The Mysterious Island: The Rise of Hydrogen and Fuel Cells in Japan

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The Triple Threat of Fossil Fuels

**Climate Change**

Temperature rise since 1850

Global mean temperature change from pre-industrial levels, °C

1 °C

Source: Met Office

**Public Health**

PM2.5 < 2.5 μm

© NASA

**Energy Security**

Europe’s gas-pipeline network

Theoretical capacity of selected pipelines

Yamal (33 bcm/pa)

Nord Stream 1 & 2† (both 55 bcm/pa)

Via Ukraine (40 bcm/pa)†

TurkStream (31.5 bcm/pa)

Blue Stream (16 bcm/pa)

* Billion cubic metres per annum
† Nord Stream 2 not yet operational
‡ 2021 actual flows

The Economist

[Map and illustrations related to gas pipelines and energy security]

Source: JPMorgan

2009 vs. 2015

[Images showing glaciers in 2009 and 2015, indicating climate change]
Electrification with Renewables

Intermittency and Curtailment

Difficult to Electrify Sectors

Solar farm, Itoshima

Wind Lens, Karatsu

Steel Manufacture

Cement Production

Heating & Cooling Mobility
Energy Storage using Batteries

Batteries are suited to **short-term** energy storage.

Cobalt, lithium and graphite are **critical raw materials** with limited supply.
The lithium-rush threatens disastrous ecological damage on an industrial scale...

Cobalt mining in the Democratic Republic of Congo uses child labour...

Faulty batteries can cause fires (Samsung Galaxy Note 7 recall cost >US$17 billion)...

Meanwhile, demand is rapidly increasing!
“I believe that water will one day be employed as fuel, that hydrogen and oxygen will furnish an inexhaustible source of heat and light”.

The Mysterious Island, Jules Verne (1874)
Hydrogen Balloons and Airships

First crewed hydrogen balloon (1783)

The first powered hydrogen airship (1852)

The Hindenburg disaster (1937)

Japan’s first hydrogen airship (Yamada Shiki, 1911)
Coal Gas: Hydrogen Lighting

First gas lamp in Japan (Kyushu, 1857)

Ginza, Tokyo (1875)

Steam reforming is still the primary method of hydrogen production today.
Where does hydrogen come from?

How is hydrogen used?
Brown Coal Gasification + CCS (Australia)

Off-peak Renewable Electrolysis

Hydrogen Liquefaction Plants

Cryogenic Liquid Hydrogen Transport to Japan

Liquid Hydrogen Storage

Liquid Hydrogen Trucks

Compressed Hydrogen Trucks

Brown coal, which exists about five meters underground in Latrobe Valley, Australia. The reserves are estimated to be equivalent to 240 years' worth of total electric power generation in Japan. Hydrogen is produced from brown coal, and then transported to Japan by liquefied hydrogen carriers.

Solar, Wind, Geothermal

Hydraulic, Biomass

Water electrolysis

100%
**AHEAD Project**

- Hydrogen produced in Brunei
- React with toluene to form methylcyclohexane (MCH).
- Transport by ship to Japan, in conventional ISO tanks.
- Dehydrogenation in Kawasaki port (MCH $\rightarrow$ toluene)
- Supplied to the Mizue thermal power plant.
- Toluene returned to Brunei where it is transformed back into MCH.
Flush, then fill up: Japan taps sewage to fuel hydrogen-powered cars

An attendant prepares to fill up a Toyota Mirai at a Fukuoka sewage treatment plant, which is creating hydrogen from biogas. (Julie Makinen / Los Angeles Times)
Hydrogen + Oxygen $\rightarrow$ Electricity + Heat + Water
Combined Heat & Power (CHP): ENE-FARM

Over 320,000 units sold since 2008
Output of 700 W, with 95% efficiency
Price: ~800,000 JPY


Decreasing price
• 250 kW pressurized SOFC Micro Gas Turbine (800 ºC)
• Mitsubishi Hitachi Power Systems, Ltd.
• ~10 installed in Japan.
1 MW Mitsubishi-Hitachi Prototype

Many companies developing similar technologies:

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Denso</th>
<th>Miura</th>
<th>Fuji Electric</th>
<th>Hitachi Zosen</th>
<th>MHPS</th>
<th>Bloom Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Demostration model</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Business model</td>
</tr>
<tr>
<td>Appearance</td>
<td><img src="image1.jpg" alt="Denso" /></td>
<td><img src="image2.jpg" alt="Miura" /></td>
<td><img src="image3.jpg" alt="Fuji Electric" /></td>
<td><img src="image4.jpg" alt="Hitachi Zosen" /></td>
<td><img src="image5.jpg" alt="MHPS" /></td>
<td><img src="image6.jpg" alt="Bloom Energy" /></td>
</tr>
<tr>
<td>Output</td>
<td>5 kW</td>
<td>5 kW</td>
<td>20 kW</td>
<td>50 kW</td>
<td>250 kW</td>
<td>200 kW</td>
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</table>
In the 1990’s, Japanese manufacturers took the lead in the development of fuel cell electric vehicles (FCEVs).

These used metal hydrides to store hydrogen fuel. Later switched to compressed hydrogen tanks.
First Commercially Available FCEV

Toyota MIRAI FCEV (2016)

Power Control Unit

Traction Motor

Fuel Cell Stack

Battery

Hydrogen Storage Tanks

Two Type IV hydrogen tanks
2nd Generation Toyota MIRAI FCEV (2020)

- Nominal range is 650 km, but the record is 1360 km!
- Three Type IV compressed hydrogen tanks hold 6 kg H\textsubscript{2} at 70 MPa.
- The current price is around 60,000 EUR.
Comparison to Batteries

- For cars, the cost equivalence of FCEVs and BEVs is at ~850 km range.
- For trucks, this cost equivalence occurs at ~400 km range.
- In 2040 these numbers will be ~550 km and ~200 km, respectively.
- Fuel cells better suited to long range and/or large scale applications.
Diversity of Fuel Cells
Planetary Rovers
Kyushu University Hydrogen Project

Hydrogen Town (>150 PEFCs)

International Research Center for Hydrogen Energy (HY30)

Future Energy Demonstration Facility

Department of Hydrogen Energy Systems
Hydrogen Distribution

- >137 H₂ stations in Japan (Dec. 2020)
- Planned 1000 stations by 2030
Platinum Demand for FCEVs

- Fuel cells require platinum catalysts, but platinum is a critical raw material.
- Around 190 tonnes of Pt is extracted annually (only 10,000 tons in history).

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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Number of FCEVs</td>
<td>25210</td>
<td>5 million</td>
<td>92 million</td>
<td>1.6 billion</td>
</tr>
<tr>
<td>Pt Required (tonnes)</td>
<td>0.756</td>
<td>150</td>
<td>2760</td>
<td>18,000</td>
</tr>
<tr>
<td>% of annual production (190 tonnes)</td>
<td>0.4</td>
<td>79</td>
<td>1453</td>
<td>9474</td>
</tr>
<tr>
<td>Time to extract Pt</td>
<td>1.5 days</td>
<td>284 days</td>
<td>14.5 years</td>
<td>95 years</td>
</tr>
</tbody>
</table>

- Matching BEV units manufactured to date would require **150 tons** of Pt.
- Replacing every ICE vehicle would require ~**18,000 tons** of platinum.
- This does not take into account other important applications.
Platinum-free Electrocatalysts

Red Blood Cell

Hgb (Fe$^{2+}$) $\leftrightarrow$ Hgb (Fe$^{3+}$)

Haemoglobin

O$_2$

Carbon
Nitrogen
Iron
**Synthesis of Nitrogen-doped Carbon**

Ethanol + Triethanolamine + Sodium → STP 24h → Sodium Alkoxide → 900°C 2h → Nitrogen-doped Carbon Foam

Four + Water + Yeast → Mix → Dough → 180°C 1h → Bread (Toast)
Fe-N-C Catalyst

Iron Chloride + Nitrogen-doped Carbon

Dry → Heat → Fe-N-C Catalyst

Water + Iron Chloride + Nitrogen-doped Carbon
Microstructure of the Support

- Very large surface area
- Atomically thin cell walls
- Micron-scale macropores
- Very large surface area
Platinum-free Electrocatalysts

- Investigation of different iron sources on the oxygen reduction activity.
- Differences due to porosity induced in the nitrogen-doped carbon support.
- Fuel cell performance similar to commercially developed Fe-N-C catalyst.
- Advantage is low cost – still much work needed to compete with performance of platinum in real-world hydrogen fuel cell applications.

Iron-decorated nitrogen-doped carbon foam (Fe-N-C) is a cheaper alternative.

Platinum-decorated carbon black (Pt/C) electrocatalysts are very expensive.
Thank you for your attention.

CO₂ emissions in Japan since 1970

lyth@kyudai.jp
Bumps on the road to hydrogen mobility:
Experiences from Japan, California and Germany

Carbon Neutral Society Action Month 20 May 2022
Assoc. Prof. Gregory Trencher
Kyoto University: Graduate School of Global Environmental Studies
INTRODUCTION
A ‘battle is occurring between battery electric vehicles (BEVs) and fuel-cell electric vehicles (FCEVs) (De Kaa 2017)

Numerous countries are pursuing electrification via both technologies:
• **Asia**: Japan, Korea, China
• **USA**: California, New England
• **Europe**: Germany, England, France

**But in 2021, global on road-vehicle numbers:**
BEVs: 11,000,000
FCEVs: 40,000

*International Energy Agency (2021)*
In all markets, BEV sales are dwarfing FCEVs

However, interest in passenger FCEVs remains high:
- Suitability for larger platforms (SUVs etc)
- Reduce costs for heavy-duty market via economies of scale in part production e.g. fuel cell stacks, tanks, refuelling stations
- Fewer land requirements for infrastructure compared to BEV charging
- Attractive ZEV solution for users unable to install home chargers => e.g. in rental properties, multi-family apartments
- Attractive driving ranges and refuelling times => Potential to increase driving range with more tanks and higher fuel-cell efficiency
- Less reliance on precious raw materials (cobalt, lithium, copper etc.)
California, Japan and Germany are three leading markets for:
• Testing and developing FCEVs
• Vehicle adoption
• Installation of refuelling stations

Japan’s situation
• Two car makers serially producing FCEVs: Toyota and Honda
• Long history of R&D in fuel cells (stationary and mobile)
• FCEVs are a key part of road electrification strategy
INTRODUCTION
LEADING MARKETS

Half of global market

<table>
<thead>
<tr>
<th></th>
<th>March 2022</th>
<th>2030 target</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Japan*</td>
<td>California</td>
</tr>
<tr>
<td>FCEVs (on-road)</td>
<td>~6,900</td>
<td>~9,650</td>
</tr>
<tr>
<td>FC buses (on-road)</td>
<td>104</td>
<td>54</td>
</tr>
<tr>
<td>Refuelling stations (operating retail)</td>
<td>159*</td>
<td>52</td>
</tr>
<tr>
<td>FCEV to station ratio</td>
<td>43 : 1</td>
<td>185 : 1</td>
</tr>
</tbody>
</table>

* Includes truck-based mobile stations

California’s stations are heavily used. Japan and Germany underused

Sources
INTRODUCTION

FEU LLING STATION IN TOKYO
INTRODUCTION

FUEL CELL BUS AT TOKYO STATION
INTRODUCTION

APPLICATION OF EACH TECHNOLOGY: TRADITIONAL VIEW
INTRODUCTION

PROGRESS IN BEV MOBILITY

Battery electric bus (BYD) in Europe

BEV pick-up truck (Ford) in USA
Due to improvements in battery performance, EVs will perform many roles previously expected for hydrogen.
DIFFUSION BARRIERS
BARRIERS RELATED TO VEHICLE PRODUCTION

How to increase the supply of FCEVs?
How to accelerate technological progress?
How to lower costs?
### Strategies to Overcome Diffusion Barriers

**Supply-Side: Supporting Strategies**

<table>
<thead>
<tr>
<th>Region</th>
<th>Stimulating effect on FCEV production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany and Japan</td>
<td></td>
</tr>
<tr>
<td>State support for R&amp;D</td>
<td>Uncertain</td>
</tr>
<tr>
<td>Testing and knowledge sharing platforms mediated by government</td>
<td>Uncertain</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Region</th>
<th>Stimulating effect on FCEV production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td></td>
</tr>
<tr>
<td>Sharing of patents and supply of fuel cell and tank systems by Toyota</td>
<td>Uncertain</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Region</th>
<th>Stimulating effect on FCEV production</th>
</tr>
</thead>
<tbody>
<tr>
<td>California</td>
<td></td>
</tr>
<tr>
<td><strong>Regulation:</strong> Forced minimum production of ZEVs</td>
<td></td>
</tr>
<tr>
<td>=&gt; FCEVs receive high credits from driving range and travelling provision</td>
<td>Certain</td>
</tr>
</tbody>
</table>
FCEV production is still limited, insufficient to drive market growth

**Japan:** ~7,000 in circulation against government target of 40,000

=> Only Toyota producing. Honda suspended FCEV production.

**Germany:** Local automakers not currently producing

=> Overall, automakers focusing ZEV portfolios on BEVs

=> But BMW iX5 expected in 2022

**Barriers for automakers**

- **Cost:** Technological difficulty of mass-producing fuel cells and fuel tanks at low-cost
- **Infrastructure:** Limited availability prevents the ability to produce in volume
- **Time:** Setting up part supply chains requires several years

**These barriers are lower in the BEV market**
INFRASTRUCTURE BARRIERS
How to build a fleet of refuelling stations at low-cost?
## STRATEGIES TO OVERCOME DIFFUSION BARRIERS

### REFUELLING STATIONS: SUPPORT POLICIES

<table>
<thead>
<tr>
<th>Construction subsidies</th>
<th>Strategy</th>
</tr>
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<tbody>
<tr>
<td>Germany</td>
<td>Government subsidies ~50% of construction costs</td>
</tr>
<tr>
<td>Japan</td>
<td>Same</td>
</tr>
<tr>
<td>California</td>
<td>Same</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operation support</th>
<th>Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>• None</td>
</tr>
<tr>
<td>Japan</td>
<td>• Subsidies from national/local government</td>
</tr>
<tr>
<td></td>
<td>• Revenue via JHyM platform</td>
</tr>
<tr>
<td>California</td>
<td>Revenue via market mechanisms:</td>
</tr>
<tr>
<td></td>
<td>• Low Carbon Fuel Standard (carbon credits from fuel sales)</td>
</tr>
<tr>
<td></td>
<td>• Capacity payments to larger stations</td>
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OEMs and government provide revenue support

Market mechanisms provide revenue
Germany and Japan

**Underused** stations due to low vehicle to station ratio
- Japan = 43:1
- Germany and 16:1

“The business case is a nightmare”
(Stakeholder in Germany)

California

- **Overused** stations (and breakdowns) due to high vehicle to station ratio

https://cafcp.org/stationmap
Inconvenience in refuelling station network is:

• Damaging public reputation of technology

• Causing some drivers to abandon the technology (reported in California and Japan)

• Constraining FCEV production ambitions from OEMs
ADOPTION BARRIERS
How to encourage drivers to buy FCEVs?
## STRATEGIES TO OVERCOME DIFFUSION BARRIERS

### ADOPTION: BARRIERS

<table>
<thead>
<tr>
<th>Consumer subsidies</th>
<th>Explanation</th>
</tr>
</thead>
</table>
| Germany            | National government:  
|                    | • Private buyers: EUR 7,500  
|                    | • Fleet buyers: Up to 80% of cost difference |
| Japan              | National subsidy (~$18,000)  
|                    | Local subsidy (Tokyo ~$8,500) |
| California         | State government (~$4500) *inc. for leases |

**Big subsidies but no ownership incentives**

<table>
<thead>
<tr>
<th>Other</th>
<th>Explanation</th>
</tr>
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<tbody>
<tr>
<td>Germany</td>
<td>Tax waivers (motor vehicle tax)</td>
</tr>
<tr>
<td>Japan</td>
<td>Tax waivers (stamp duty etc.)</td>
</tr>
<tr>
<td>California</td>
<td></td>
</tr>
</tbody>
</table>
|        | • Free fuel from OEMs (3-years or $15,000)  
|        | • Free use of carpool lanes (HOV decal)  
|        | • Lease arrangements to decrease ownership cost |

**Small subsidy but big ownership incentives**
All markets
Running costs (from fuel) are much higher than BEVs. The incentive to buy is low

Germany and Japan
Most FCEVs bought by corporations (companies, municipalities)

“I cannot remember seeing one private fuel cell car in Germany”
(Stakeholder in Germany)

“If consumers are not seeing them on the streets, why would they go and buy one?”
(Stakeholder in California)

“What is missing is the fuel cell Tesla. Without Tesla, I don’t think there would be hype with BEVs”
(Stakeholder in Germany)
SUMMARY

KEY MESSAGES

All markets
Speed of FCEV rollout behind initial expectations, with BEVs racing into market

Main reasons
• Low supply of FCEVs
• High cost or making/purchasing
• Limited refuelling infrastructure

Positive signs
• Hyundai FCEVs entering Japan
• Honda will re-enter market
• All three markets expanding refuelling infrastructure
Perspectives of Carbon-Free Energy Sources in the Decarbonized Society

APRU Carbon Neutral Society – Action Month
20 May 2022
Society 5.0 and SDGs

Digital Transformation × Imagination & Creativity of diverse people

Problem Solving → Value Creation

Source:
http://www.unic.or.jp/activities/economic_social_development/sustainable_development/2030agenda/sdgs_logo/
Energy Sustainability: Energy Triangle

Energy Security
Security of supply, energy quality, diversification, accessibility

- SDG16: Peace justice and strong institution
- SDG9: Industry, innovation and infrastructure
- SDG8: Decent work and economic growth
- SDG12: Responsible consumption and production
- SDG13: Climate action

Environmental Sustainability
Climate and environment

- SDG4: Quality education
- SDG6: Clean water and sanitation
- SDG7: Affordable clean energy
- SDG14: Life below the water
- SDG17: Partnerships

Energy Equity
Energy for quality of life, competitiveness, opportunity, economic growth

- SDG1: No poverty
- SDG3: Good health
- SDG4: Quality education
- SDG5: Gender equality
- SDG11: Sustainable Cities and communities
- SDG16: Peace justice and strong institution
- SDG2: Zero hunger
- SDG12: Responsible consumption and production
- SDG7: Affordable clean energy
Sustainability

• Meeting and fulfilling the needs of humanity without harming future generations.

• The sustainability pursues three types of interests:

1. **Economic Interests**
   The economic impact on the localities where it does business, such as creating jobs, paying decent wages, and initiating public works. In addition, it also covers ending the energy poverty and strengthen economic growth

2. **Social Interests**
   Performance in terms of social justice, such as avoiding child labor and sweatshops, and providing decent employee benefits.

3. **Environmental Interests**
   Impact on the natural environment.

**Sustainable Energy:**
Sustainable provision of energy that meets the needs of the present humanity without compromising the ability of the future generations to meet their needs
Energy Transition

- Energy sector as a key contributor to global warming
- Transition strategies need to be pursued simultaneously to achieve a well below 2 °C scenario

(WB2C Scenario, annual emission, 2040; business as usual 47 Gt-CO₂ with BB2C 2040 20 Gt-CO₂)

- Decarbonization of power combined with extended electrification
- Decarbonization of activities which cannot be cost-effectively electrified
- Acceleration in the pace of energy productivity improvement to 3% per annum
- Optimization of fossil fuels use within overall carbon budget constraints

Short term
- Energy efficiency
- Integration of low carbon technologies and REs

Mid term
- Integration of low carbon technologies and REs for electricity and hydrogen
- Zero emission target

Long term
- Circulated (closed circulation, local production – local consumption)
Concerns in Energy Transition

**Environmental**
- Carbon emission/neutrality
- Balanced management of clean air, water, soil, food, primary energy resources, etc.
- Conservation of biodiversity and wildlife

**Economic**
- Dynamic change of local/national economies to the speed of change in energy transition
- Balanced and adaptive structural changes to facilitate new business potential and growth
- Affordability and economic growth and resilience
- Management of vested interest as an obstacle in transition

**Social**
- Challenges in fossil-dependent communities (jobs, cultural changes, economic declines, etc.)
- Inclusive and wider benefits/impacts from transition, including job creation, positive social experiences, etc.
- Social acceptability and well-being
- Mutual capacity building and understanding toward inclusive culture

Minimization of climate change risks, and correlation of energy with other aspects
Transformation in Energy System and Price

**Current condition**
- High-ratio of base-load generator (nuclear, coal, hydro)
- Small share of renewables
- Curtailment of renewables due to limitation in adjusting/transmitting capacity
- Middle-load and adjusting generators dominated by fossils (gas, oils)
- Limited energy storage and fast-responsive system
- Higher price for renewables (although fluctuating)

**Future**
- Lower ratio of base-load generator (nuclear, biomass, waste, geothermal, hydro)
- Larger share of renewables
- Lower price for fluctuating sources
- Minimization in curtailment of renewables
- Significant role for middle-load and adjusting generator
- Energy storage, hydrogen, fast-responsive system as middle-load and adjusting generator (higher/premium price)
Future Energy Options and Beyond Net Zero

Optimization of renewable sources
- Appropriate scenario building for each region/country
- Revaluing of biomass
- Technological maturity for potential REs
- Maintenance and parts supports/access
- Facilitative policies, incentives, and supports

Adoption of carbon-free secondary energy sources
- Mutual utilization of electricity and hydrogen-based fuels
- Potential of metal fuels
- Integrated system toward high total efficiency

Control on CO2 generation
- Controlling the CO2 amount through controllable generation (emission), separation, storage/sequestration, and utilization
- Established CO2 utilization
- Carbon tax scenarios
Indicators for Low-Carbon Growth Encouragement

**What and Why**

- Direct response of local governments to the indicators
- Identification of appropriate carbon intensity indicators
- Inclusion of indicators in local government performance evaluations

**Indicators**

- **Carbon Emissions**: Emissions/capita, emission intensity
- **Energy**: Energy consumption/capita, share of renewable energy
- **Green Buildings**: Energy consumption per m2 in commercial and residential buildings
- **Sustainable Transport**: Share of green transport mode trips
- **Smart Urban Form**: Population density and mixed land use

**Energy efficiency measures**:
- building material
- transport system
- sewerage and water supply systems,
- street lighting, air-conditioning systems
- energy consumption in buildings
Energy Transition and Circular Economy (CE)

- Energy transition should become the driver for circular economy, combining economic and environmental gains.
- Implies reduction of energy, material, waste, and emission through changes in design, production, distribution, and consumption, as well as emphasize on repair, reuse, remake, and recycle.
- Reasonable growth (economy, population, employment) with low environmental damage at both local and global levels.
- Demands mutual and integrated innovation, as well as monitoring (traceability) and global network resilience.
- It is needed to promote the goals of sustainable development (SD).
- Sustainable development demands other factors of social and human dimensions.
Adaptive Energy Transition Toward CE and SD

- Adaptive scenarios for each different regions (resources, demand, knowledge and technological mastery)
- Progressive and dynamic transition scenario
- Mutual and bi-directional communications for all the stakeholders (both local and global, producers and consumers)
- Shift of consumption
  - Adaptive behavior
  - Ownership and responsibility
  - Concerns to the environment
- Evaluation
  - Scenario analysis
  - Energy and material flow analysis
  - Circularity evaluation
  - Impacts assessment

Energy-related keys toward realization of CE and SD
A city that makes use of **advanced information and communications technologies (ICTs)** to make the critical infrastructure components and services of a city in a more **aware, interactive, and efficient** way.

**Aims of a Smart City**

- Provide a **high quality of life**
- Ensure **resource efficiency** and **reduce costs**
- Result in **sustainable growth** and **economic prosperity**
- Increase **interaction** between government and citizens
Energy and Living Space Development

General Principles

- **COLLABORATION OF KEY STAKEHOLDERS**
- **INNOVATIVE, RATIONAL, & INTEGRATED APPLICATION OF ICT**
- **INTEGRATION OF DOMAINS**
- **SUSTAINABILITY EVALUATION**

**OBJECTIVES**
- Optimized Sustainable Self-Sufficient Resilient
- Optimized Accessible Affordable Adequate

**1st ENERGY CONSERVATION**
- TARGET GROUPS
- DECISION MAKERS
- SERVICE PROVIDERS
- LATERAL EFFECTIVE STAKEHOLDERS

**HARD DOMAINS**
- Buildings & Districts
- Transportation & Mobility
- Energy & ICT Infrastructures

**SOFT DOMAINS**
- Collaborative Planning
- Consumer Behavior Management
- Data & Energy Management

**BENEFITS**

**COSTS**

Mosannenzadeh et al. Smart energy city development: A story told by urban planners. Cities 64 (2017) 54-65
Pezzutto et al. FP7 SINFONIA project, deliverable 2.1 SWOT analysis report of the refined concept/baseline (SINFONIA deliverables) European Academy of Bolzano, Bolzano (2015)
The initiatives of CEMS comes from the needs of harmonization between optimal energy services, potential economy and environmental benefits.

CEMS manages the overall energy supply and demand across the community. It communicates the information with other systems both inside and outside of the community.
An approach in which **smart electricity, thermal and gas** grids are combined with **storage technologies** and coordinated to identify **synergies** between them in order to achieve an **optimal solution** for each individual sector as well as for the overall energy system.

**Smart electricity grids**
Connects flexible electricity demands such as heat pumps and electric vehicles to the intermittent renewable resources such as wind and solar power.

**Smart thermal grids**
connect the electricity and heating sectors. This enables the utilization of thermal storage for creating additional flexibility and the recycling of heat losses in the energy system.

**Smart gas grid**
connect the electricity, heating, and transport sectors. This enables the utilization of gas storage for creating additional flexibility. If the gas is refined to a liquid fuel, then liquid fuel storages can also be utilized.
Smart Electricity Grid

Electricity network using digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources.

Key Characteristics

- Uses information technologies to improve how electricity travels from power plants to consumers
- Allows consumers to interact with the grid
- Integrates new and improved technologies into the operation of the grid
- Self healing: grid detects, analyzes, responds,…
- Provides power quality to consumer and industry
- Accommodates demand responds, combined heat and power, wind, PV, and end-use efficiency
- Transform the power sector into a secure, adaptive, sustainable and digitally
Carbon-free secondary resources

- Efficient conversion of primary to secondary energy sources
- Mutual conversion and utilization among potential carbon-free secondary resources

**Mutual conversion and utilization**
Mutual co-utilization of Electricity and H2-based fuels
Reevaluating and Revaluing Biomass

- Optimum utilization of its characteristics (carbon neutral, storability, flexibility)
- Biomass has high flexibility to be converted to various kinds of fuels and broad utilization
- Excellent storability to provide stable and balanced energy supply, as well as storage and transportation
- Short-to-long terms energy supply
- Restructurization of energy price (base load, as well as green, supply can be higher than fluctuating one)
- Complex and standalone (single) conversion system leads to low energy efficiency
- Integration with other resources and the need for advanced and integrated system to realize high total energy efficiency
Mutual Conversion of Secondary Energy Sources

- Electrical energy
- Chemical energy
- Thermal energy
Hydrogen: Flexible Secondary Energy Source and Potential Energy Carrier

Hydrogen as potential secondary energy source (cleanliness, high efficiency, high variety of production and utilization)

Utilization of hydrogen: reciprocating combustion engine, fuel cells, combustion, co-combustion, etc.

Energy density by weight is high (33 kWh/kg), but by volume is very low (3 Wh/l)

Produced mainly from natural gas, oil reforming, coal gasification, water electrolysis

>50% of global H2 transport needs by 2050

Already more than 10,000 tpd by 2030

Primary energy sources

Production

On site conversion and storage

Conversion

H2

Storage

Separation

Direct use

H2 production and utilization

Utilization

H2

FC vehicles

Chemical industries

Power generation

Global energy systems in transition sources

Decarbonization pathway toward zero carbon
Hydrogen and Ammonia Applications

- Aviation
- Maritime vehicles
- Trains, buses
- Material handling vehicles
- Industrial applications (amines, alcohols, cycloalkanes, hydrogen peroxide)
- Ammonia production
- Large-scale power generation
- Domestic power generation

H2/NH3
Electric Vehicle and Vehicle-to-Grid (V2G) Technology

- Integration of transportation and energy sectors
- V2G facilitates new economic and social opportunities to the owners/drivers, not only as transportation, but also energy services
- Increasing the total energy efficiency and reducing CO2 emission

Conceptual architecture of V2G technology
(Source: Parker project final report)

Various ancillary services which can be provided through V2G:

- Frequency regulation
- Spinning reserves
- Congestion management
- Black start provision
- Congestion management
- Load shifting
- Peak shaving
- Valley filling
- Voltage control
- Reactive power support
- Smooth grid integration
- Intermittence reduction
- Energy curtailment reduction
- Frequency regulation
- Spinning reserves
- Congestion management
- Black start provision
- Congestion management
- Load shifting
- Peak shaving
- Valley filling
- Voltage control
- Reactive power support
- Smooth grid integration
- Intermittence reduction
- Energy curtailment reduction

Transmission:
- Various ancillary services which can be provided through V2G

Distribution:
- Various ancillary services which can be provided through V2G

Renewable energy:
- Various ancillary services which can be provided through V2G

Conceptual architecture of V2G technology
(Source: Parker project final report)
Carbon Utilization

Toward longer carbon life cycle

- Materialization
- Mineralization
- Sequestration (EOR, ECBM)

Source: U.S. DOE, National Energy Technology Laboratory, CO2 Utilization Focus Area, at https://www.netl.doe.gov/research/coal/carbon-storage/research-and-development/co2-utilization
Coupling the Forestation in Energy Transition

- The plants have the highest carbon absorption rate for their first 5-20 years, and then it decreases. Once the plantation cycle has been reached (e.g., after 50-60), there is no further positive carbon absorption.

- Coupling the CO2 capture by forestation (especially for initial 20 years growth) in the energy transition (establishing H2/NH3 readiness level, etc.)

- In the future, through cycled plantation, the forest is potential to supply the biomass as promising carbon neutral feedstock/fuel (after 50-60 years from forestation/plantation)

- Furthermore, through advanced technologies (CCUS, chemical looping, etc.), the carbon emission can be controlled to be zero or negative emission (controllable emission, after 2050/2060)
CO₂ Capture by Forestation

- Planted forests and woodlots have the highest CO₂ removal rates, 4.5–40.7 t-CO₂/ha·y during the first 20 years of growth.
- Mangrove tree restoration was the second with rates up to 23.1 t-CO₂/ha·y in the first 20 years post restoration.
- Natural regeneration removal rates were 9.1–18.8 t-CO₂/ha·y during the first 20 years of forest regeneration.
- Agroforestry has the lowest and regionally broad removal rates (10.8–15.6 t-CO₂/ha·y)

Table 1 Removal factors (tons CO₂ ha⁻¹ year⁻¹) and associated uncertainty (C95) of the planted forests and woodlots FLR and subcategories, for stand ages of 0–20 years old

<table>
<thead>
<tr>
<th>Planted species</th>
<th>Climatic region</th>
<th>Removal rate (t CO₂ ha⁻¹ year⁻¹)</th>
<th>Half C95</th>
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<tr>
<td>Oak</td>
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<td>Tropical, dry</td>
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<td>Broadleaf⁶</td>
<td>Broadleaf</td>
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<td></td>
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<td>Conifer⁶</td>
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<tr>
<td></td>
<td>Tropical, humid</td>
<td>23.6</td>
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</tr>
<tr>
<td></td>
<td>Tropical, dry</td>
<td>38.7</td>
<td>2.5</td>
</tr>
</tbody>
</table>

* Excluding eucalyptus and teak
⁶ Excluding pine

Fig. 2 Carbon sequestration rate (tons CO₂ ha⁻¹ year⁻¹) of the six plantations and woodlots groups. a. Broadleaf excluding eucalyptus and teak, b. eucalyptus, c. teak, d. oak, e. pine, and f. conifer, excluding pines during the first 20 years of tree growth. Light green represents aboveground biomass, while dark green represents belowground biomass. Error bars indicate the C95 of the total biomass growth. Different bars within graphs represent climatic regions.

Fig. 3 Carbon sequestration rate (tons CO₂ ha⁻¹ year⁻¹) of a. natural regeneration FLR, b. agroforestry FLR, and c. mangrove restoration FLR. Green colors represent rates during the first 20 years of tree growth (aboveground biomass in light green, belowground biomass in dark green), while orange colors represent rates during 30–60 years of tree growth (aboveground biomass in light orange, belowground biomass in dark orange). Error bars indicate the C95 of the total biomass growth. Different bars within graphs represent FLR categories.
Thank you.

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