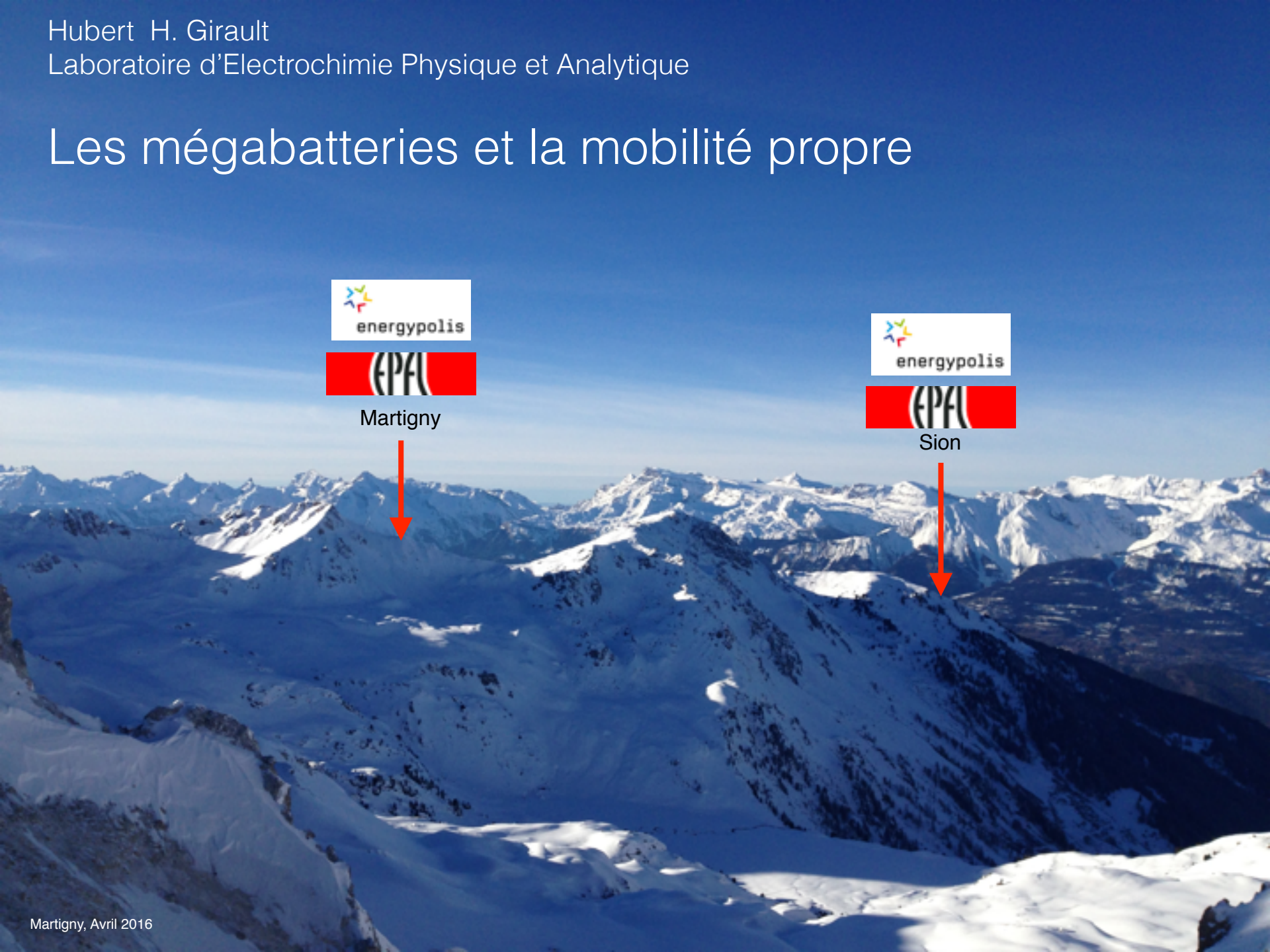
Hubert H. Girault
Laboratoire d'Electrochimie Physique et Analytique

Les mégabatteries et la mobilité propre

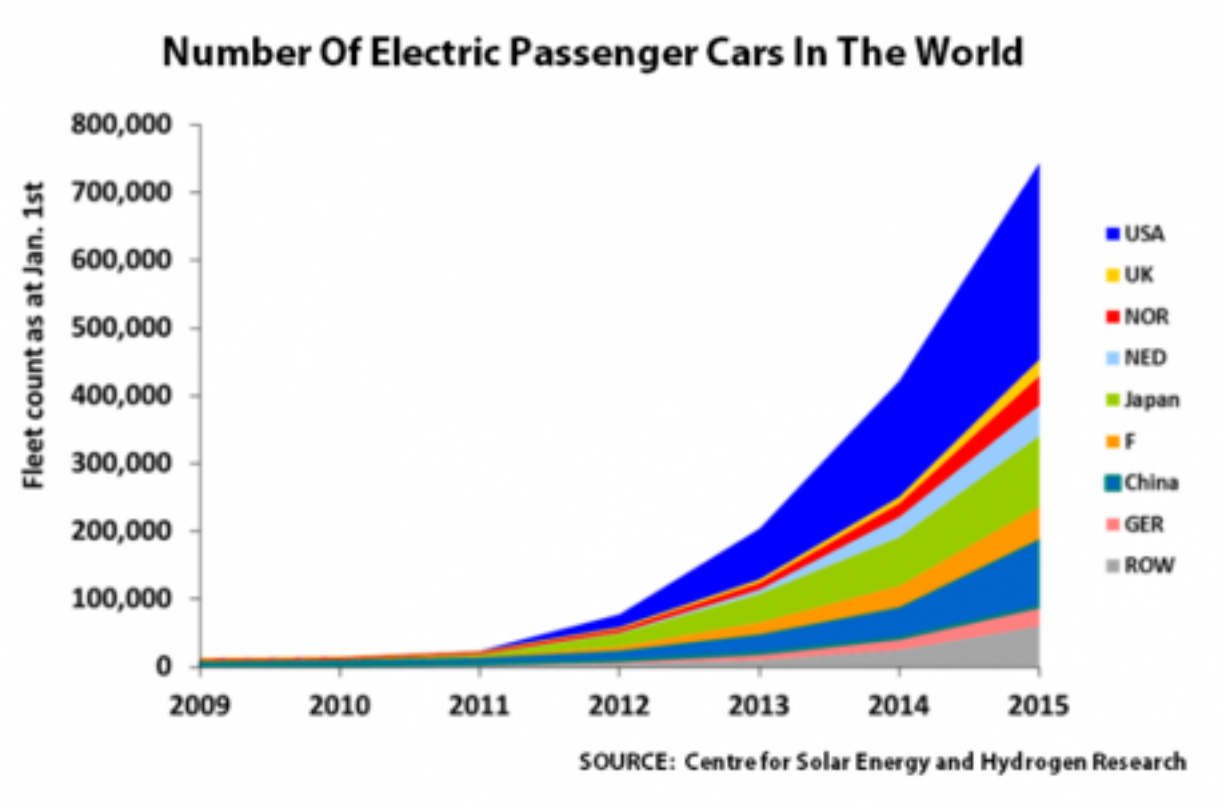


Martigny, Avril 2016

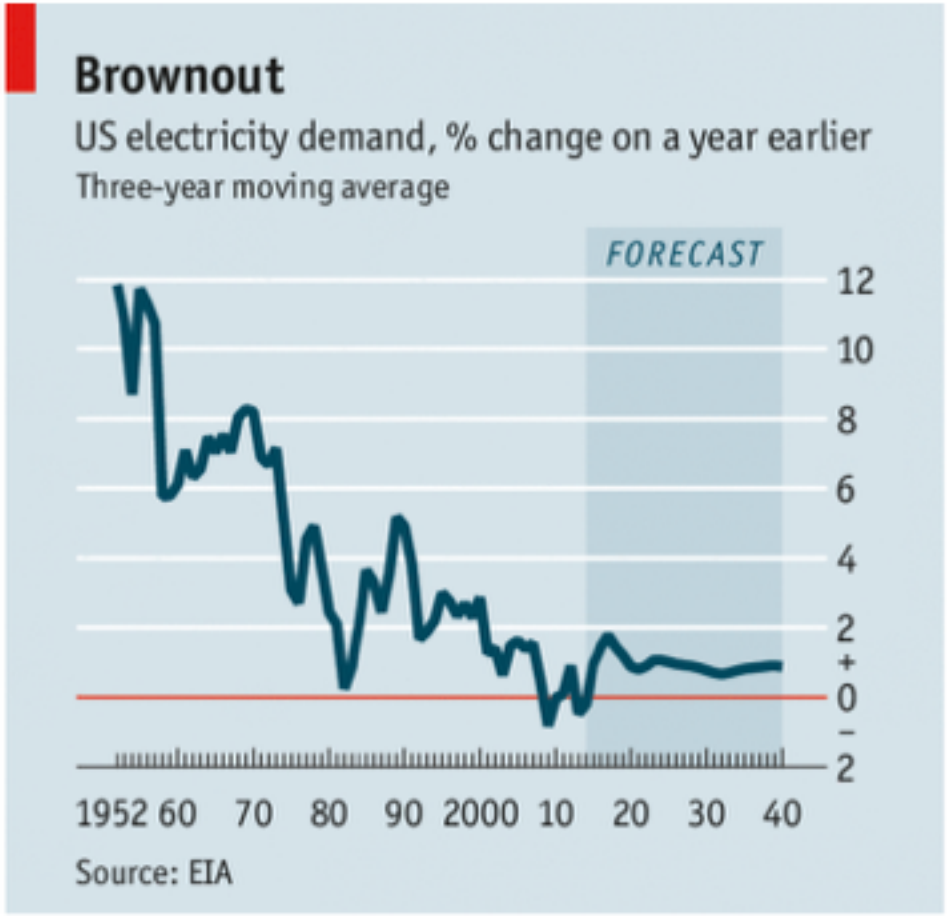
Electric vehicles

"I think electrification is not a question of 'I want it or don't want it.' **Electrification is happening**," said Carlos Ghosn.
"We are obviously precipitating it. We are accelerating it, because we believe in it. We can't just say there is a risk behind electrification – the risk is not to partner or not to participate, or to contribute, or to understand. The trend is coming,"

January 25th, 2016



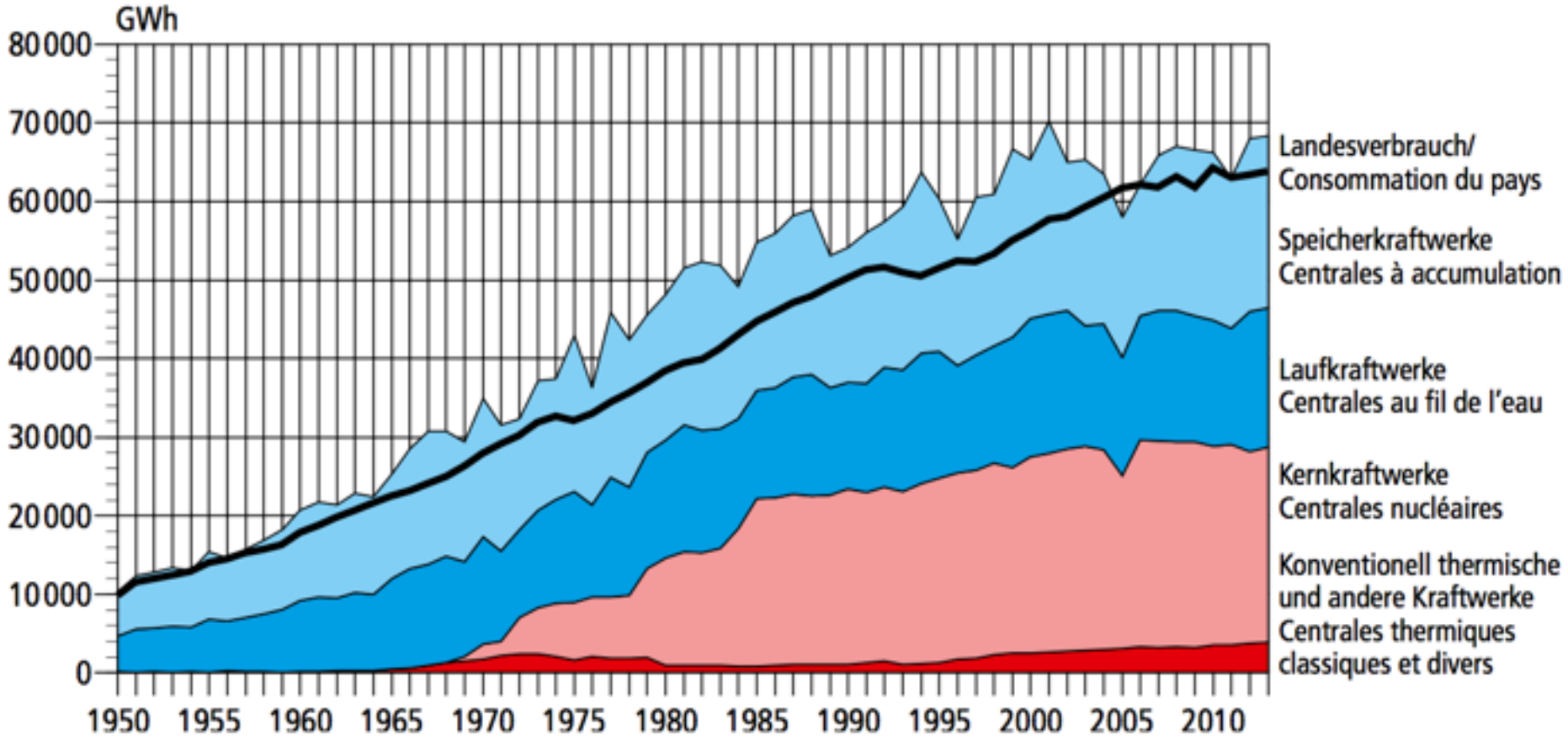
Electric cars could help save power utilities from a “death spiral”



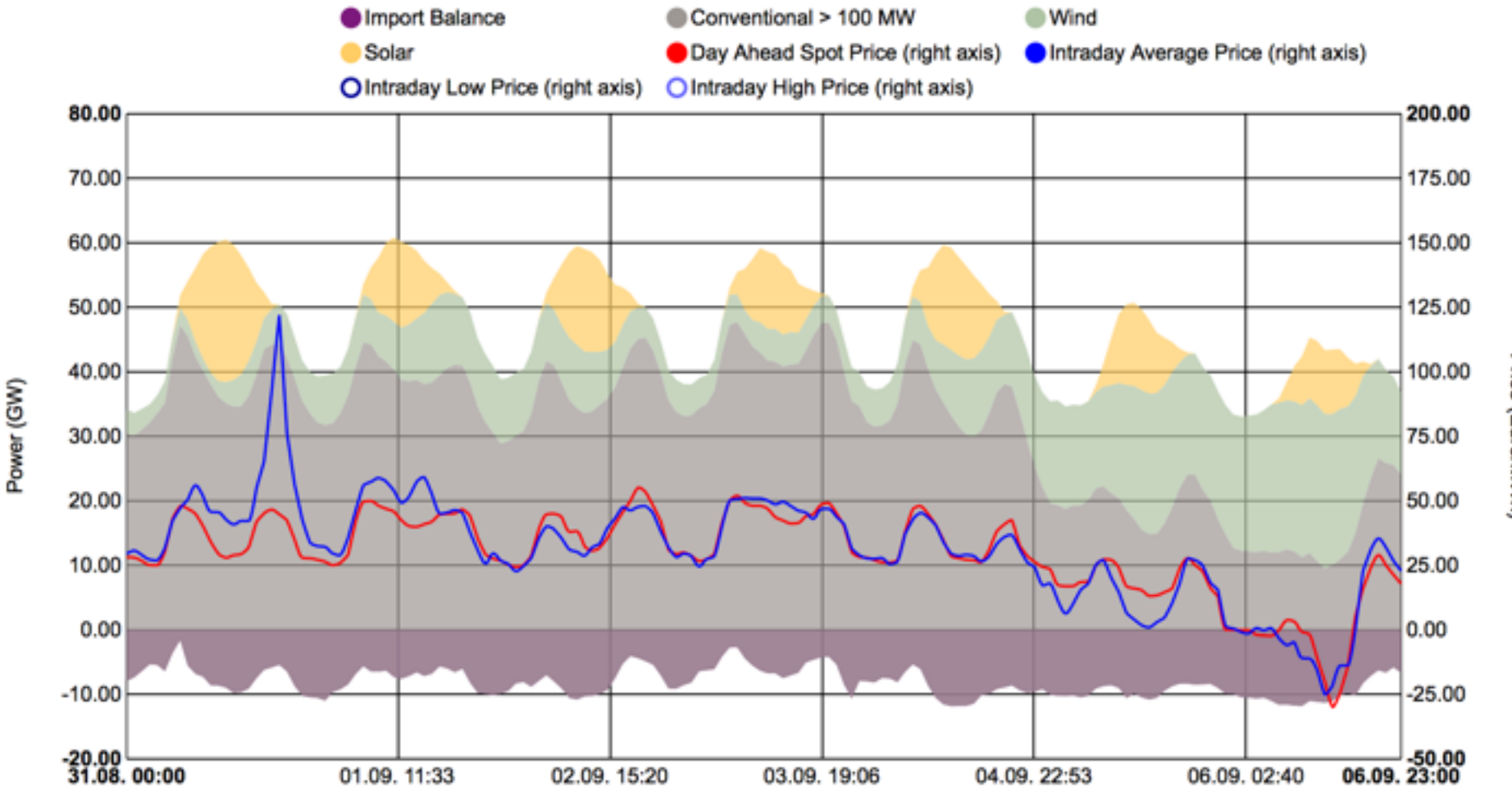
Today, Americans’ daily spending on energy can be split into two large chunks: about $1 billion on electricity and $1.4 billion on fuel for their vehicles. In the past, electricity providers had no way to tap into the latter market. Plug-in cars (and fuel cell cars) should change that.

http://www.economist.com/news/business/21621850-electric-cars-could-help-save-power-utilities-death-spiral-adapting-plug-ins

Swiss Electricity



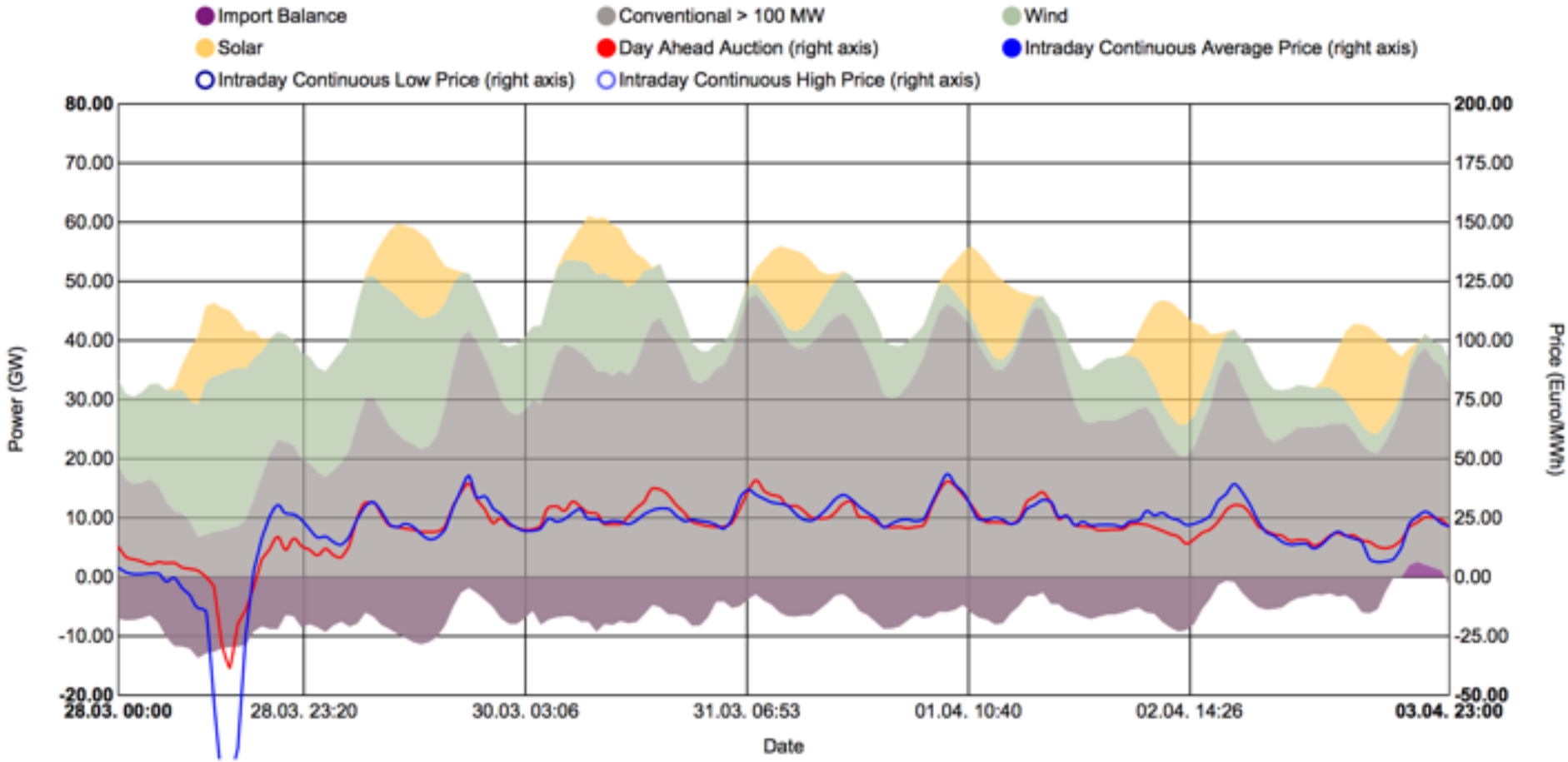
German Electricity production



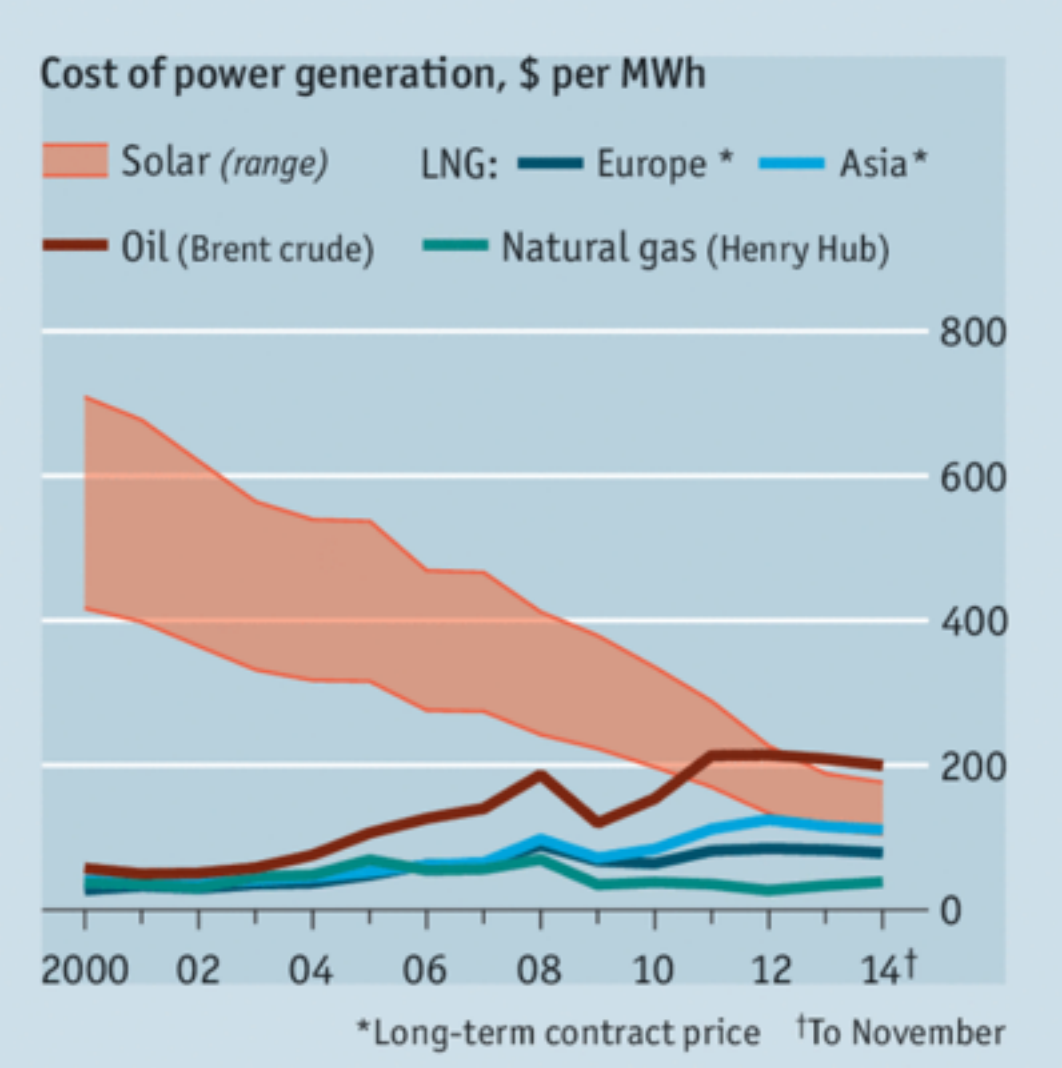
One buys 1 MWh at 25 € and sells 600 kWH at 50 € : Profit = 5 €

Average Swiss Power 8 GW

Last week…


Import Balance
Conventional > 100 MW
Wind
Solar
Day Ahead Auction (right axis)
Intraday Continuous Average Price (right axis)
Intraday Continuous Low Price (right axis)
Intraday Continuous High Price (right axis)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
-25.00
-50.00
Power (GW)
Price (Euro/MWh)
28.03. 00:00
28.03. 23:20
30.03. 03:06
31.03. 06:53
01.04. 10:40
02.04. 14:26
03.04. 23:00
Date

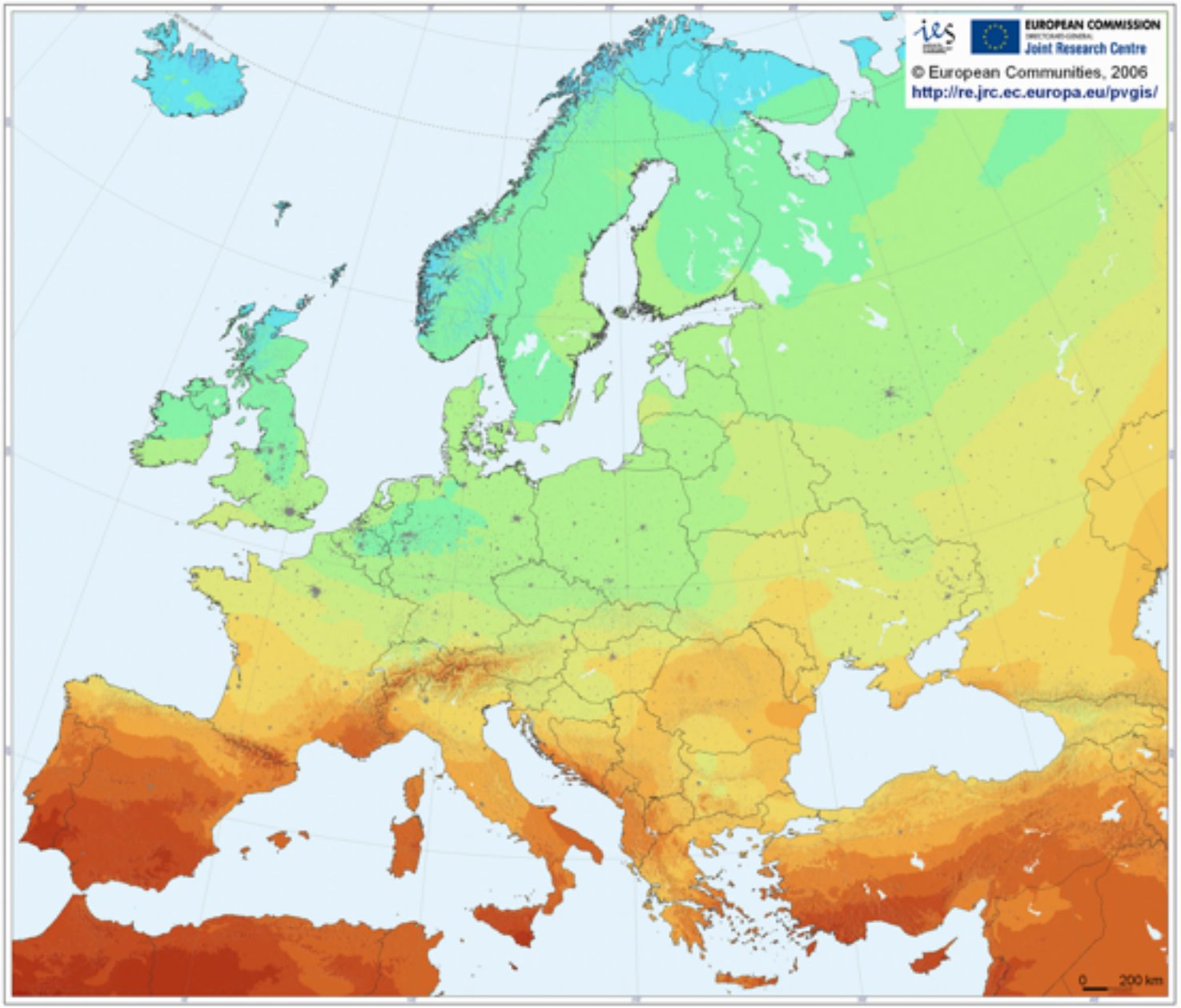
The beginning of a new era…



Apr 11th 2015

The Economist

Photovoltaic Solar Electricity Potential in European Countries



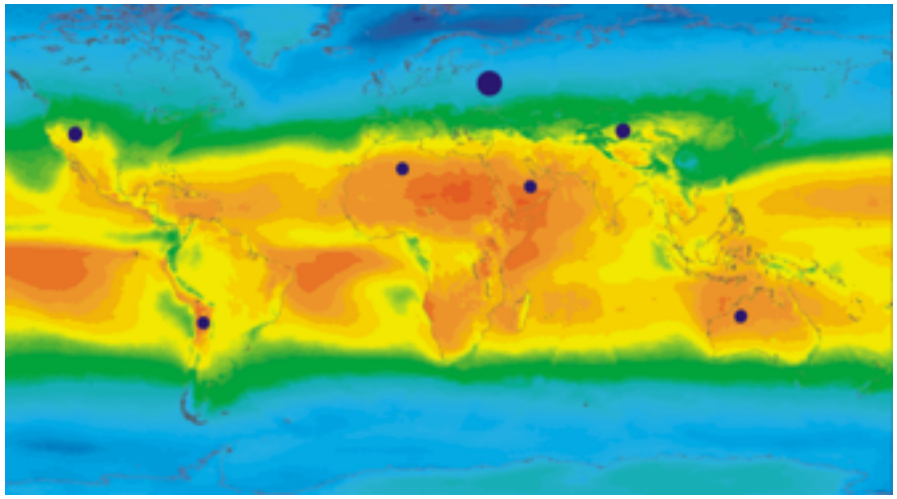
Yearly sum of global irradiation incident on optimally-inclined south-oriented photovoltaic modules

Global irradiation [kWh/m²]
<600 800 1000 1200 1400 1600 1800 2000 2200>

Yearly sum of solar electricity generated by 1 kWp system with optimally-inclined modules and performance ratio 0.75

<450 600 750 900 1050 1200 1350 1500 1650>
Solar electricity [kWh/kWp]

Solar irradiation and energy consumption



The Sheffield Solar Farm

NASA

1% of Switzerland

Gries Mountain 2,465 meters above sea level

The new turbine at Gries, Switzerland, is higher than any other in Europe. The site was chosen because of the good electrical connection at the adjacent hydro-dam. Photo: obs/SIG Services Industriels de Genève

Energy Conversion

Storage

Solar

Chemical

Mechanical

Electrical

Photosynthesis

Water splitting

CO_2 reduction

H_2

Coal
Gas
Oil

CO_2

Hydro

Grid

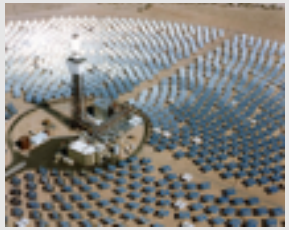
Oil

Electrolysis

Wind

Tide

Solar thermal



Photovoltaics

Fuel Cells

Batteries

Nuclear 40%
Import
> 8 months a year

e-fuelling

Solar

Chemical

Electrical

Grid

H_2

Electrolysis

Photovoltaics

Batteries

Energypolis - Martigny

From electricity to fuel

H_2 storage

H_2

Fuel cell car

www.auctigo.com

O_2

Redox flow battery

Electrolyser

DC Fast charge

Electric car

www.earthtimes.org

50 kWh = 1 kg hydrogen

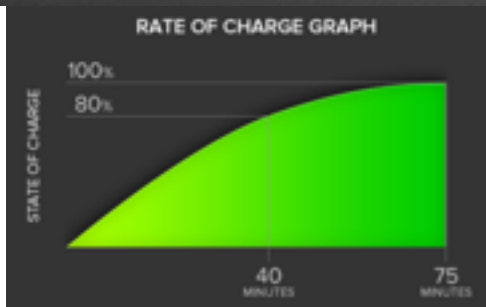
How to fuel electric cars?

Slow charge vs Fast charge

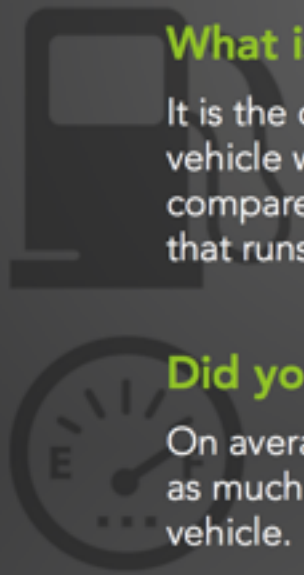
Charging time for 100 km of BEV range	Power supply	Voltage	Max current
6–8 hours	Single phase - 3.3 kW	230 VAC	16 A
2–3 hours	Three phase - 10 kW	400 VAC	16 A
3–4 hours	Single phase - 7 kW	230 VAC	32 A
1–2 hours	Three phase - 22 kW	400 VAC	32 A
20–30 minutes	Three phase - 43 kW	400 VAC	63 A
20–30 minutes	Direct current - 50 kW	400 - 500 VDC	100 - 125 A
10 minutes	Direct current - 120 kW	300 - 500 VDC	300 - 350 A

Wikipedia

60 or 85 kWh microprocessor controlled, lithium-ion battery
120 kW Supercharger, 50% charge in 20 min, 80% in 40 min



eGallon: Compare the costs of driving with electricity



What is eGallon?

It is the cost of fueling a vehicle with electricity compared to a similar vehicle that runs on gasoline.

Did you know?

On average, it costs about half as much to drive an electric vehicle.

Find out how much it costs to fuel an electric vehicle in your state

US Average

regular gasoline	2.07
electric eGallon	1.09

Data and Methodology
Updated: April 02, 2016

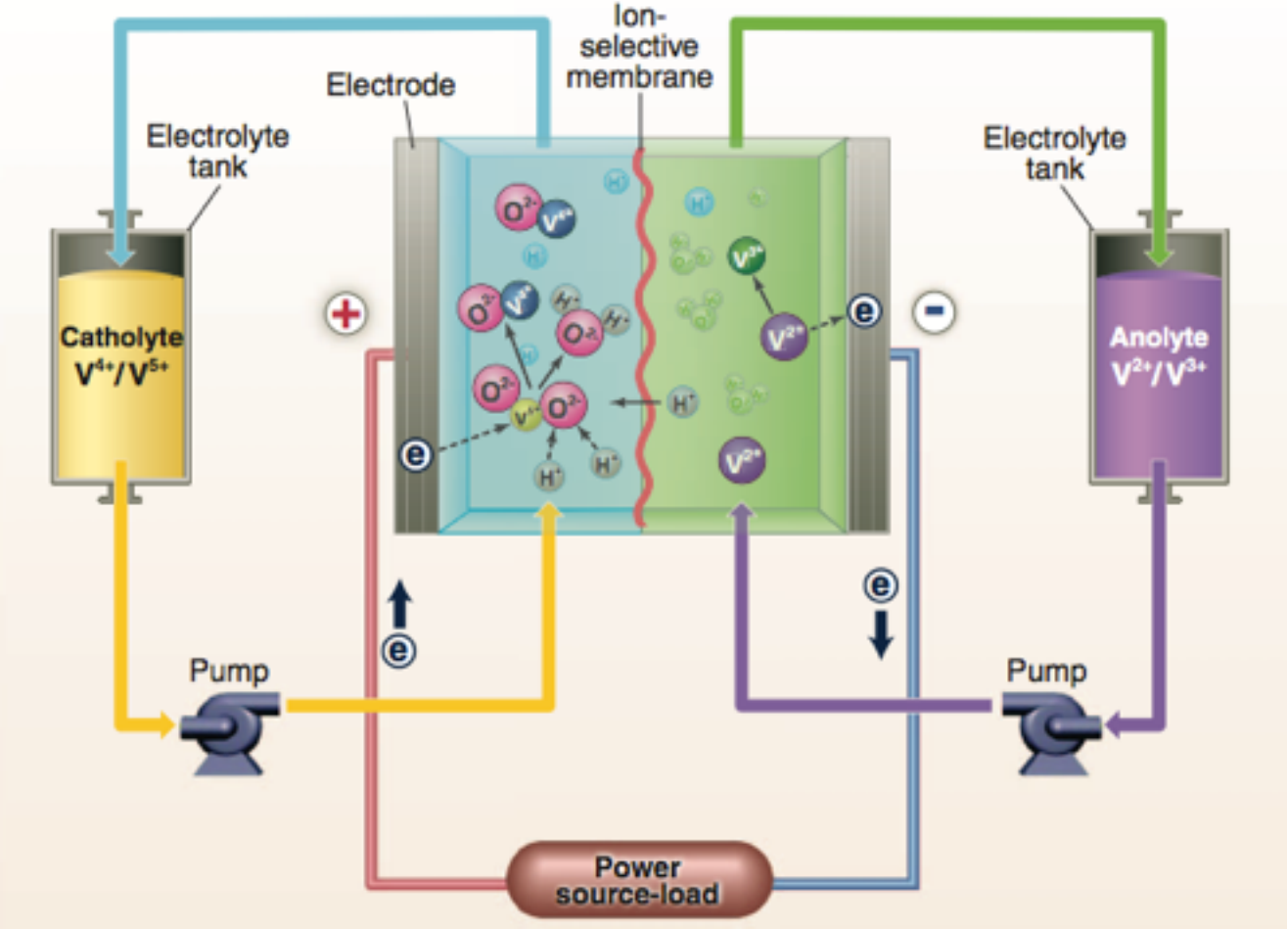
The eGallon price is calculated using the most recently available state by state residential electricity prices. The state gasoline price above is either the statewide average retail price or a multi-state regional average price reported by EIA. The latest gasoline pricing data is available on EIA's webpage. Find out more at www.energy.gov/eGallon.


Fuel Cell

Redox Flow Battery

Charge, reduction of V(III) to V(II) & oxidation of V(IV) to V(V)

Discharge, oxidation of V(II) to V(III) & reduction of V(V) to V(IV)

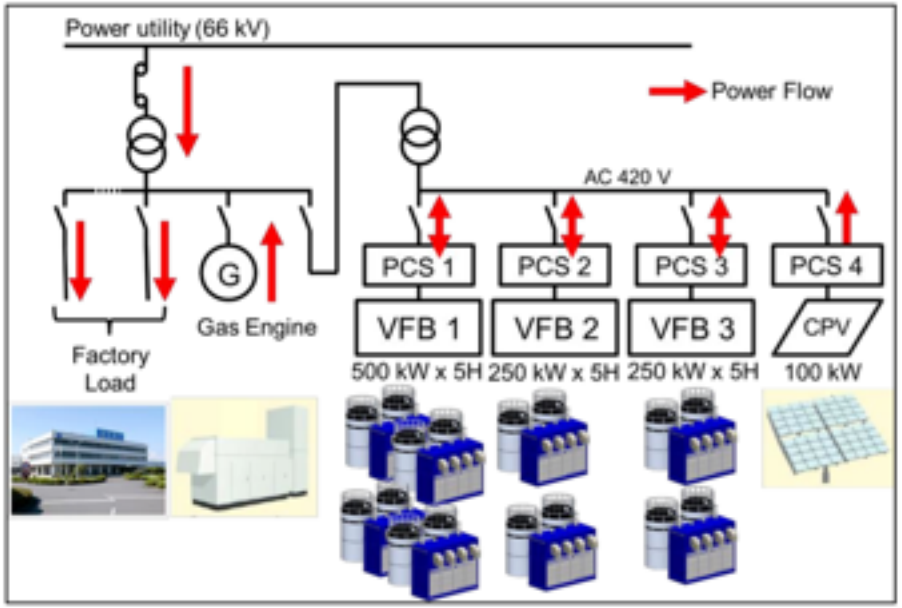


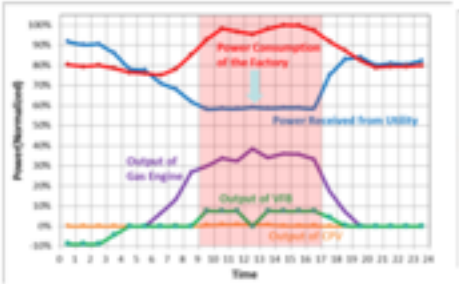
Science 334(6058), 928–935 (Nov. 2011).

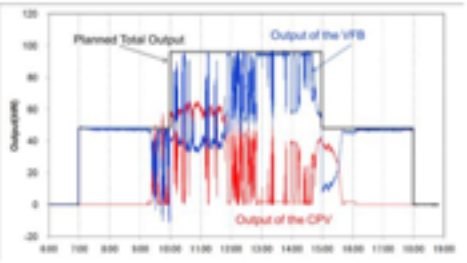
Maria Skyllas-Kazacos (1985)
University of New South Wales, Australia

Sumitomo Yokohama Works

- 2012/7 -
- LL & Peak shaving, Smoothing PV output and Time shift of PV output
- Maximum AC Output : 1 MVA = 0,5 MVA + 0,25 MVA + 0,25 MVA
- Rated Energy Capacity : 5 MWh = 2,5 MWh + 1,25 MWh + 1,25 MWh

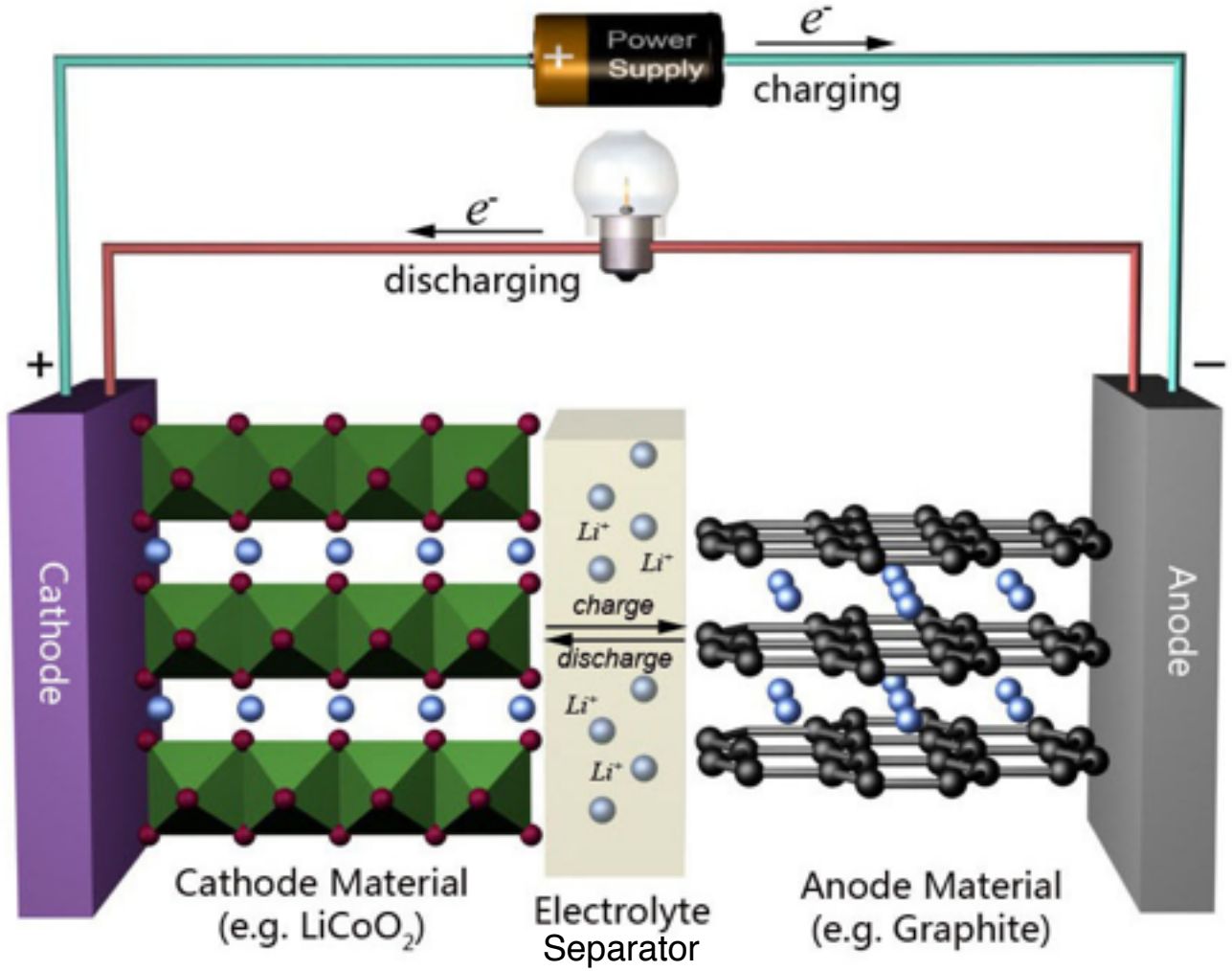






SUMITOMO ELECTRIC

Lithium battery



http://www.scs.illinois.edu/murphy/Ran/research/energystorage.html

Citigroup estimates a 240GW global market for energy storage worth more than $400 billion by 2030. That is excluding car batteries.

TESLA

Technology
Wall mounted, rechargeable lithium ion battery with liquid thermal control.

Models
10 kWh $3,500
For backup applications

7 kWh $3,000
For daily cycle applications

Warranty
Ten year warranty with an optional ten year extension.

Efficiency
92% round-trip DC efficiency

Power
2.0 kW continuous, 3.3 kW peak

Voltage
350 – 450 volts

Current
5 amp nominal, 8.5 amp peak output

Compatibility
Single phase and three phase utility grid compatible.

Operating Temperature
-4°F to 110°F / -20°C to 43°C

Enclosure
Rated for indoor and outdoor installation.

Installation
Requires installation by a trained electrician. AC-DC inverter not included.

Weight
220 lbs / 100 kg

Dimensions
52.1" x 33.9" x 7.1"
130 cm x 86 cm x 18 cm

Certifications
UL listed

Leclanché

The following powers can be selected directly:

Power	Connection voltage	Battery capacity
100 kW	400 V / AC / 50 Hz	>= 60 kWh
150 kW	400 V / AC / 50 Hz	>= 60 kWh
200 kW	400 V / AC / 50 Hz	>= 100 kWh
250 kW	400 V / AC / 50 Hz	>= 150 kWh
500 kW	Mittelspannung 10 kV / 20 kV	>= 250 kWh
650 kW	Mittelspannung 10 kV / 20 kV	>= 300 kWh
1.000 kW	Mittelspannung 10 kV / 20 kV	>= 500 kWh
1.300 kW	Mittelspannung 10 kV / 20 kV	>= 600 kWh

Redox Flow Batteries

Advantages

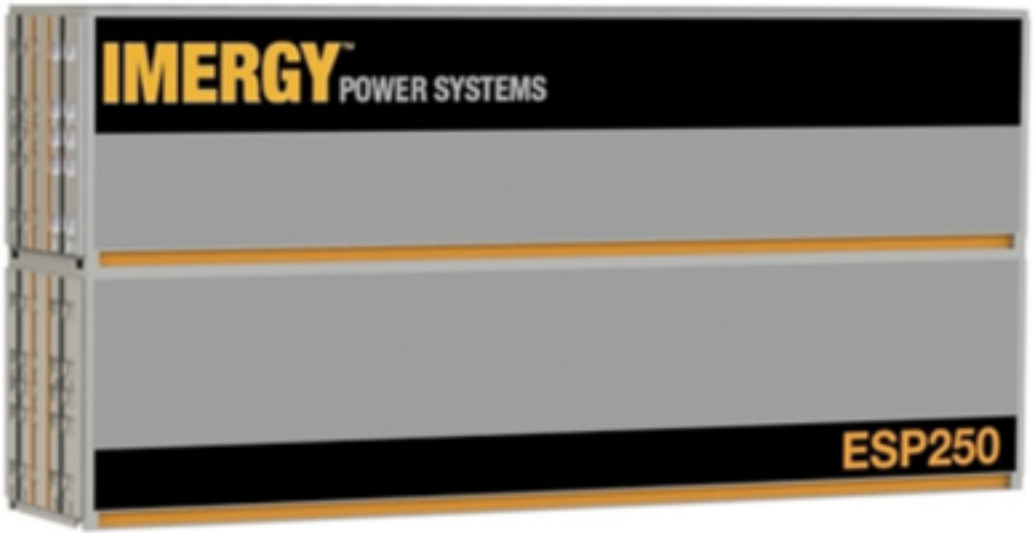
- Power independent of the energy capacity
- High flexibility
- Easy use
- Long lifetime
- **Safe**
- Short response time

Limitations

- **Low specific and volumetric energy**
- Electrode stability under deep charge and deep discharge
- Cost

Vanadium redox flow battery

IMERGY ESP30™ SERIES
30-50kW, 120-200kWh



Vanadium redox flow battery

2015 Uni.System.AC™: 500kW/4h; 600kW$_{peak}$; 2.2MWh$_{max}$

Uni.System.AC™

- ✓ Temperature Agnostic
  -40 °C to +50 °C
- ✓ SOC Agnostic
  100% capacity access
  no capacity fade
- ✓ Cycle Agnostic
  20-year design life
- ✓ Factory integration
  precision assembly & QC
- ✓ Parallel Architecture
  array sizes over 20MW/acre
- ✓ Inherently Safe
  integrated 2ndry containment
  no thermal runaway
- ✓ Plug & Play
  rapid incremental deployment
- ✓ 97% Availability
  no stripping or equalizing
- ✓ 100% recyclable
  disposal contract included

Poka-yoke

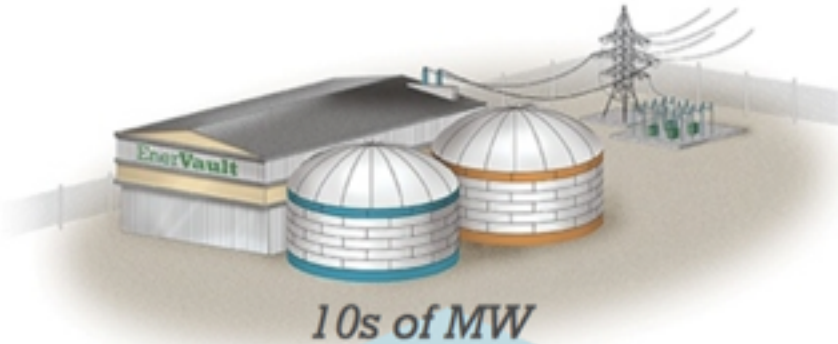
Company Overview

EnerVault
Safe, Reliable, Cost-Effective Energy Storage

Market Focus:

Long-duration = 4-12⁺ hours discharge

"Grid Scale" = power in megawatts



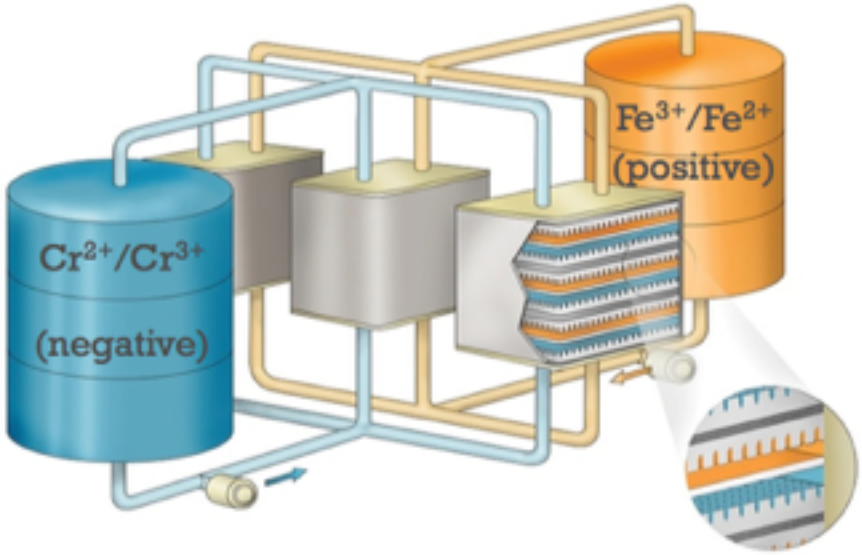
10s of MW
100s of MW-hr

Customer Benefits:

Full rated power for full rated discharge time

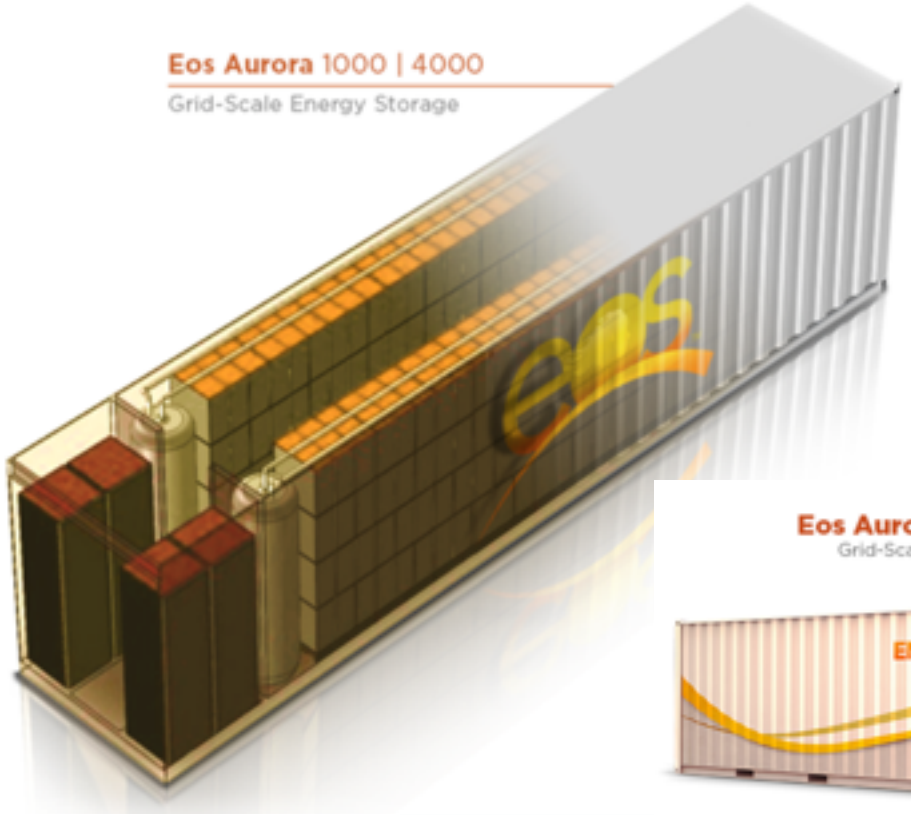
Unparalleled safety, reliability, and low cost

Power and energy matched to application



250 kW_{AC}
4 hour

Rechargeable zinc hybrid cathode battery technology



Eos's standard Aurora 1000|4000 product, a containerized 1 MW DC battery system providing four continuous hours of discharge, offers a cost-effective energy storage solution competitive with gas peaking generation and utility distribution infrastructure. The Aurora 1000|4000 will be sold at a price of **$160/kWh** in volume.

EnergyCell zinc-flow battery

PRIMUS POWER

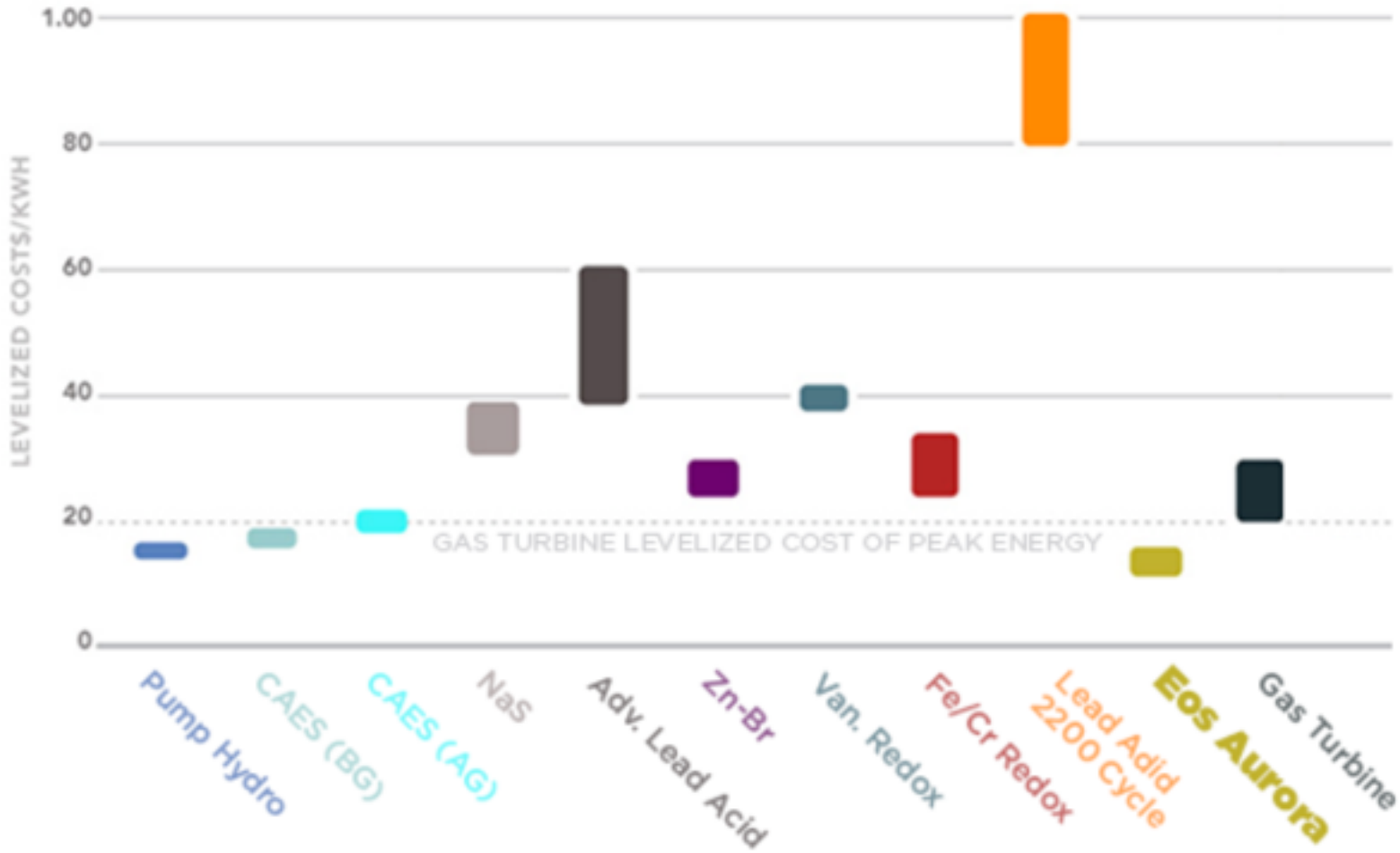
Zinc-Iron redox flow battery

"By 2018 the CapEx of ViZn Energy's 4-hour flow battery storage solution, which Energy Strategies Group uses as a proxy for the lowest cost flow battery technologies now being commercialized, is projected to be $974 per kW, or **$244 per (installed) kWh**, essentially the same as a conventional simple cycle combustion turbines (CT).

Storage will be a disruptive winner against simple cycle gas-fired CTs at that point, assuming a typical mid-range cost for competing fossil-based CT generation resources."

Megabatteries vs Gas turbines

Average cost of generating electricity over the lifetime of the system



http://www.eosenergystorage.com/technology-and-products/

From electricity to fuel

H_2 storage

H_2

Fuel cell car

www.auctigo.com

O_2

Redox flow battery

Electrolyser

DC Fast charge

Electric car

www.earthtimes.org

50 kWh = 1 kg hydrogen

UNITED STATES PATENT OFFICE.

RODOLPHE PECHKRANZ, OF CAROUGE-GENEVA, SWITZERLAND.

ELECTROLYZER.

1,415,466. Specification of Letters Patent. Patented May 9, 1922.

Application filed June 1, 1920. Serial No. 385,598.

R. PECHKRANZ.
ELECTROLYZER.
APPLICATION FILED JUNE 1, 1920.

1,415,466. Patented May 9, 1922.

Fig.1.

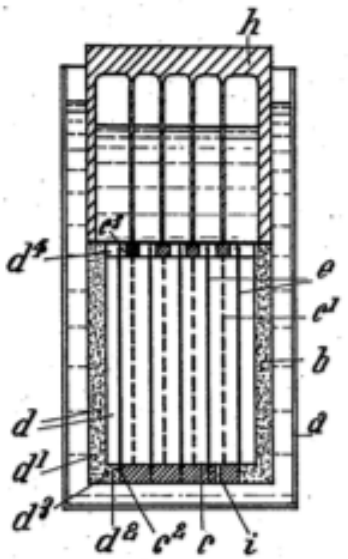
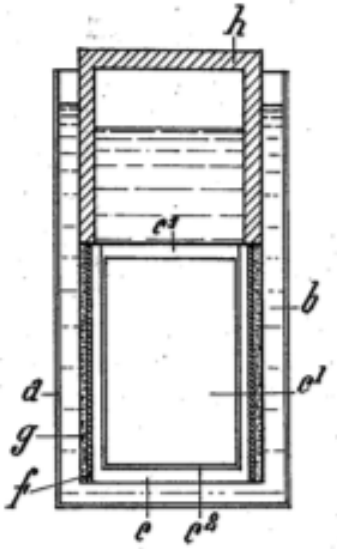
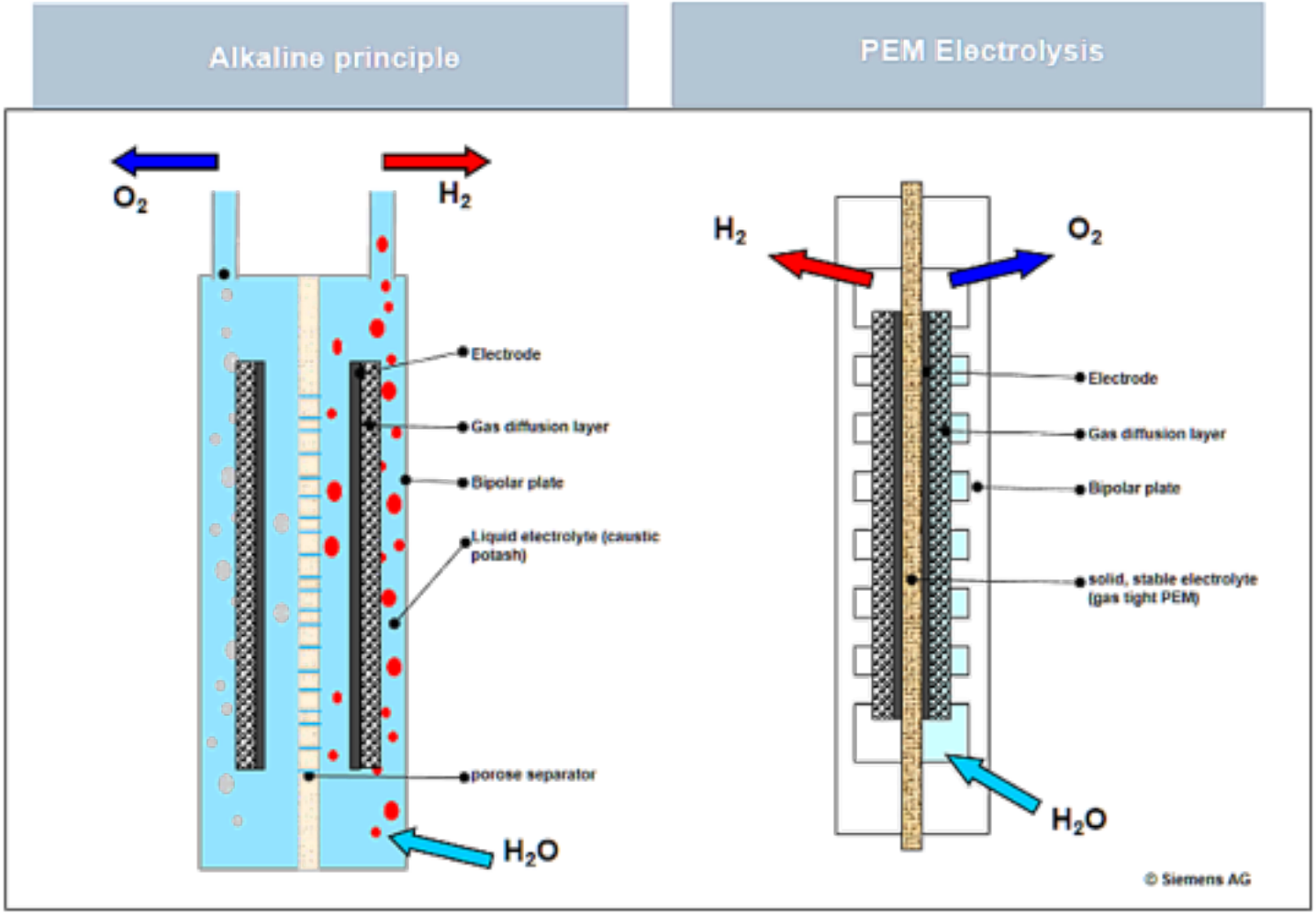


Fig2.



In the twenties, there was still no viable electrolyzer outfit for industrial-scale production of hydrogen. It was only with the discovery and development of water electrolyzers by *Pechkranz,* an engineer at *Lonza's* Valais works, that the way was opened. The electrolyzers at the Ackersand electrolysis plant were fed with di- rect current from appropriately equipped generators at the company's power station. Altogether, Visp and Ackersand produced 5800 m^3 hydrogen per hour.

Alkaline - PEM



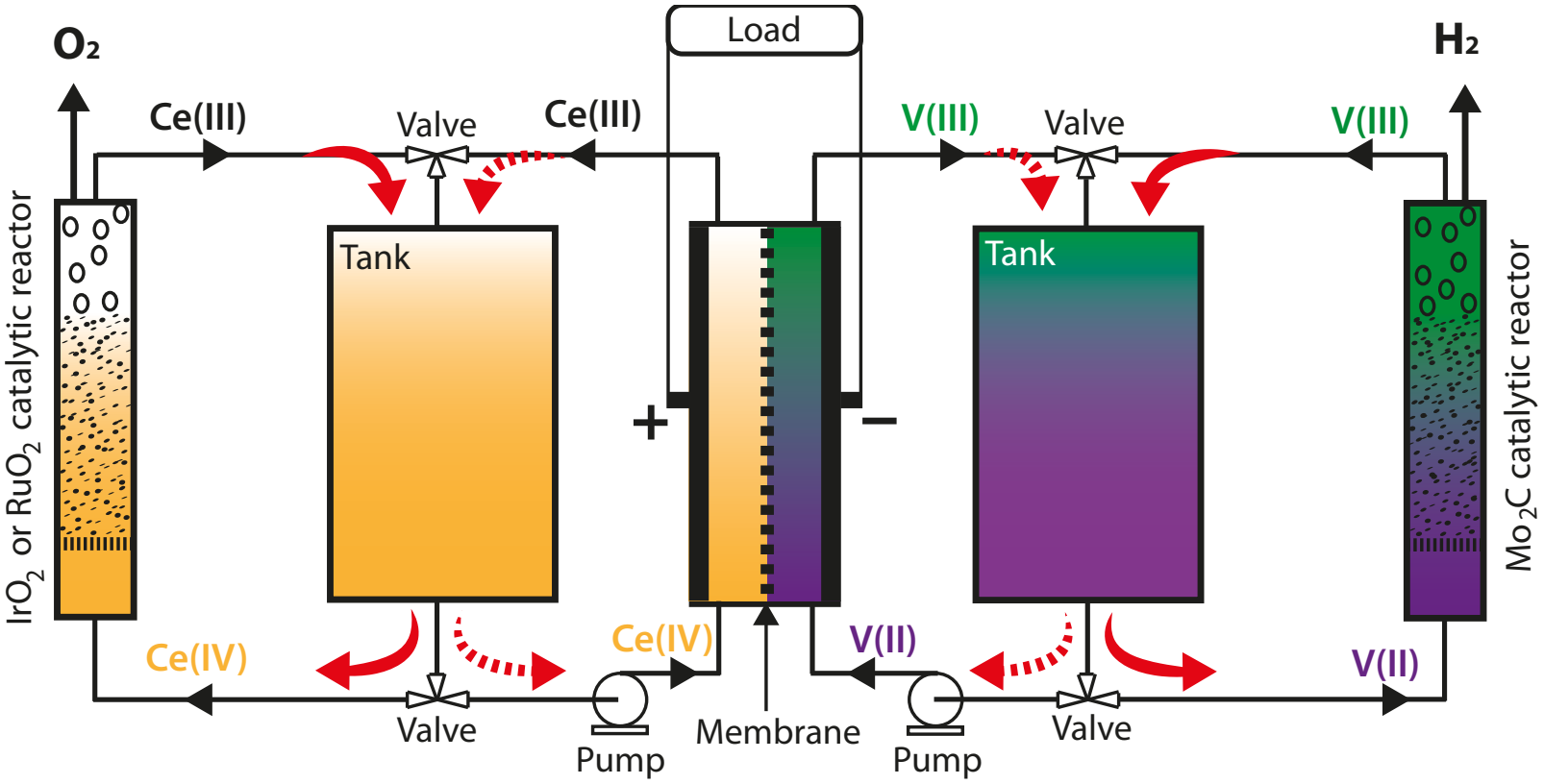
Alkaline Electrolysers

Martigny

PEM Electrolysers

EMPA

V–Ce RFB for water electrolysis

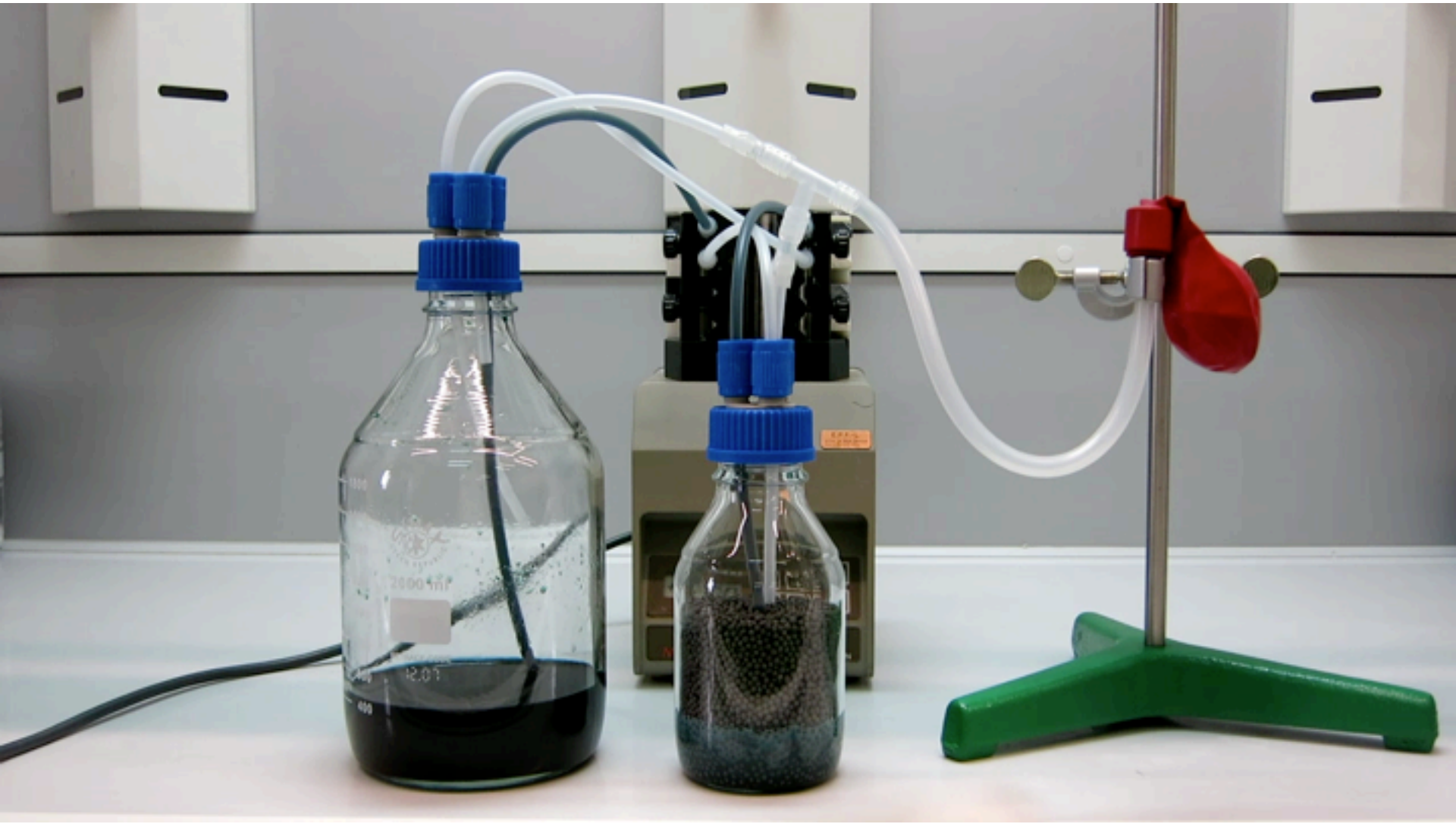


Ce-V redox flow battery : conventional electrochemical discharge

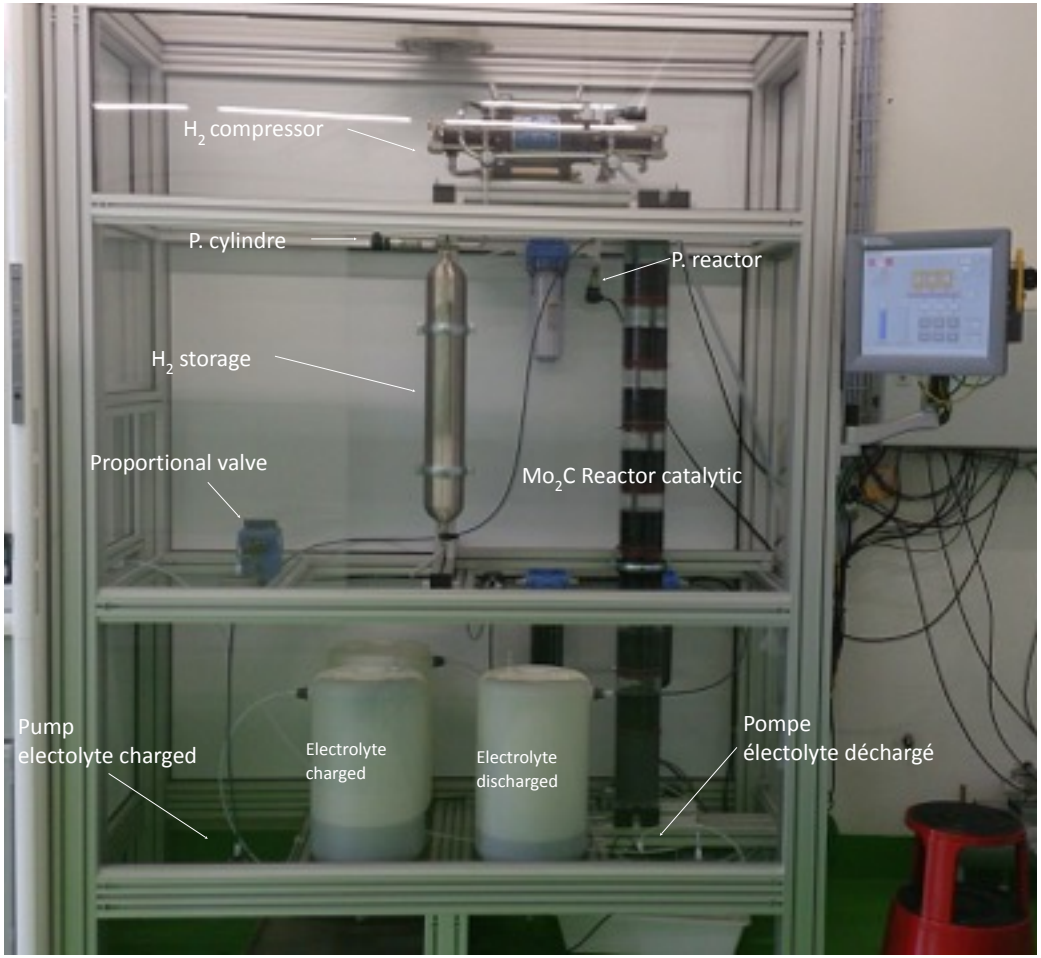
Dual-circuit system : discharge via two catalysed chemical reactions

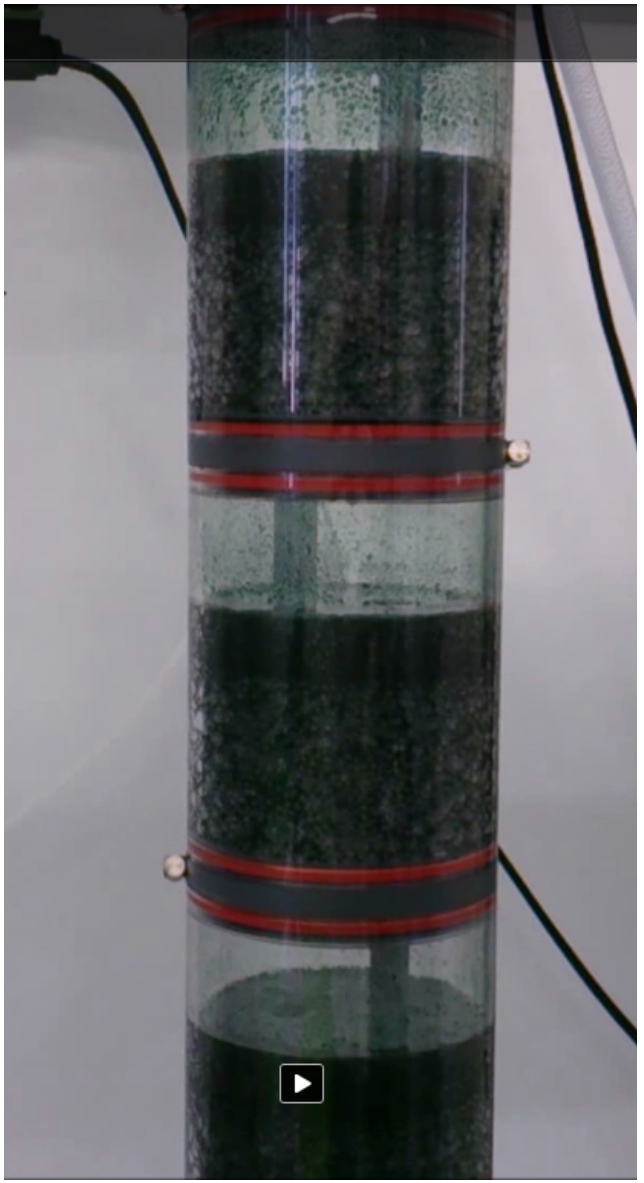
50 kWh = 1 kg hydrogen

Mo_2C on ceramics

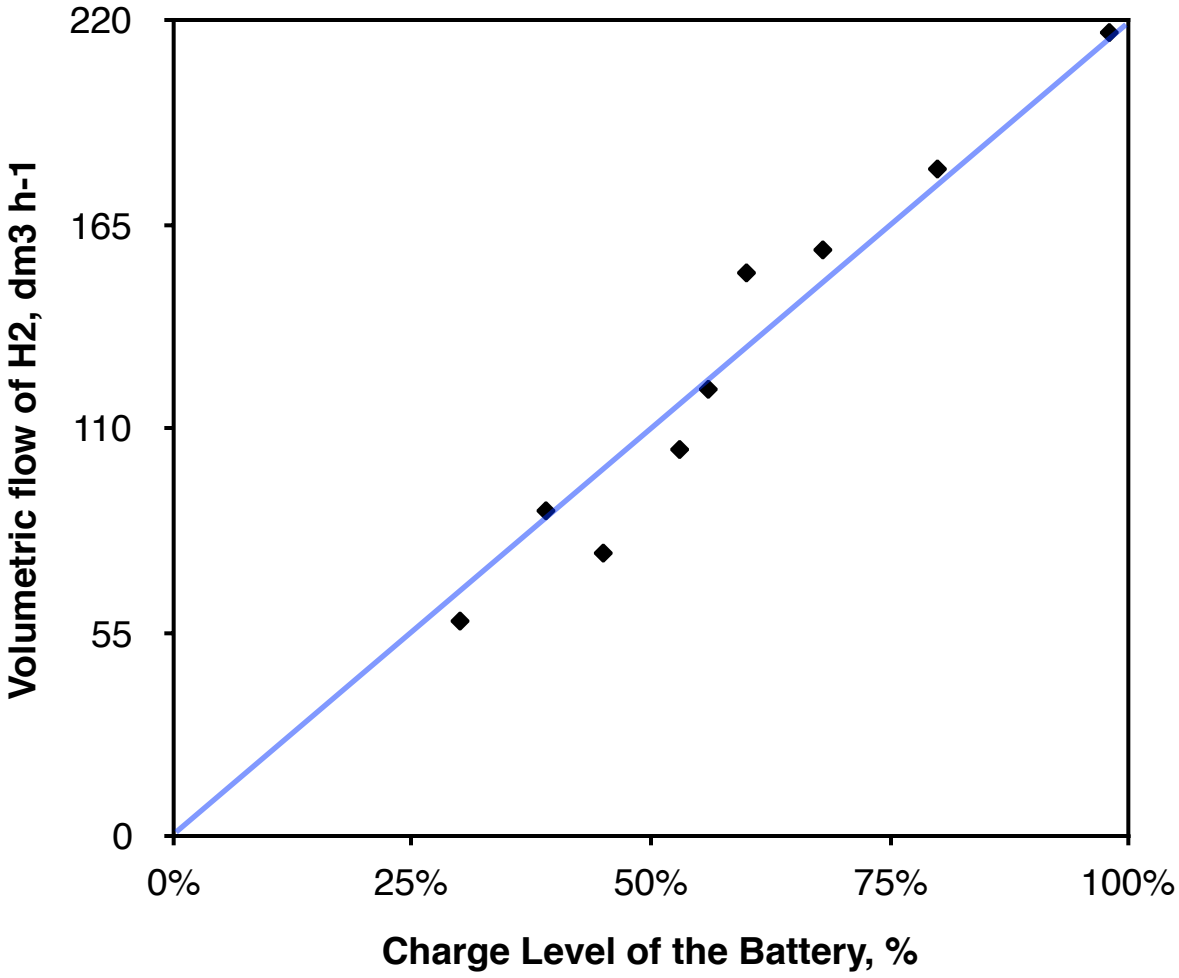


Hydrogen Production Reactor

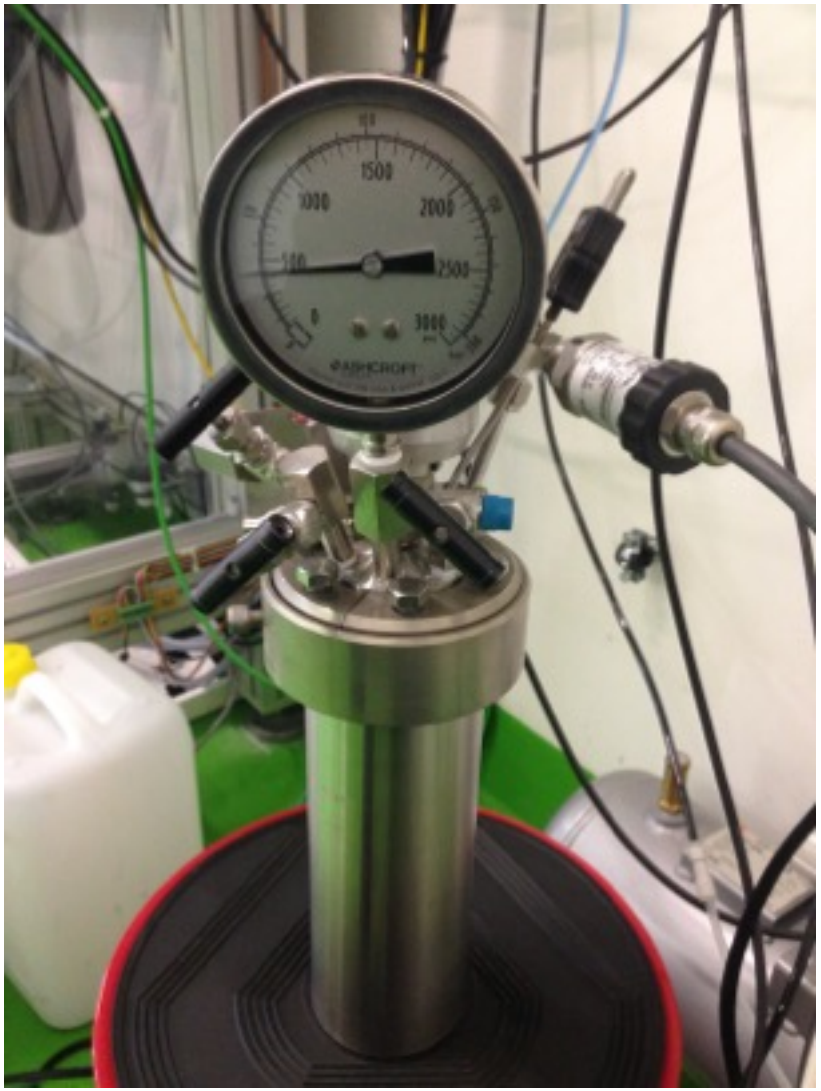




Hydrogen Production



Hydrogen Production under pressure



150 bars

New flow reactor
under construction

Sorry, we do not have any H_2 yet…

Fuel cells useful as range extenders for electric vehicles…

SWISS HYDROGEN

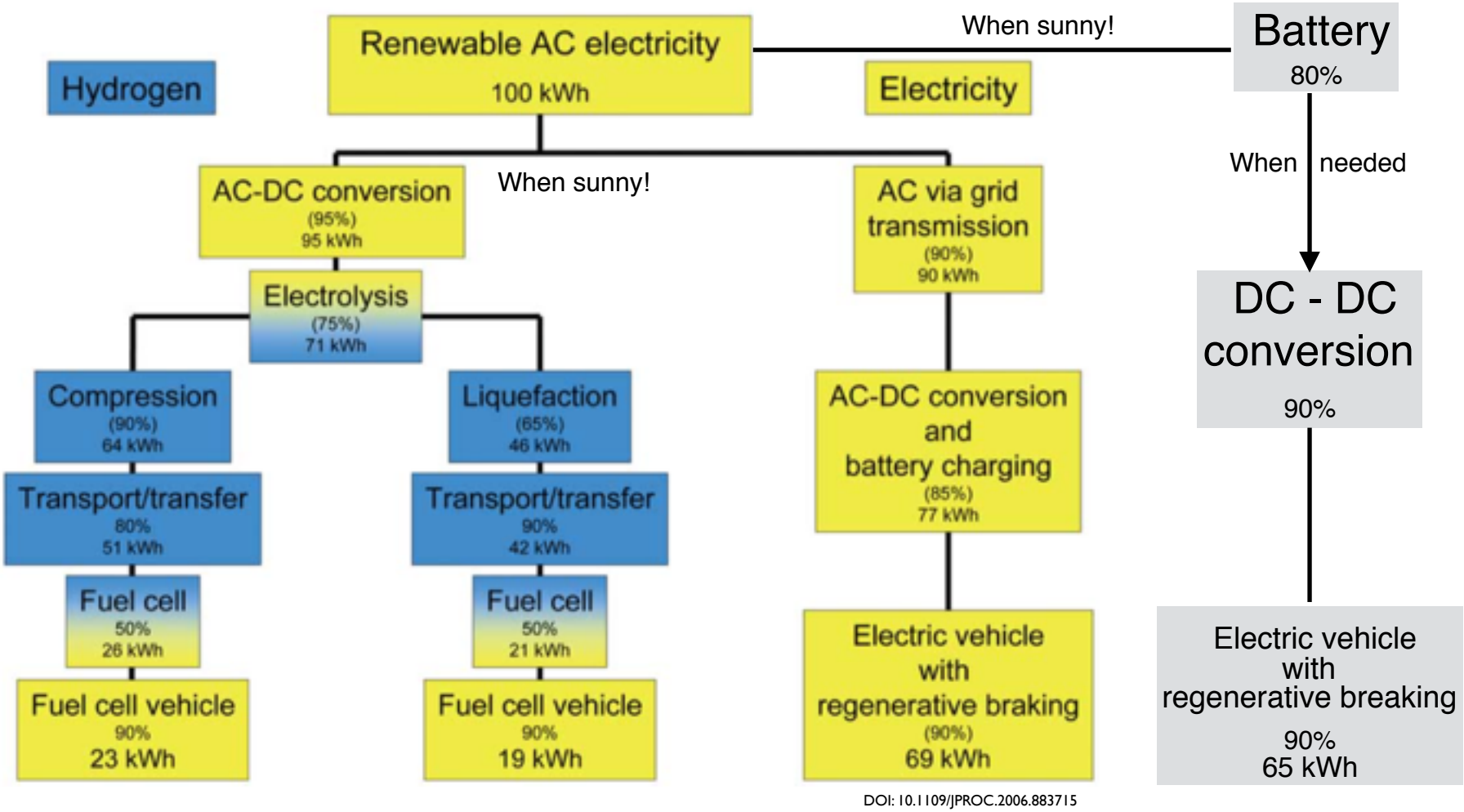
Citaro FuelCELL-Hybrid

Citaro FuelCELL Hybrid offers significant innovations: hybridisation with energy recovery and storage in lithium-ion batteries, powerful electric motors fitted in the wheel hubs with a continuous output of 120 kW, electrified PTO units

35 kg of hydrogen

The operating range of the fuel-cell bus is over 250 kilometres.

Electric cars - DC-DC charging



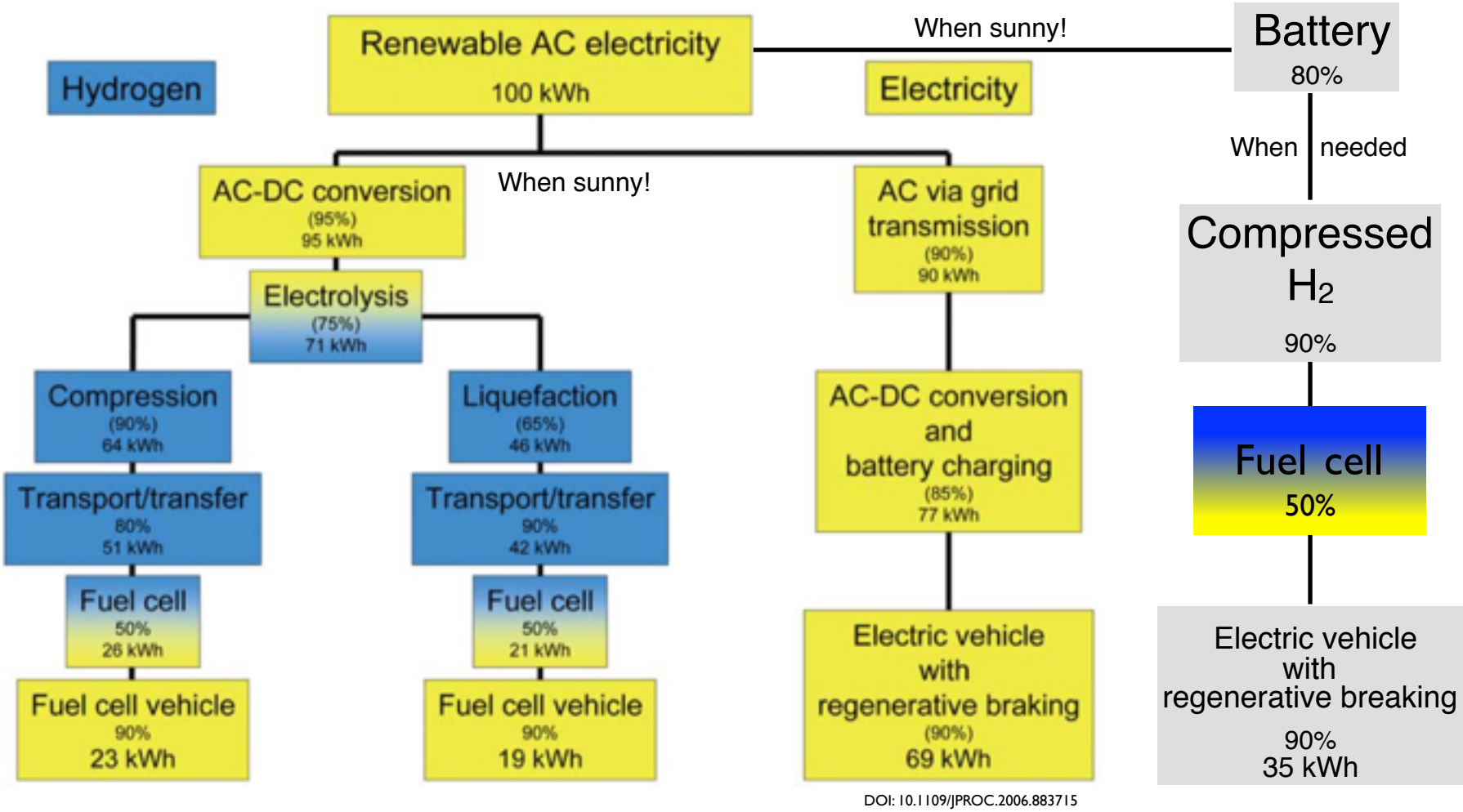
DOI: 10.1109/JPROC.2006.883715

Tank to wheel efficiency : 18 % petrol - 22% diesel

Well to wheel efficiency : 15 % petrol -18% diesel

http://ec.europa.eu/transport/themes/strategies/consultations/doc/2009_03_27_future_of_transport/20090408_eabev_(scientific_study).pdf

Electric fuel cell cars - Vanadium process



DOI: 10.1109/JPROC.2006.883715

Tank to wheel efficiency : 18 % petrol - 22% diesel

Well to wheel efficiency : 15 % petrol -18% diesel

http://ec.europa.eu/transport/themes/strategies/consultations/doc/2009_03_27_future_of_transport/20090408_eabev_(scientific_study).pdf

Mirai

Objective for mass production: 30 $ per kW of stack

Will China go for it?

Photograph: HAP/Quirky China News / Rex Feat

Conclusions

- Les voitures électriques arrivent!
- Sommes nous prêts ?
- Les mégabatteries peuvent servir à la stabilité d'un réseau alimenté en énergies renouvelables
- Les mégabatteries peuvent devenir le coeur des stations service à charge rapide (électricité et hydrogène)
- Un investissement conséquent dans le photovoltaique et les mégabatteries est le moyen d'assurer une mobilité propre

Acknowledgements:

EOS Holdings, CREM, Sinergy

Office Fédéral de l'énergie,
Fonds National Suisse