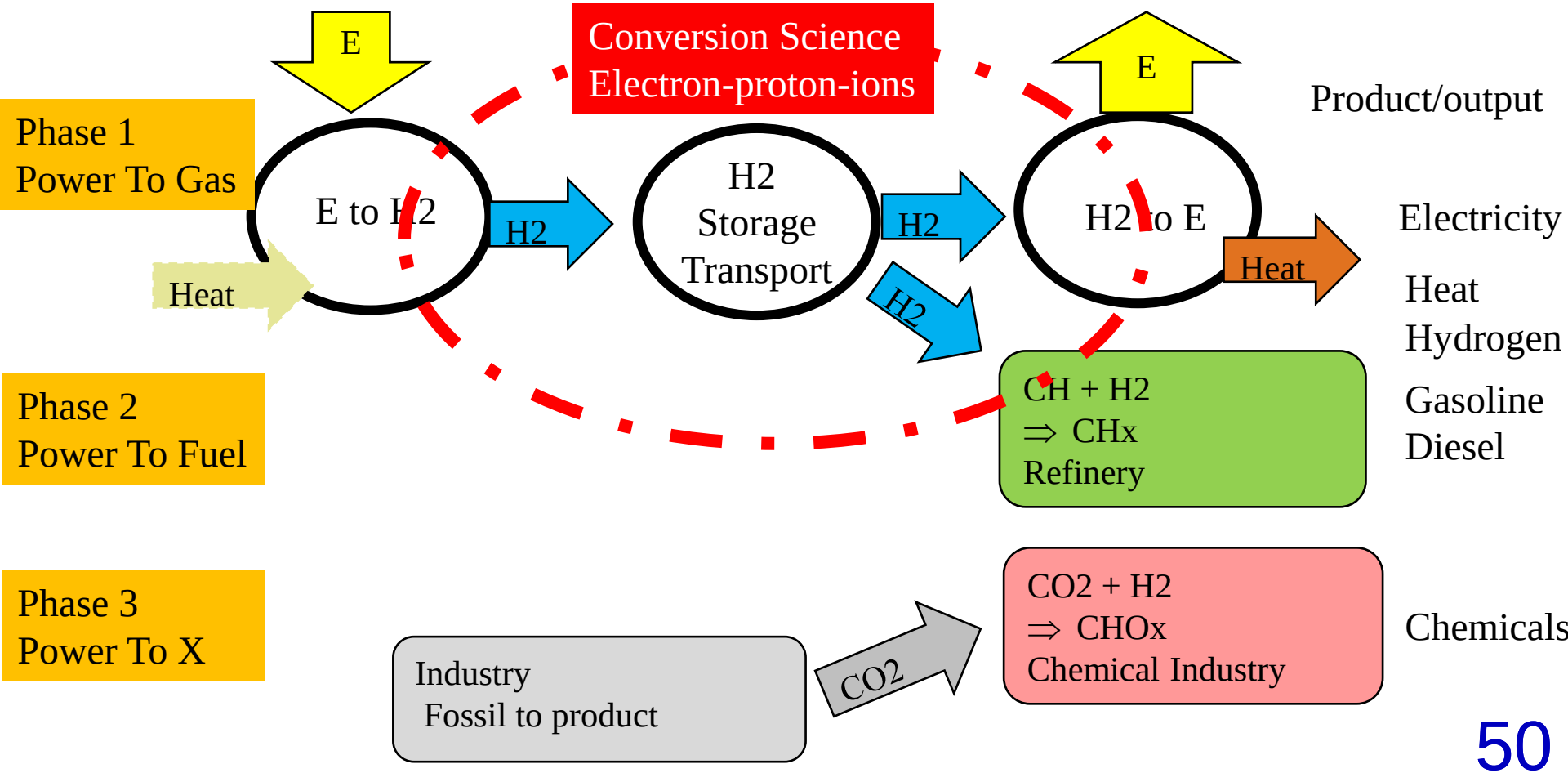
Value can be a function of energy storage

Time shift function

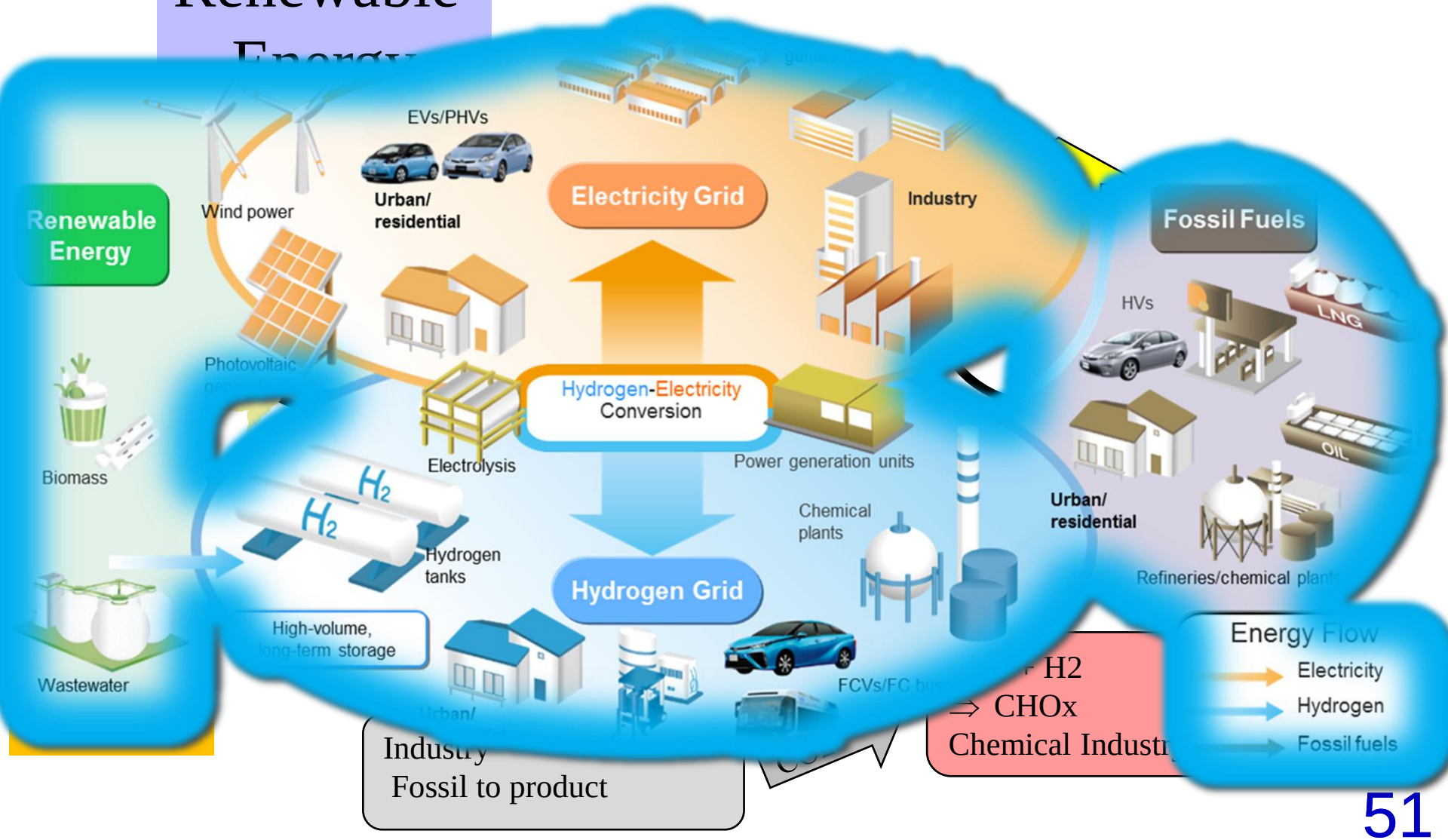


Power to X
Key to Make Society Sustainable

Renewable hydrogen to make the industrial operations sustainable



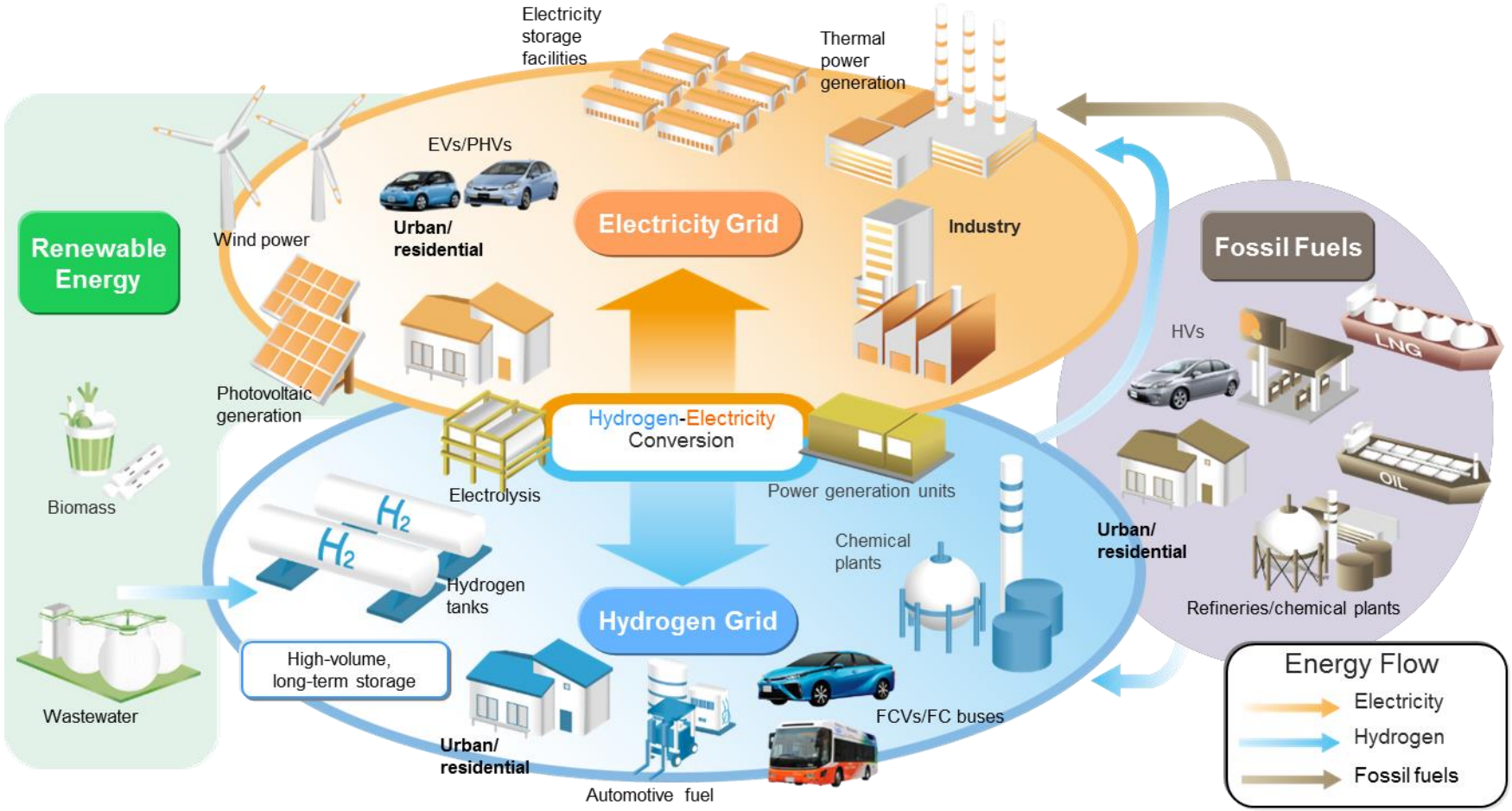
Sustainable Society



Industry
Fossil to product

H2
⇒ CHOx
Chemical Industr

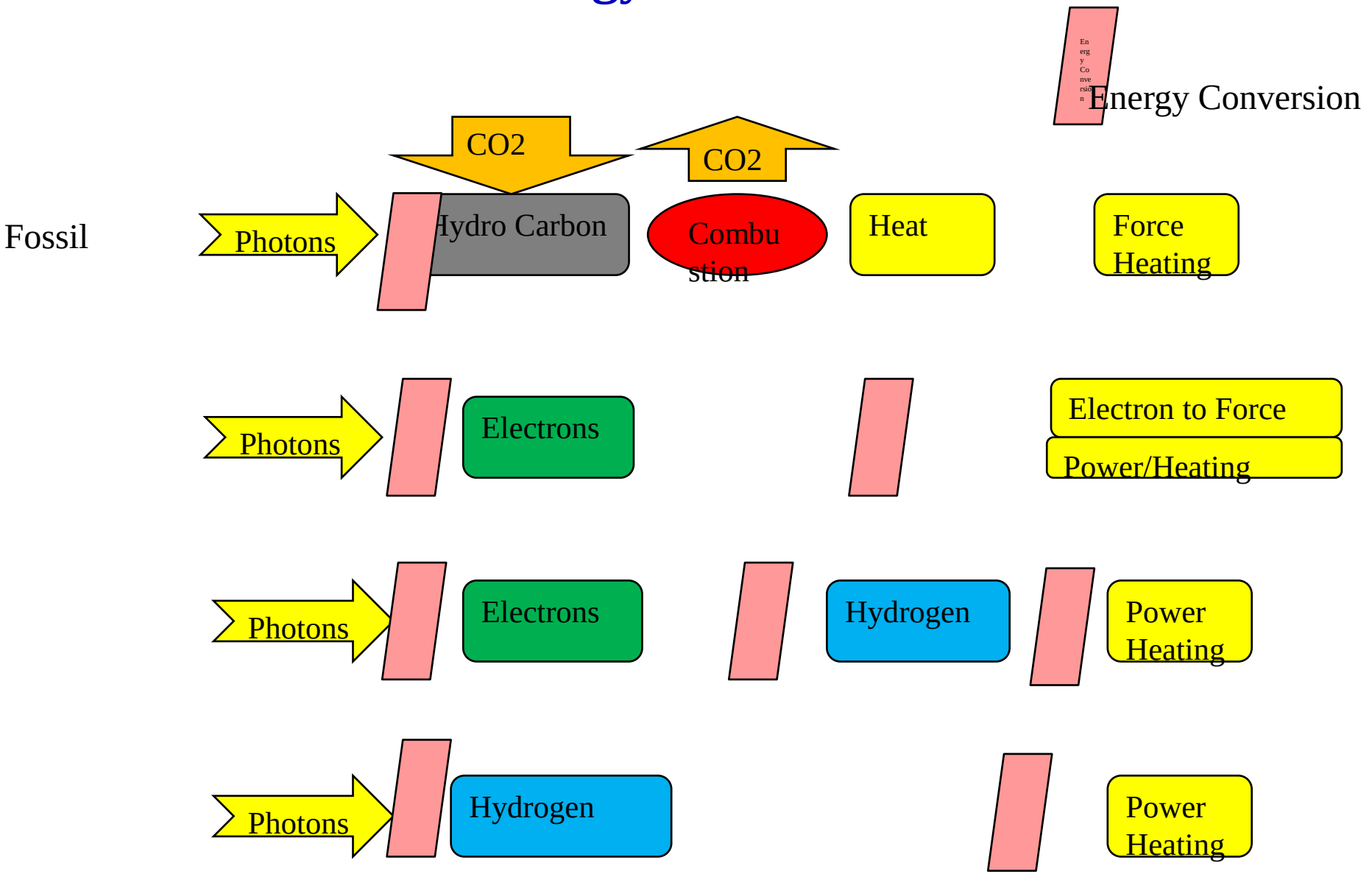
Future vision HyGrid（Hybrid Grid）
minimum use of fossil energy
and maximum use of renewables



From HyGrid Study Group HP

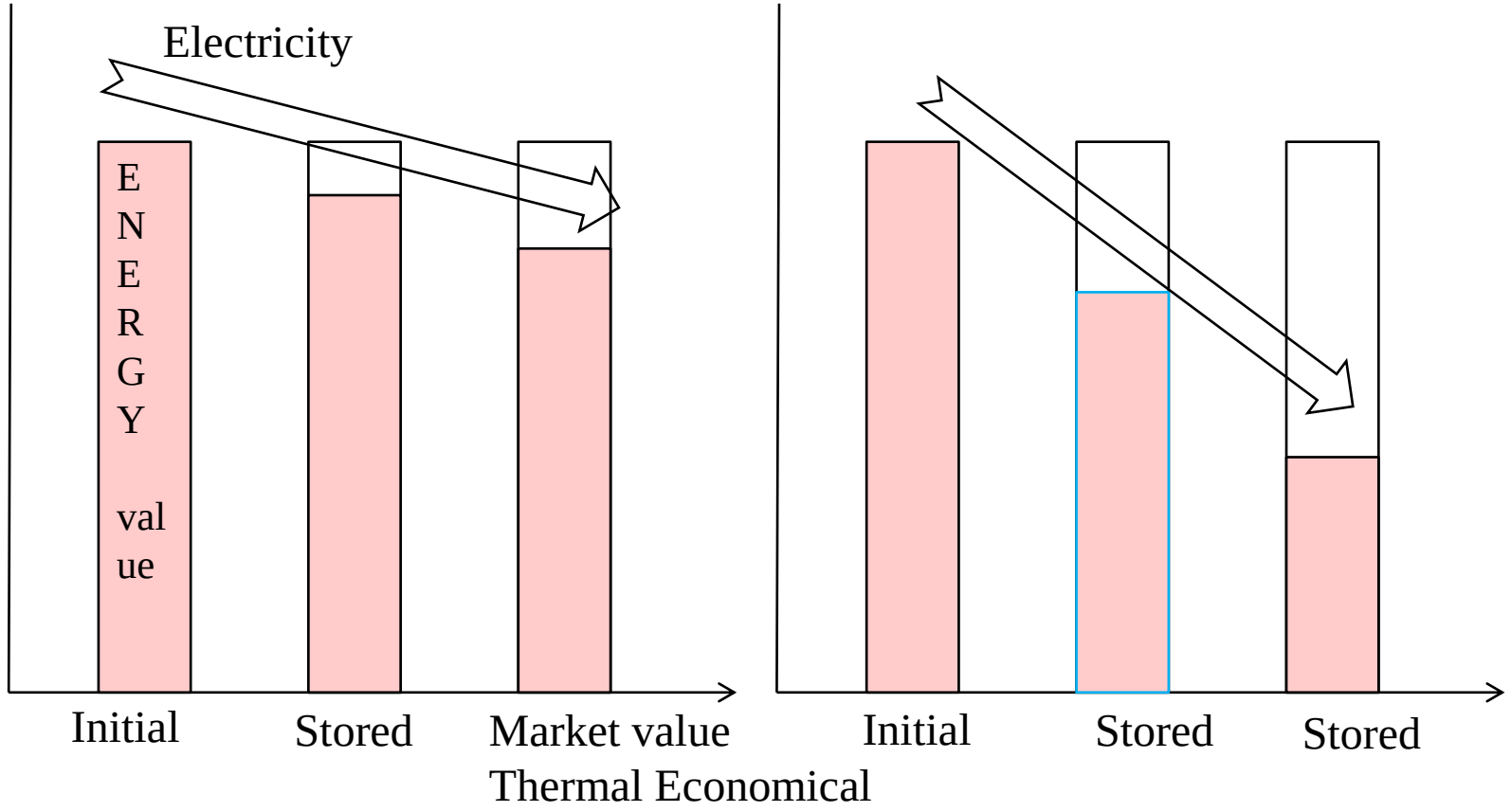
Physics and Economics

Energy conversion



Market Value and energy Value

- **Energy Efficiency of Battery storage and hydrogen Storage**

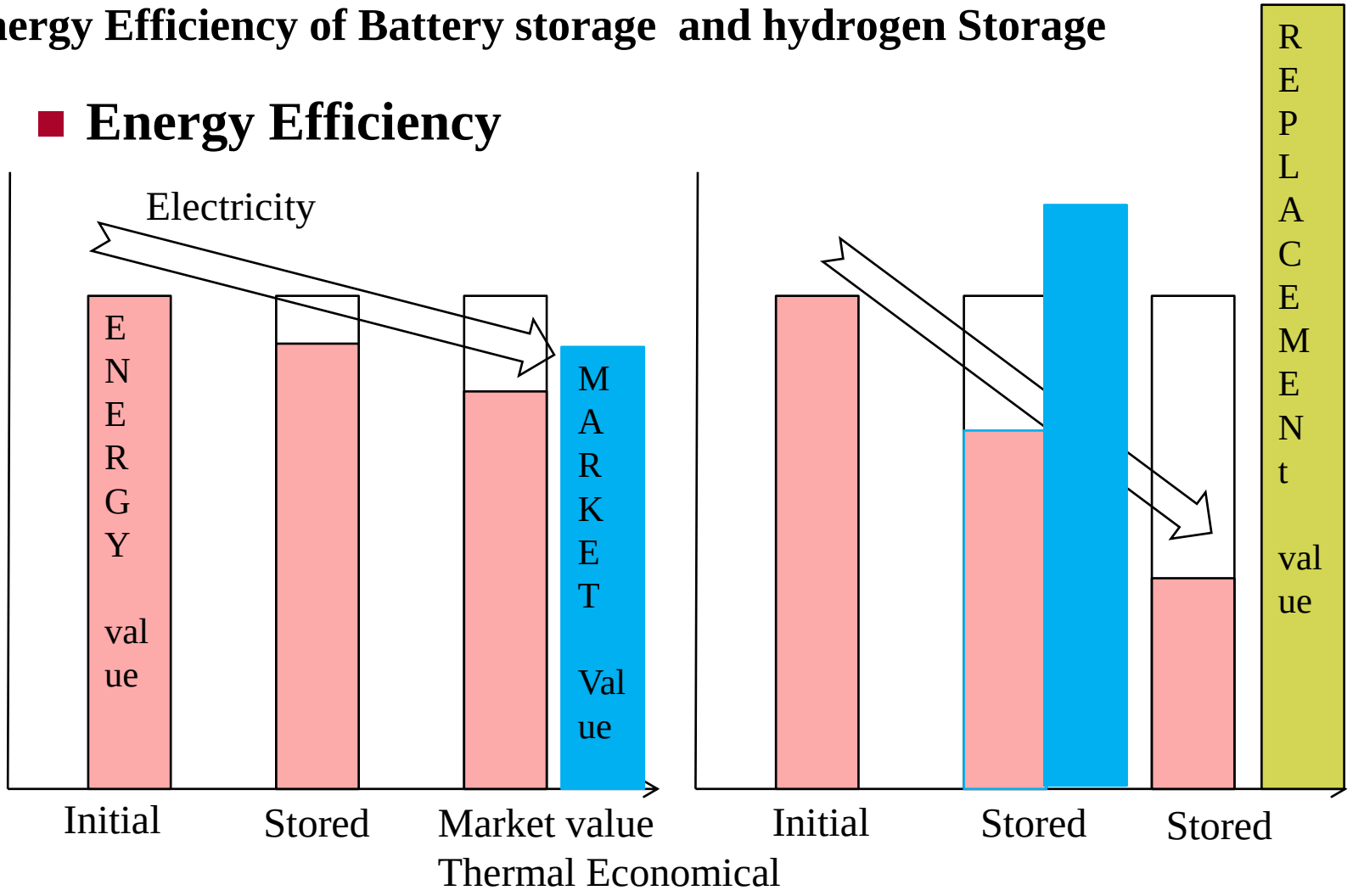


Battery system

Hydrogen system

Market Value and Energy Value

- **Energy Efficiency of Battery storage and hydrogen Storage**
  - **Energy Efficiency**

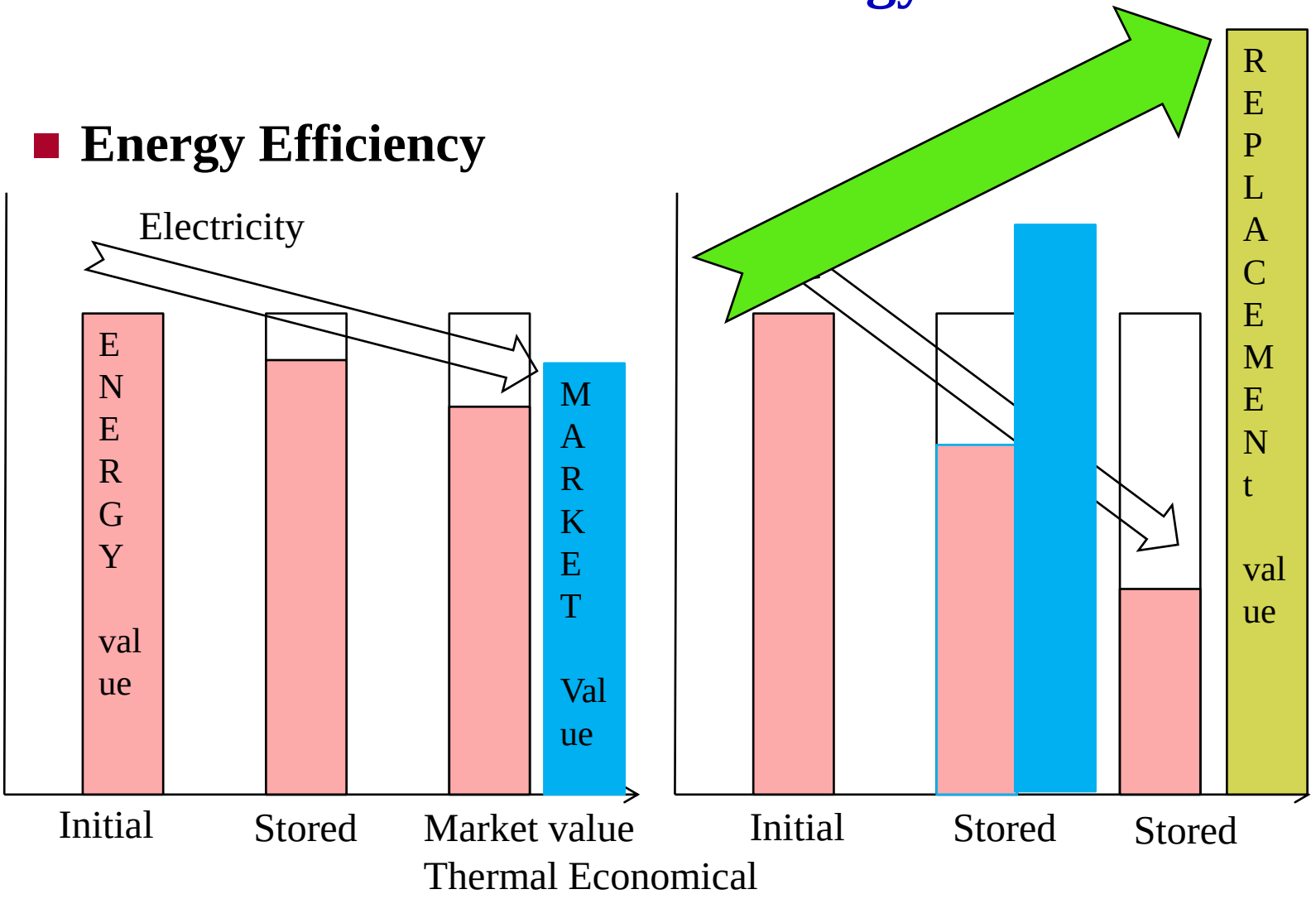


Battery system

Hydrogen system

Market Value and energy Value

- **Energy Efficiency**



Battery system

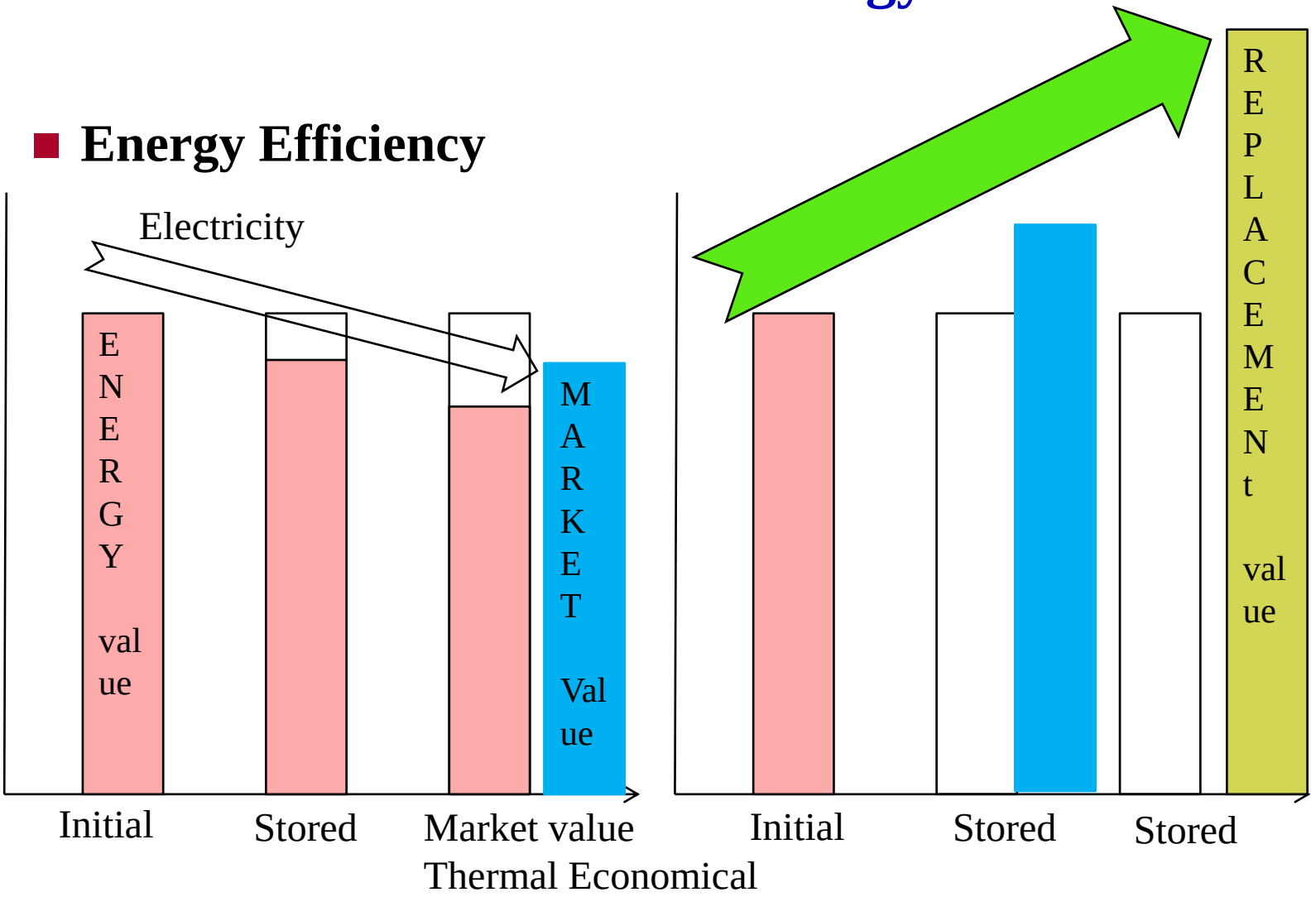
Hydrogen system

Economy of Electrons and protons

- **Electricity**
  - **Very cheap because of balance necessary generation and consumption**
  - **Battery can store the cheap electrons with high efficiency but providing only electrons**
- **If it coverts to protons/chemicals then you can upgrade to the valuable products**
- **Efficiency does matter for energy**
- **Value does matter for economy**

Market Value and energy Value

- **Energy Efficiency**



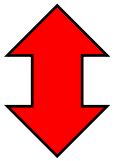
Battery system

Hydrogen system

Policy requirements for sustainable society

- **Low Carbon Society**
  - **Global Warming**
  - **Clean Local environment**

Environmental Policy



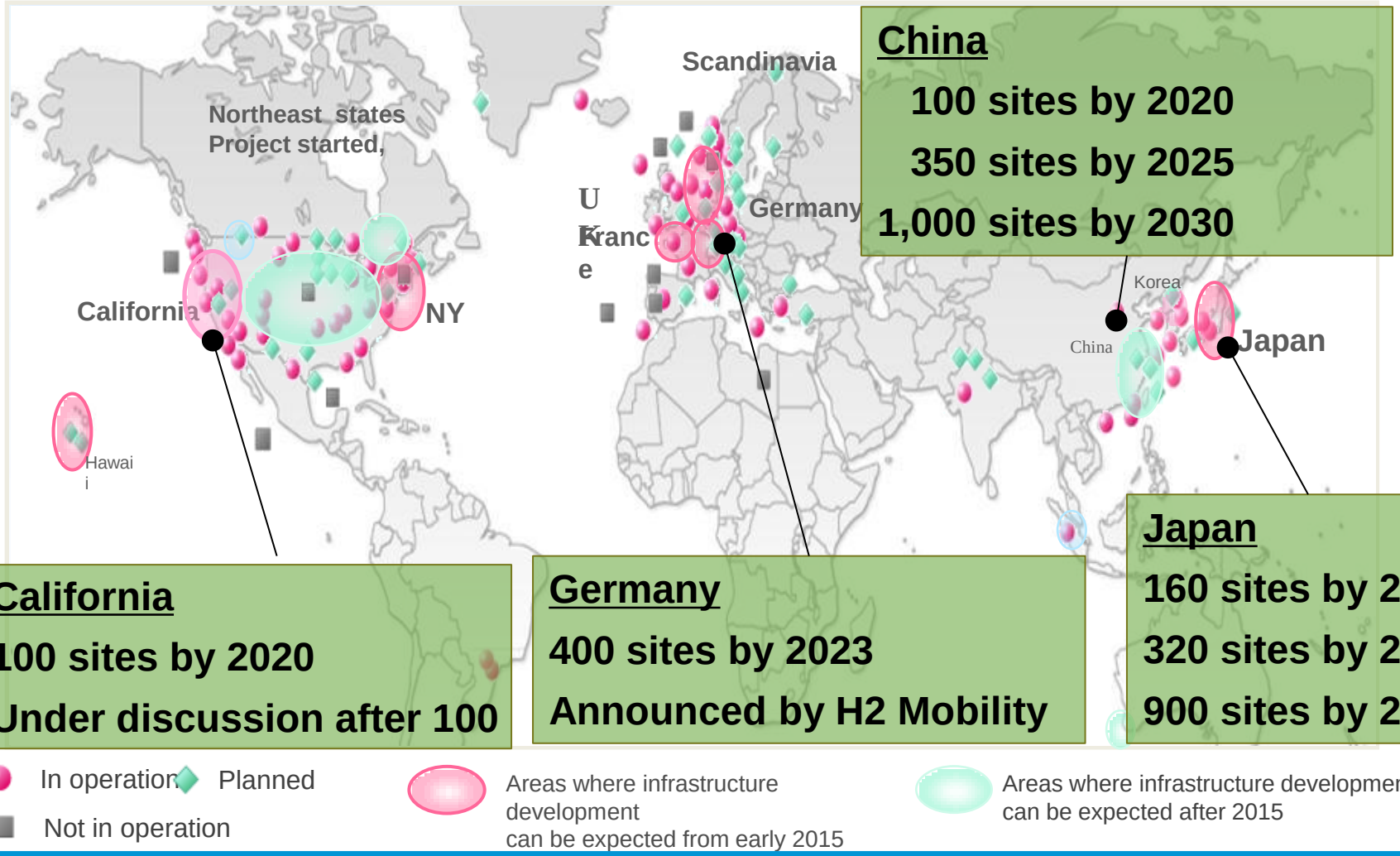
- **Sustainable Society**
  - **Sustainable Energy/Resources**
  - **Sustainable Life/Society**

Energy Policy

- **Sustainable Economy**

Total Policy

Worldwide Locations of Hydrogen Stations

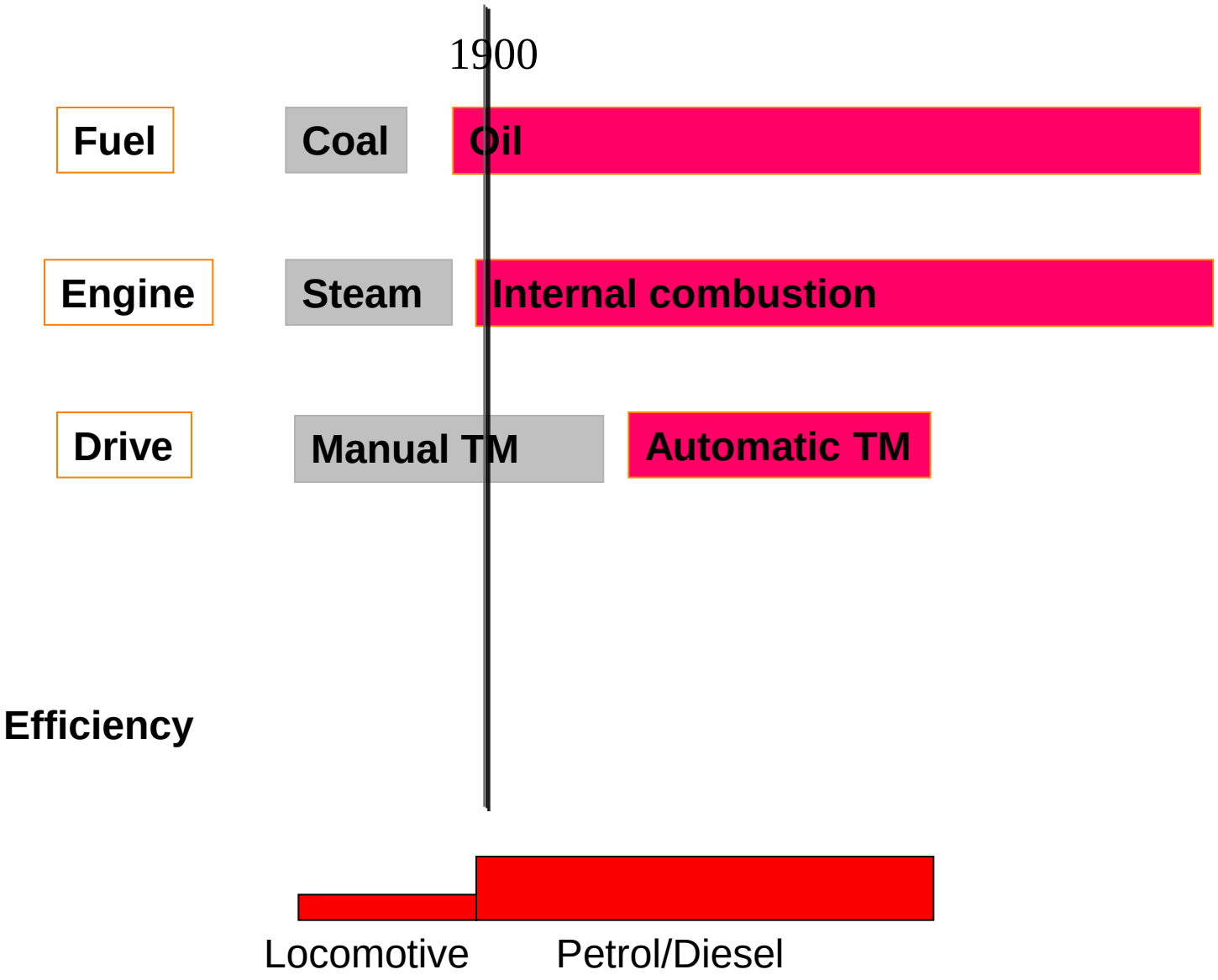


Several hundreds of hydrogen stations are expected by 2020.

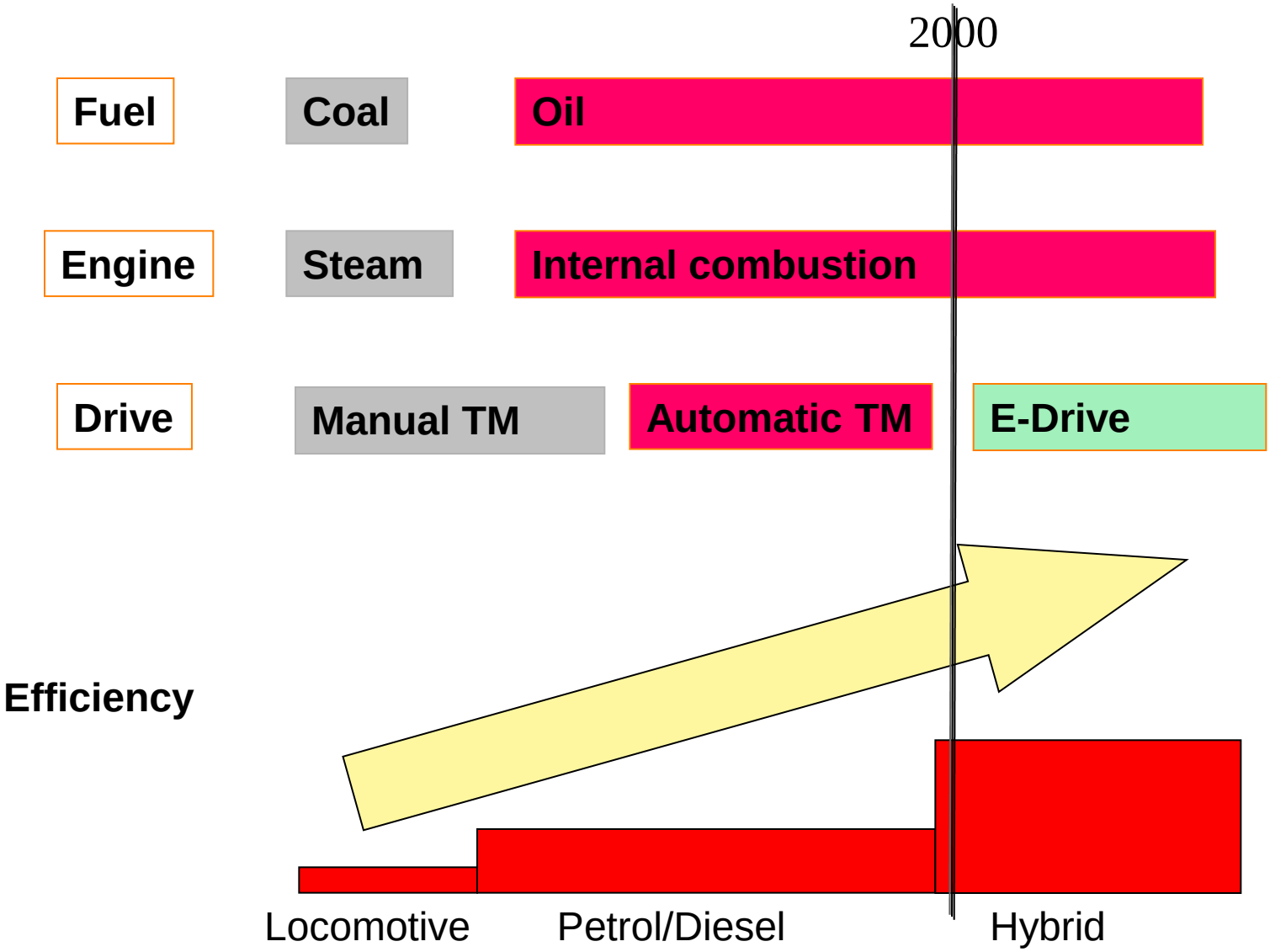
Courtesy of Toyota, Toyota presentation

Evolution of Vehicle Systems

Evolution of Vehicle System



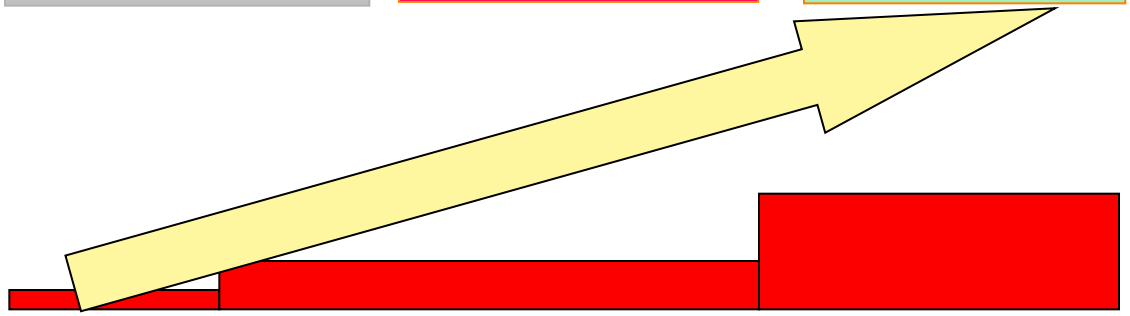
Evolution of Vehicle System



Evolution of Vehicle System

Fuel	Coal	Oil		
Engine	Steam	Internal combustion		
Drive	Manual TM	Automatic TM	E-Drive	

Efficiency



Locomotive Petrol/Diesel Hybrid

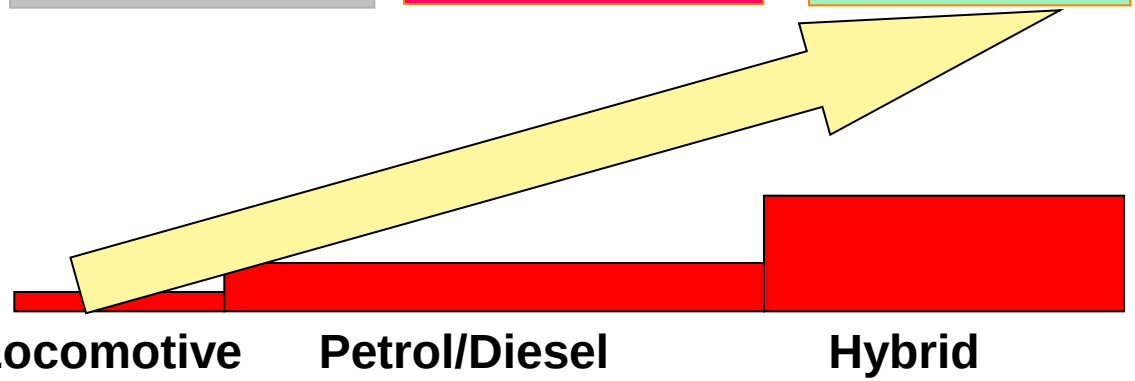
Environmental Restrain

Range Comfort High Oil Price

Evolution of Vehicle System

Fuel	Coal	Oil		
Engine	Steam	Internal combustion		
Drive	Manual TM	Automatic TM	E-Drive	

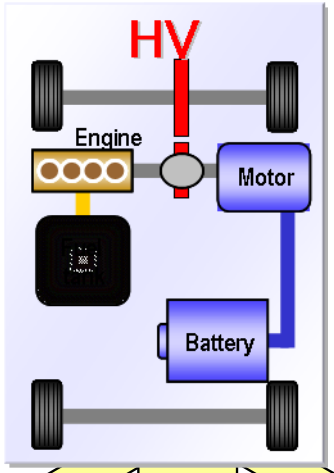
Efficiency

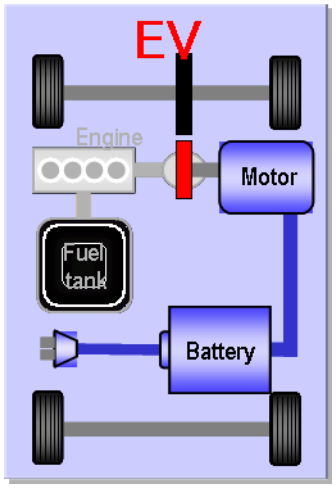


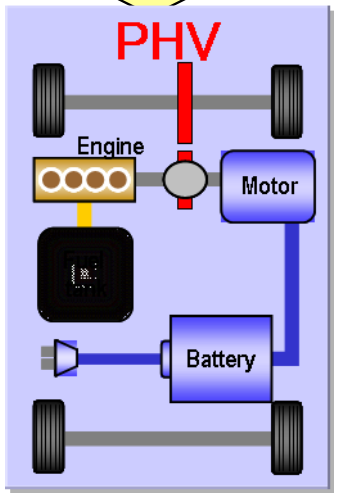
Environmental Restrain

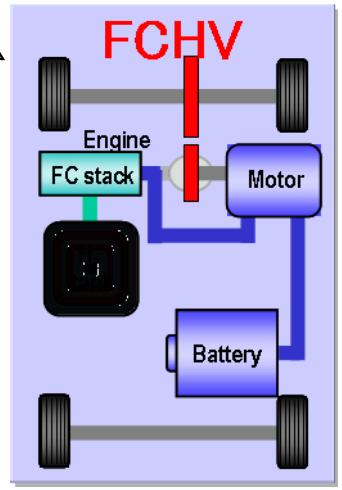
Range | Comfort | High Oil Price | Sustainability

Evolution of E-drive and Engine





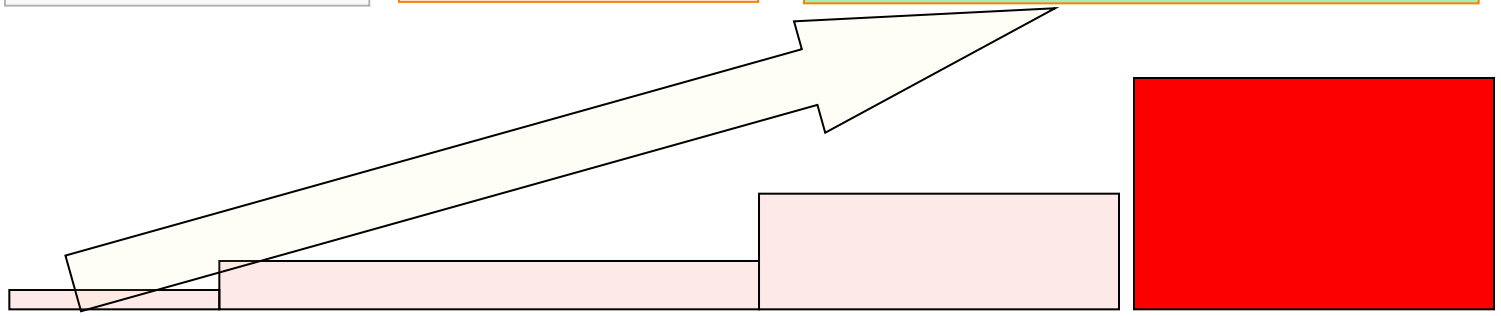




Using hybrid technology for PHV, EV, and FCHV

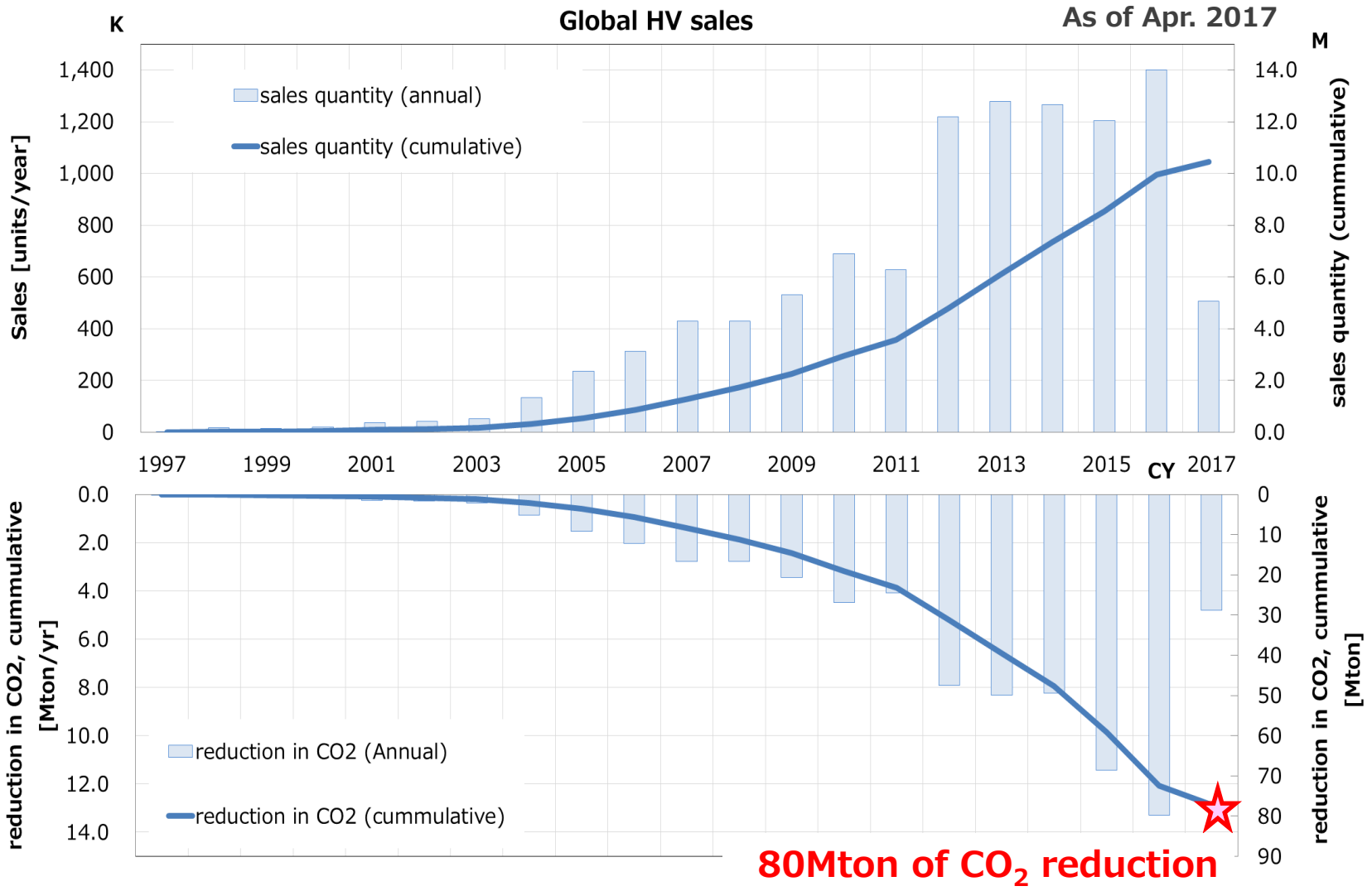
Hydrogen Today and Tomorrow

Fuel	Coal	Oil	Hydrogen
Engine	Steam	Internal combustion	Fuel Cell
Drive	Manual TM	Automatic TM	E-Drive



Environmental Restrain	Range	Comfort	High Oil Price	Sustainability

HV and CO_2 reduction history



80Mton of CO_2 reduction

HV has big role for CO_2 reduction

Courtesy of Toyota, Toyota presentation

Scientists/ Engineers are expected for Sustainable Society

- **Developing**
  - **Technologies for cheaper, higher efficient hydrogen technologies**
    - **Energy conversion (Electricity ⇔ Hydrogen)**
    - **Hydrogen storage**
    - **Combined Energy/Societal System Management**
  - **Technologies of implementing those low carbon technologies into the society**
    - **Econo-technical approach**
    - **Financial scheme**

What Prius Brought to me?

- **Small Dream's Realization is not easy.**

- **Big Dream is easier to make it True**

First Prius Oct1997

Courtesy of Toyota, Toyota presentation

What Prius and MIRAI Brought to me?

- **Small Dream's Realization is not easy.**

You need to make it happen by your own

- **Big Dream is easier to make it True**

Everybody help you to make it

“End of stone age was not due to the lack of stone”

The technological innovations and new ideas change the society.

Thank You