UiO : Department of Technology Systems
University of Oslo

Renewable Energy Systems

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INF5410 Lecture, 2 February 2023

Contents

- Energy Systems
  - Centralized
  - Distributed
  - Stand-Alone

- Energy Carriers
  - Electrical (Batteries)
  - Hydro carbons
  - Hydrogen

Smart Grids

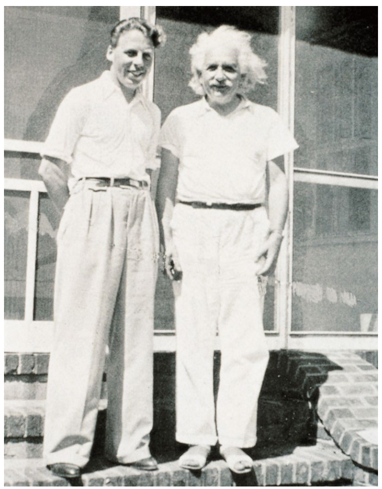
Energy Storage

Institute for Energy Technology is a non-profit foundation located in Kjeller and Halden

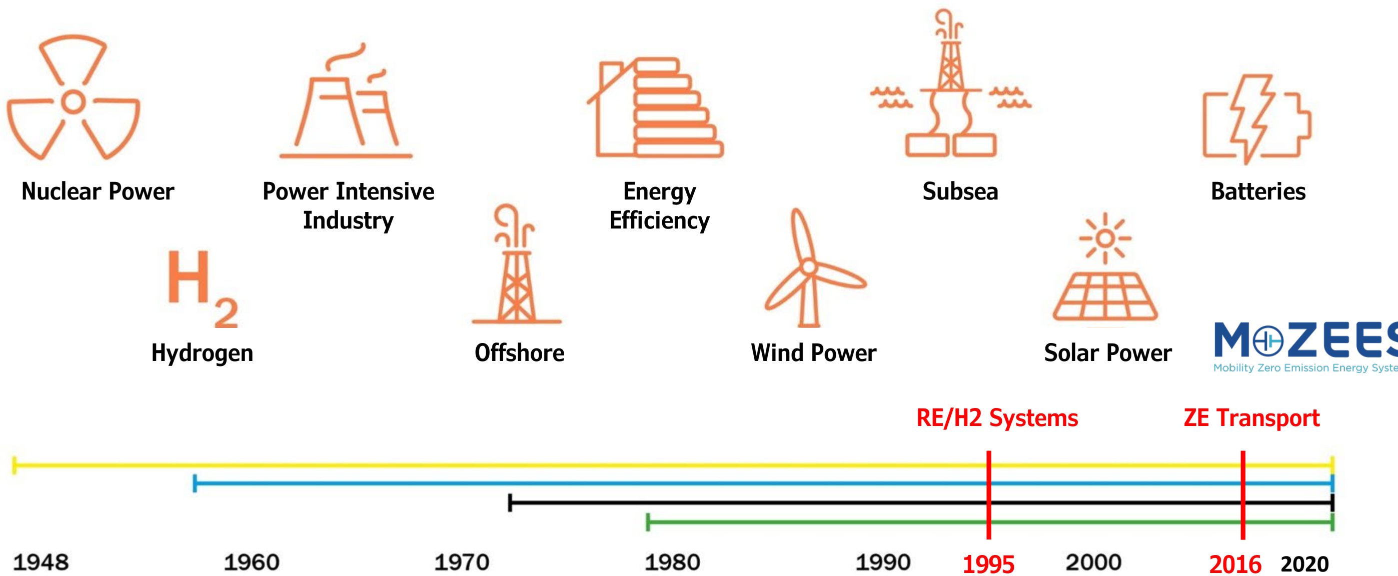
Location Kjeller

Institute for Energy Technology

IFE has contributed to the development of Norway as an energy nation for more than 70 years!

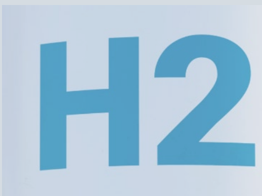


Gunnar Randers, IFE's founder



Strategic Research Areas

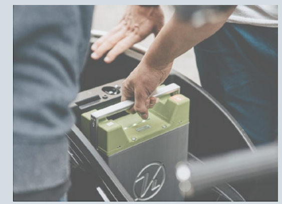
1 Hydrogen



2 Energy Systems

3 Solar PV

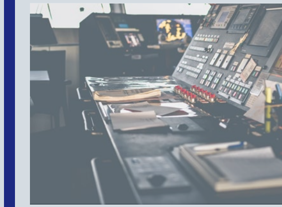
4 Battery Technology



5 CO2

6 Smart Cities

7 Nuclear Technology



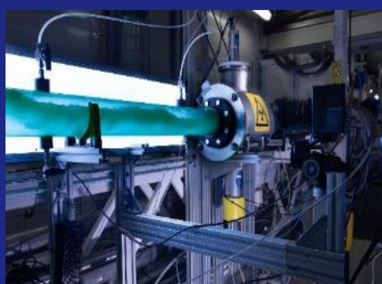
IFE – Advanced Infrastructure & Laboratories


Battery Laboratory

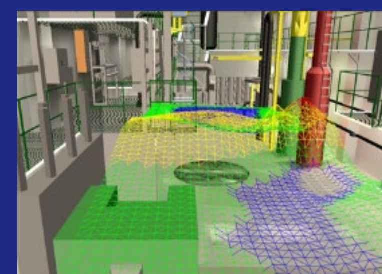

Solar Energy Laboratory


Hydrogen Laboratory


Tracer Tech Laboratory

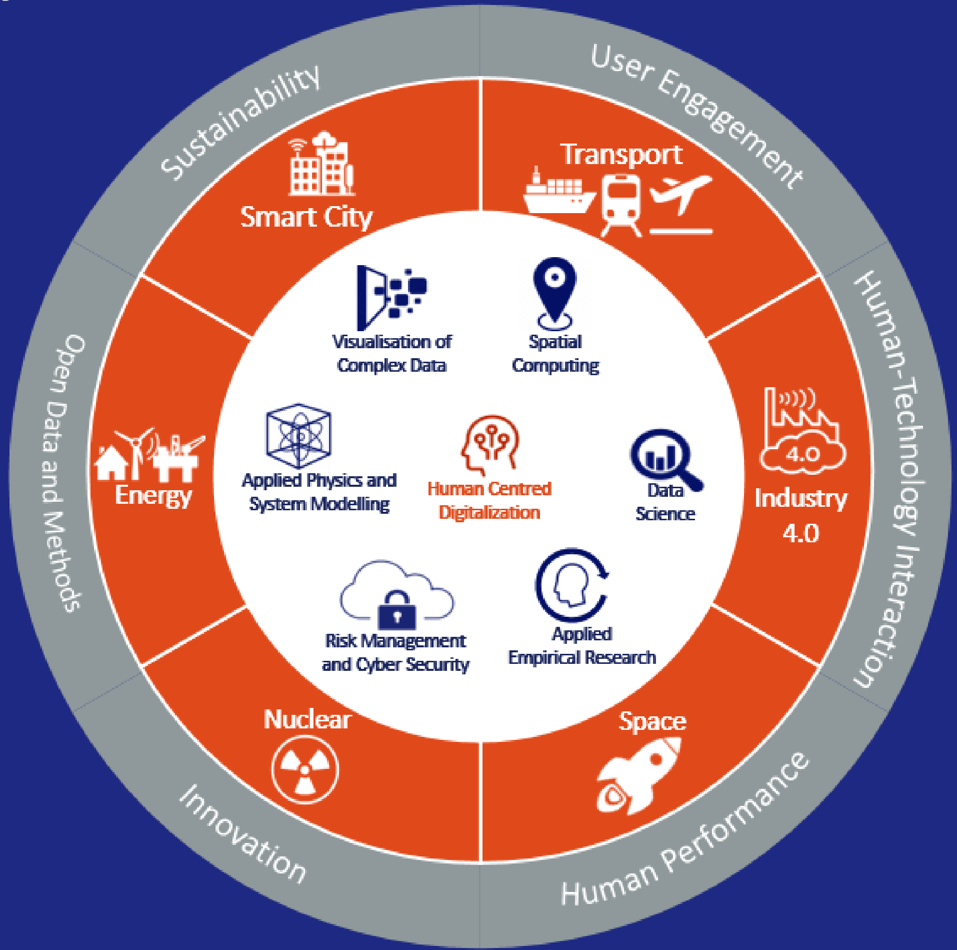

3-phase Flow Laboratory


Sensor Laboratory


VR Laboratory


Human Behavior Laboratory

IFE Digital Systems



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- Energy Systems
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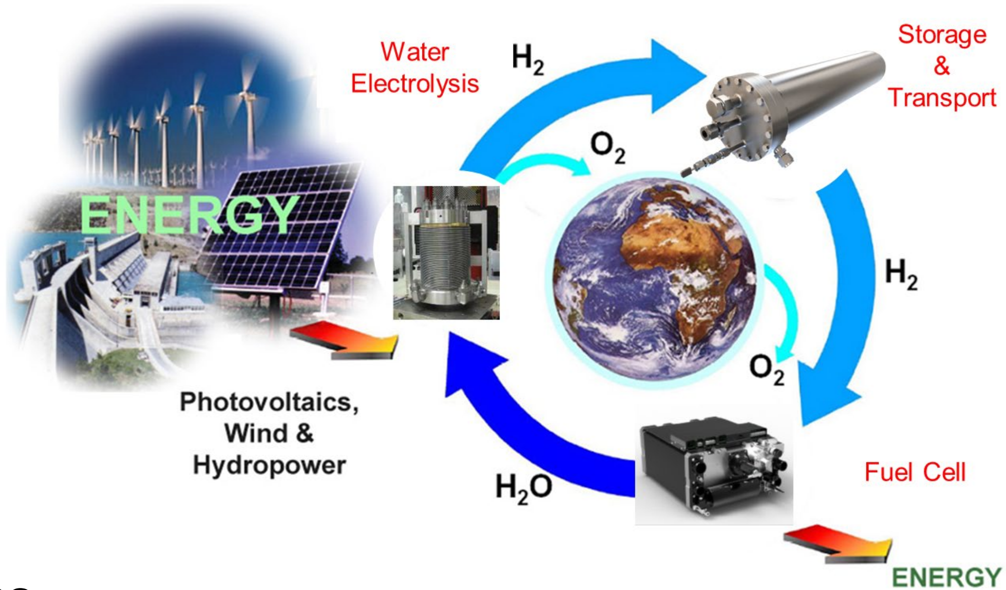
Smart Grids

Energy Storage

Definitions – General

- Energy Systems
  - Primary energy sources
  - Energy carriers
  - Energy conversion
  - End use



- Sustainable Energy Systems
  - Renewable Energy (RE)
  - Clean Energy (fossil fuels with CO_2-capture)

Definitions – Technical

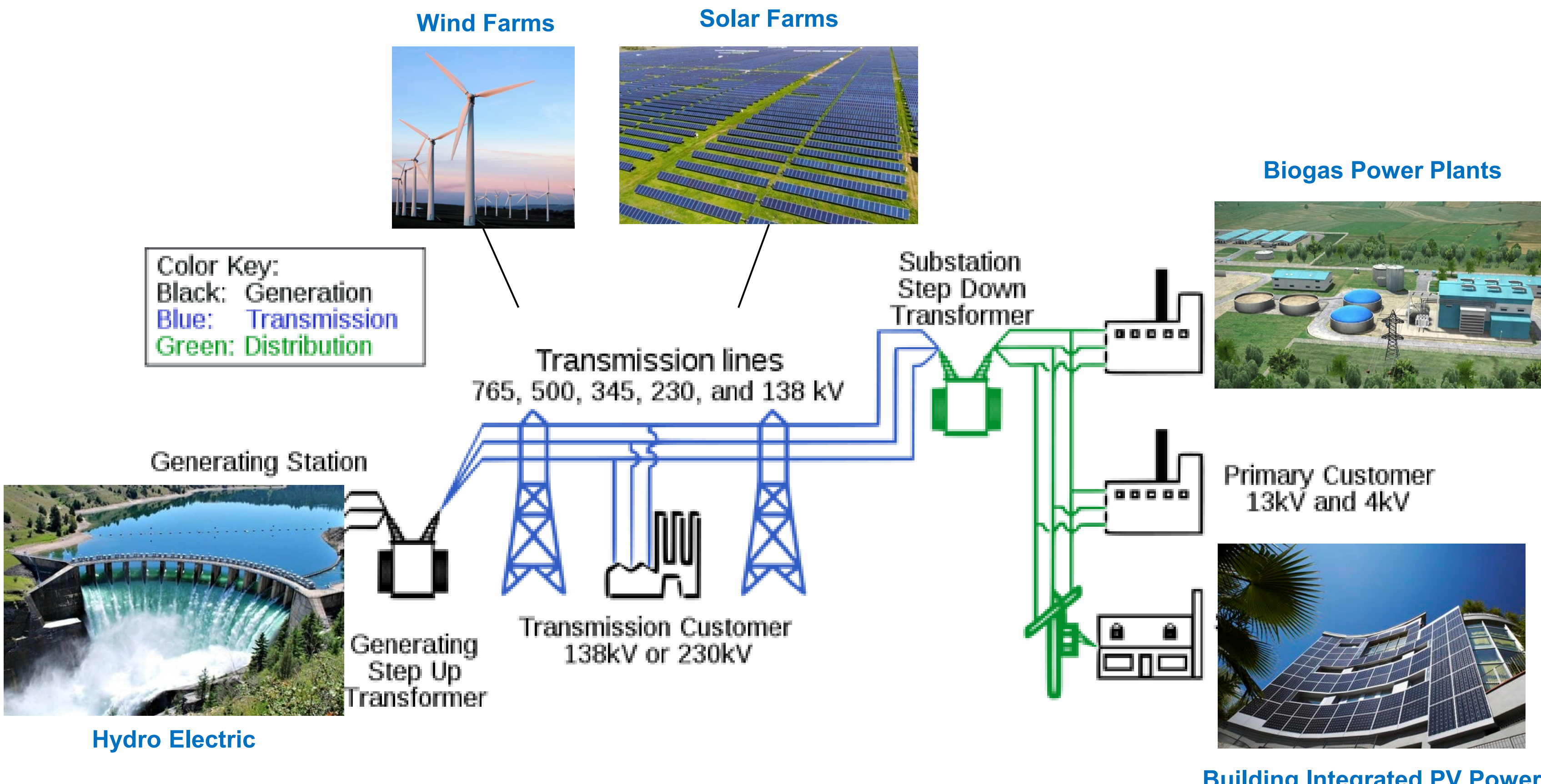
- Energi (*E*)
  - Work over time (kilowatt hour, **kWh**)
- Power(*P*)
  - Energy per time unit (kilowatt, **kW**)
  - Power = Voltage × Current
- Voltage(*V*)
  - Potential to perform electrical work (Volt, ***V***)
- Current (*I*)
  - Movement of electrons (Ampere, ***A***)
- Reactive Power (*Q*)
  - Max. Power absorbed (AC systems)

$$E = P \cdot \Delta t$$

$$P = V \cdot I$$

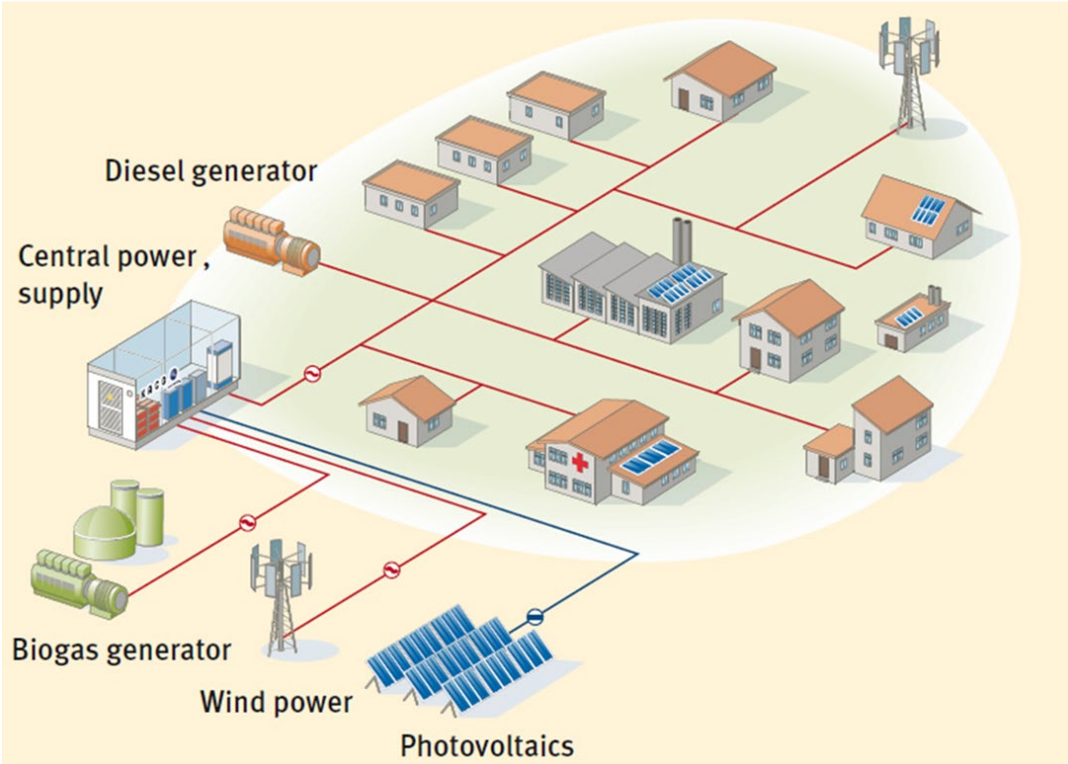
$$Q = V_{rms} \cdot I_{rms} \cdot \sin(ø)$$

Classical Power Systems



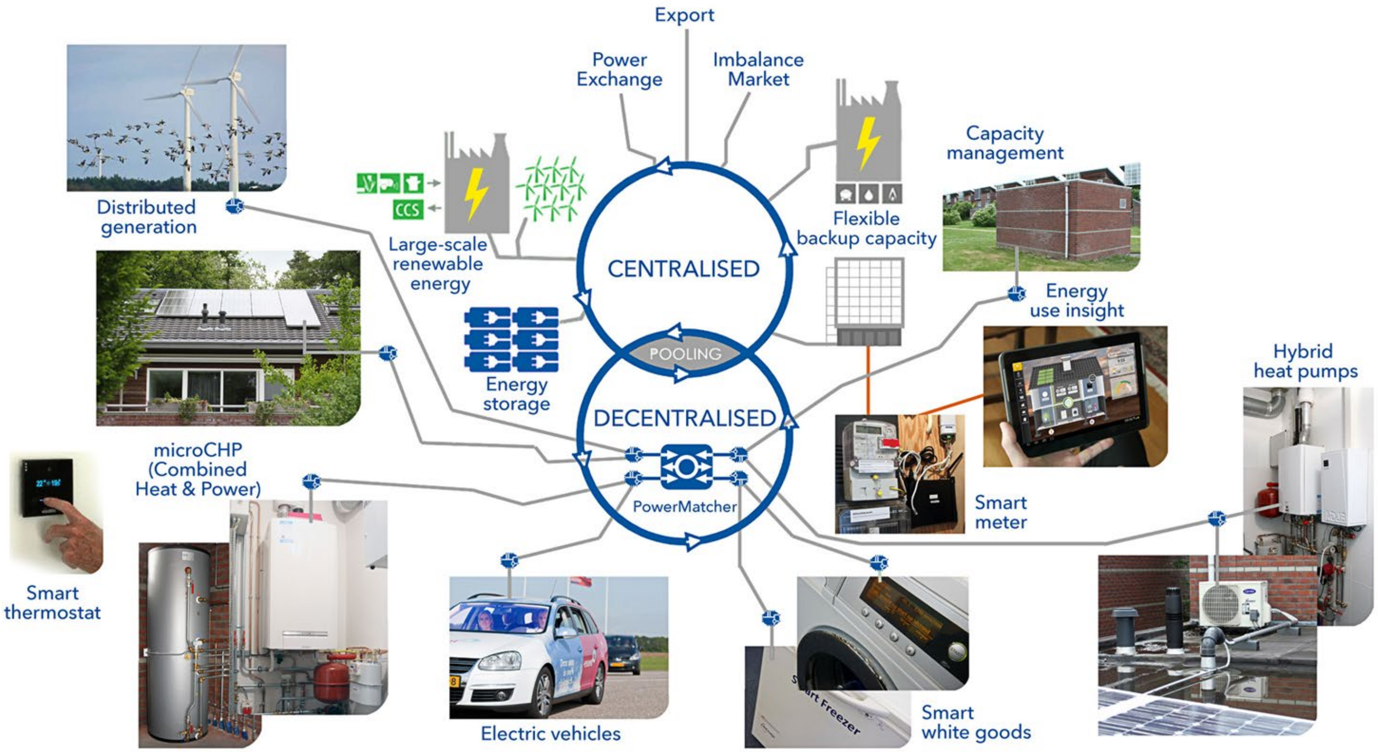
Source: https://ei.lehigh.edu/learners/energy

New RE-based Distributed Power Systems



Source: KACO new energy GmbH (Germany)

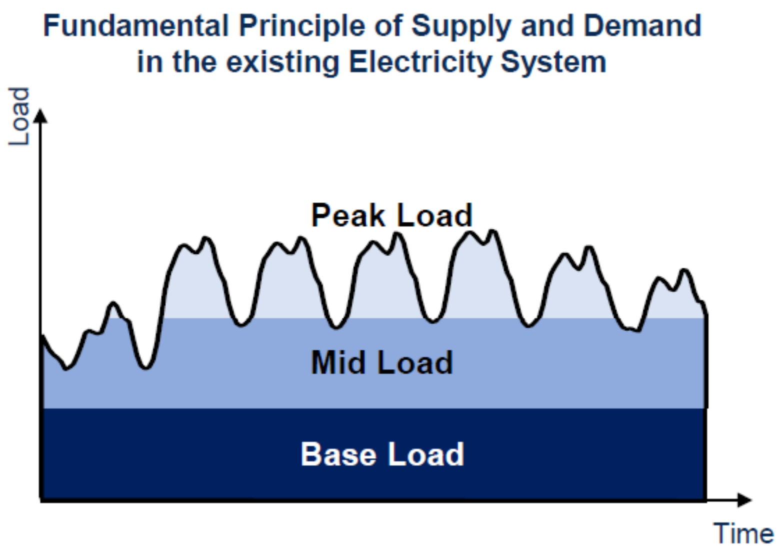
«Smart» Distributed Energy Systems – *Smart Grids*

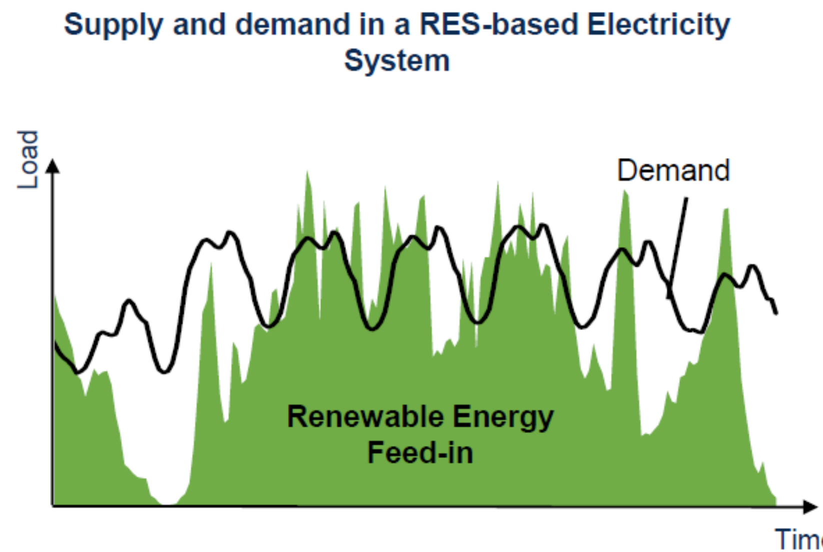


Source: DNVGL

Energy Flow in Power Grids

Existing vs. Future Systems





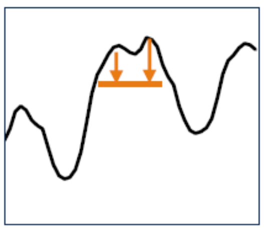
- Supply follows demand
- Supply cannot always follow demand

Source: TU Dresden

Energy Flow in Power Grids

How to match *Supply vs. Demand ?*

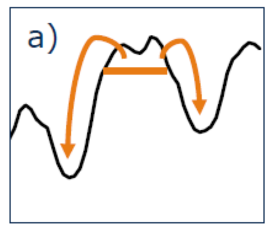
Load Shedding



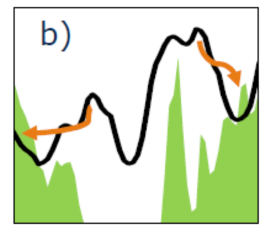
Reducing electricity demand

Energy intensive industry processes

Load Shifting



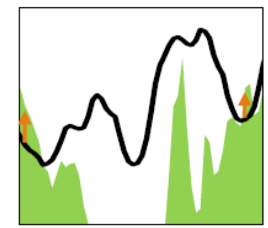
a) Smoothing the load curve



b) Demand follows RES feed-in

Applications connected to (heat or cold) storages

Load Increase



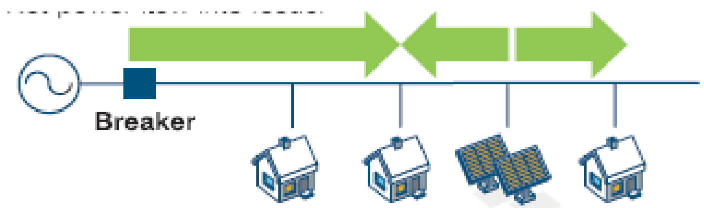
Additional electricity demand

Technologies which produce other energy carriers with electricity

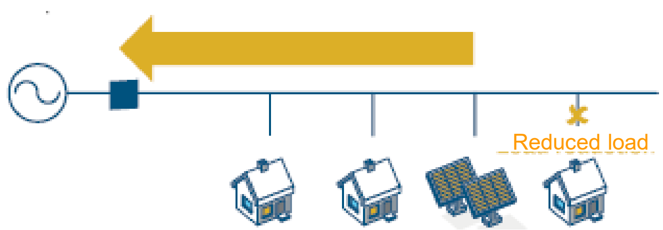
Source: TU Dresden

Distributed Power Systems

Example: Power Controls in local Solar PV-based Grids



1. Power from transformer
   PV power → End User

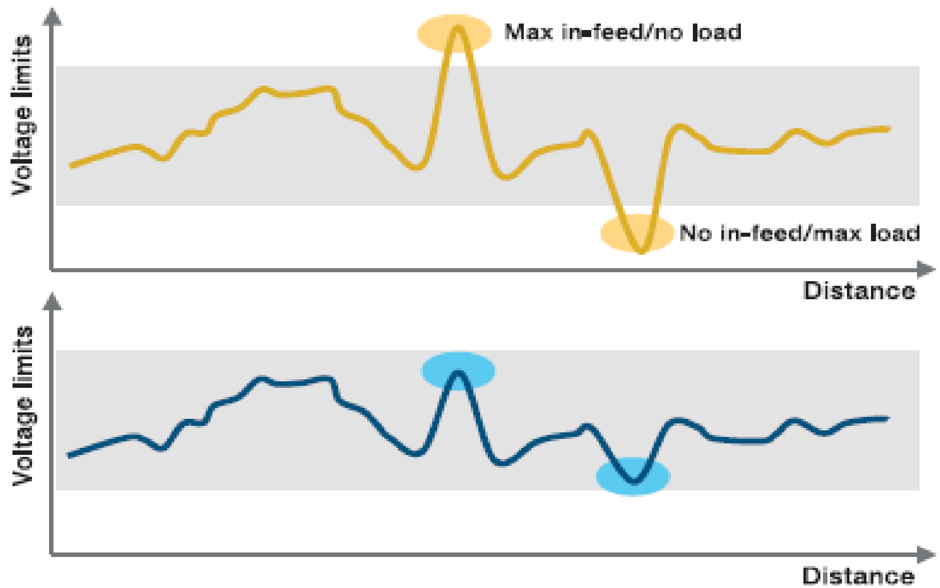


2. Power to transformer
   PV power → Export

Source: ABB

Distributed Power Systems

Example: Voltage Controls in local PV-based Grids

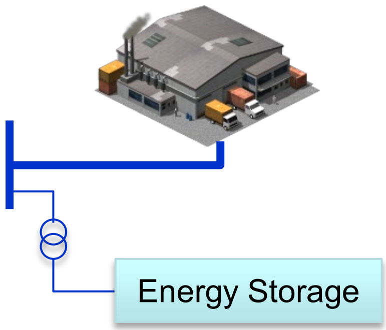


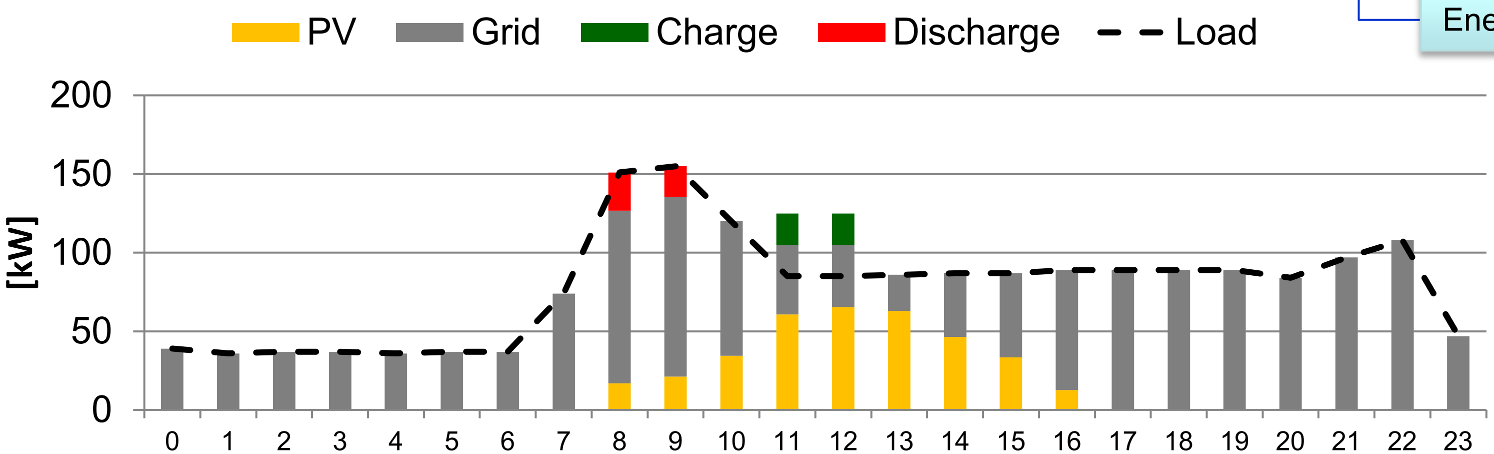
- High power production from PV → High voltage
- High power consumptiton by End Users → Low voltage

Source: ABB

Solar PV & Batteries – Case Study

- Hourly measurements of power usage
  → More efficient energy usage
- Methods to reduce energy costs
  - Increase local solar PV power production
  - Use batteries for Load Leveling and Peak Power Shaving





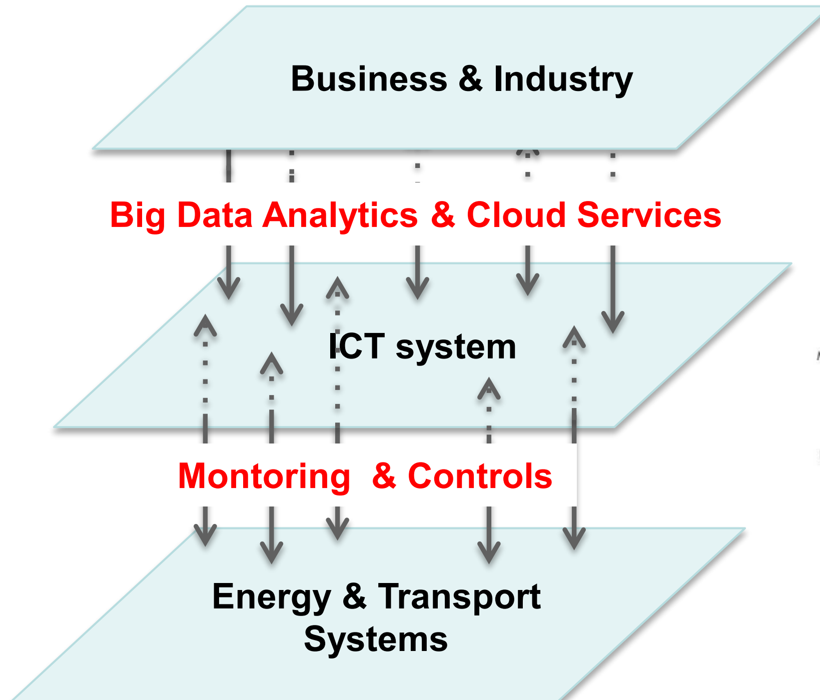
Source: IFE

Energy Systems & ICT

End Users

Cyber

Physical

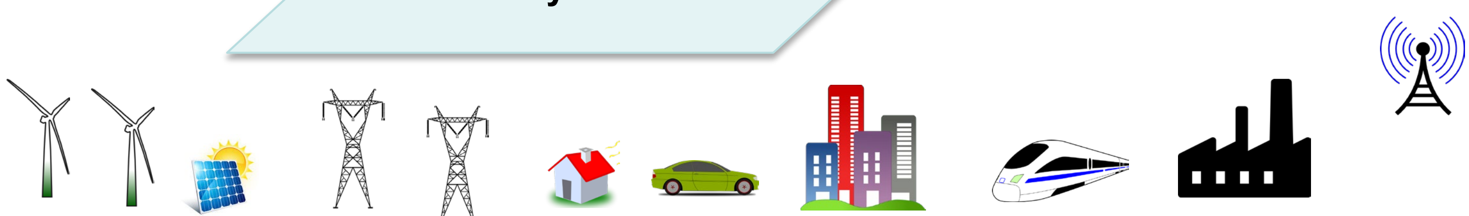


Smart Grid Services

Artificial Neural Networks

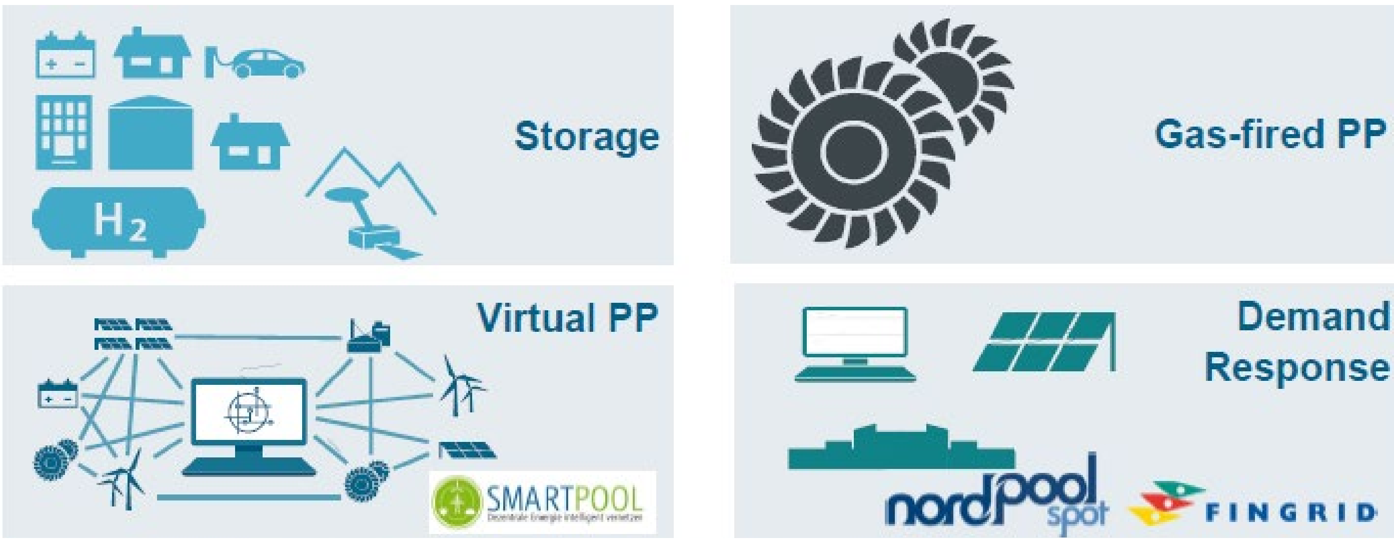
Block-Chain Technology

Sector Coupling



Future Electricity Systems

Flexibility is the key value



Source: SIEMENS

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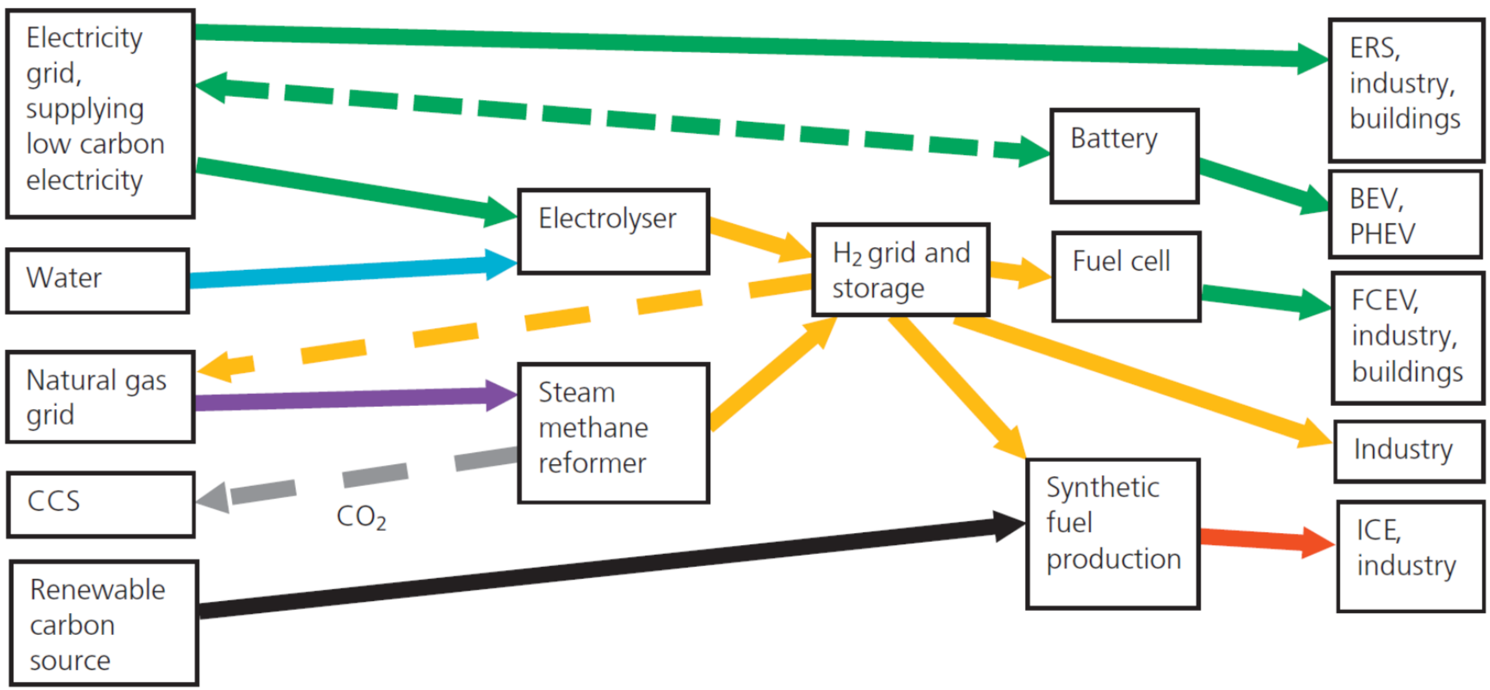
Energy Storage

Integrated Energy & Transport Systems

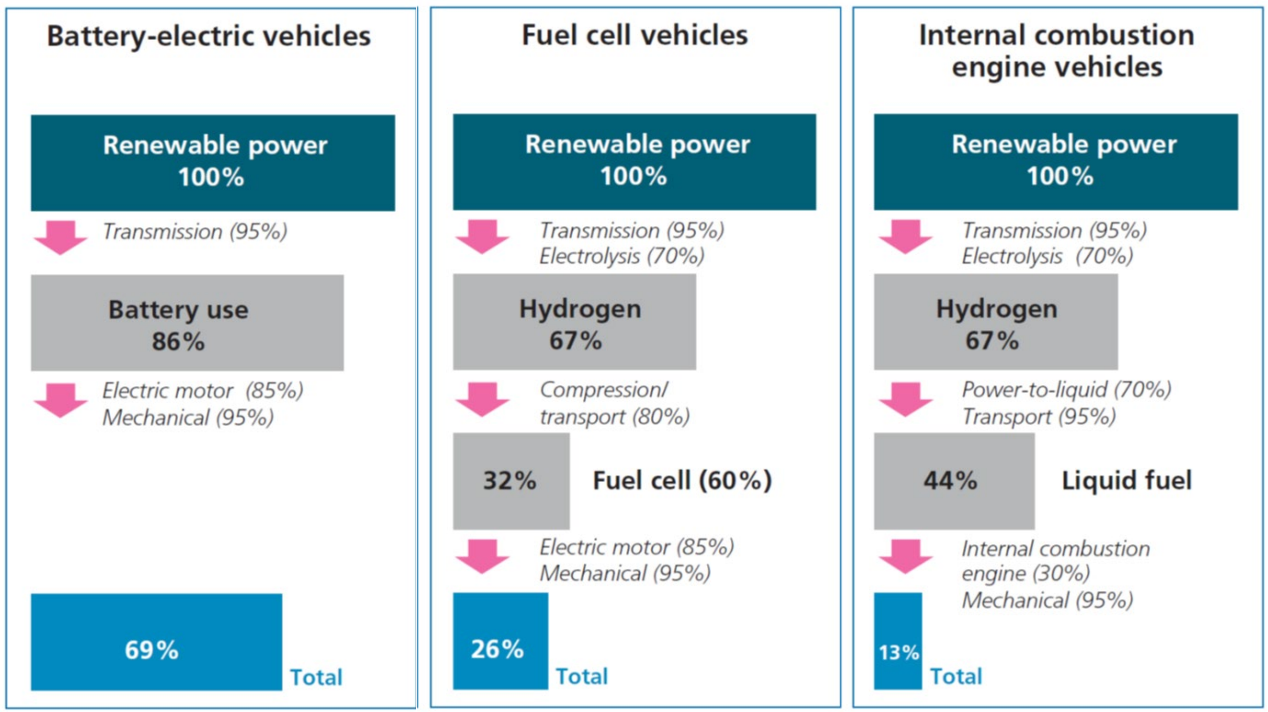
Electricity & Hydrogen



Source: EASAC (2019)

Energy Conversion

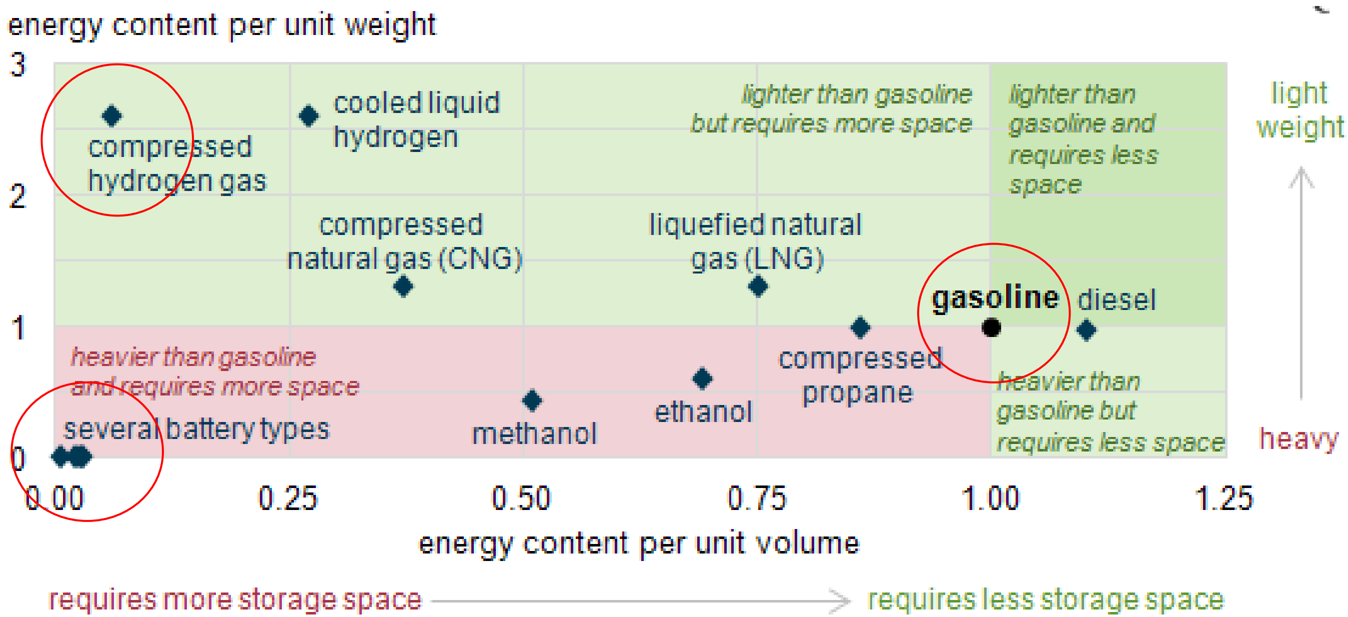
Electrical Efficiency for different RE-to-Vehicle Value Chains



Source: EASAC (2019)

Energy Storage

Volumetric versus Gravimetric Energy Density



Source: U.S. Department of Energy / EIA

Energy Storage

Example of Storage Capacity & Charging

Batteries (Li-ion)

3 MWh

60 000 kg
40' container — 460 battery modules

1-hour charging:
*1 C → **3 MW***

Hydrogen (250 bar)

20 MWh

12 000 kg
40' container — 4 × 12 m H_2-tanks

Fuel Cell (PEM)

1 MW

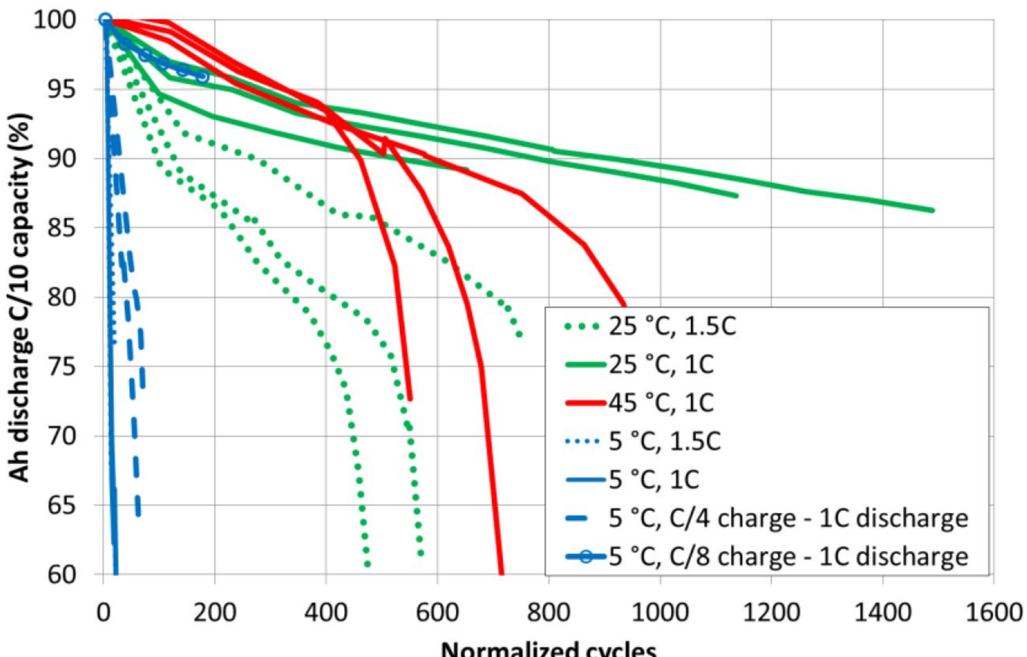
3 600 kg
10'

1-hour charging:
150 kg/h per H_2-tank
*→ **20 MW***

Source: IFE

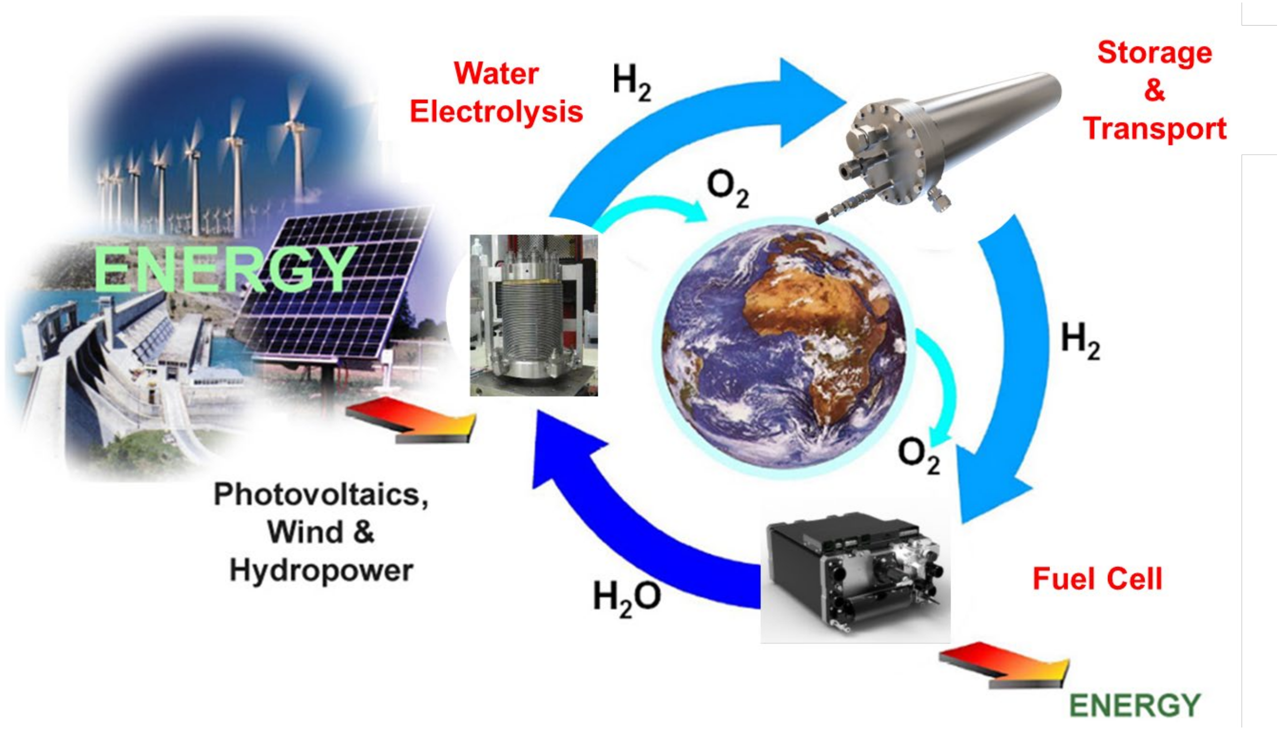
Li-ion Batteries

Charging / Discharging Rates & Temperature affects Cycle Life!!!



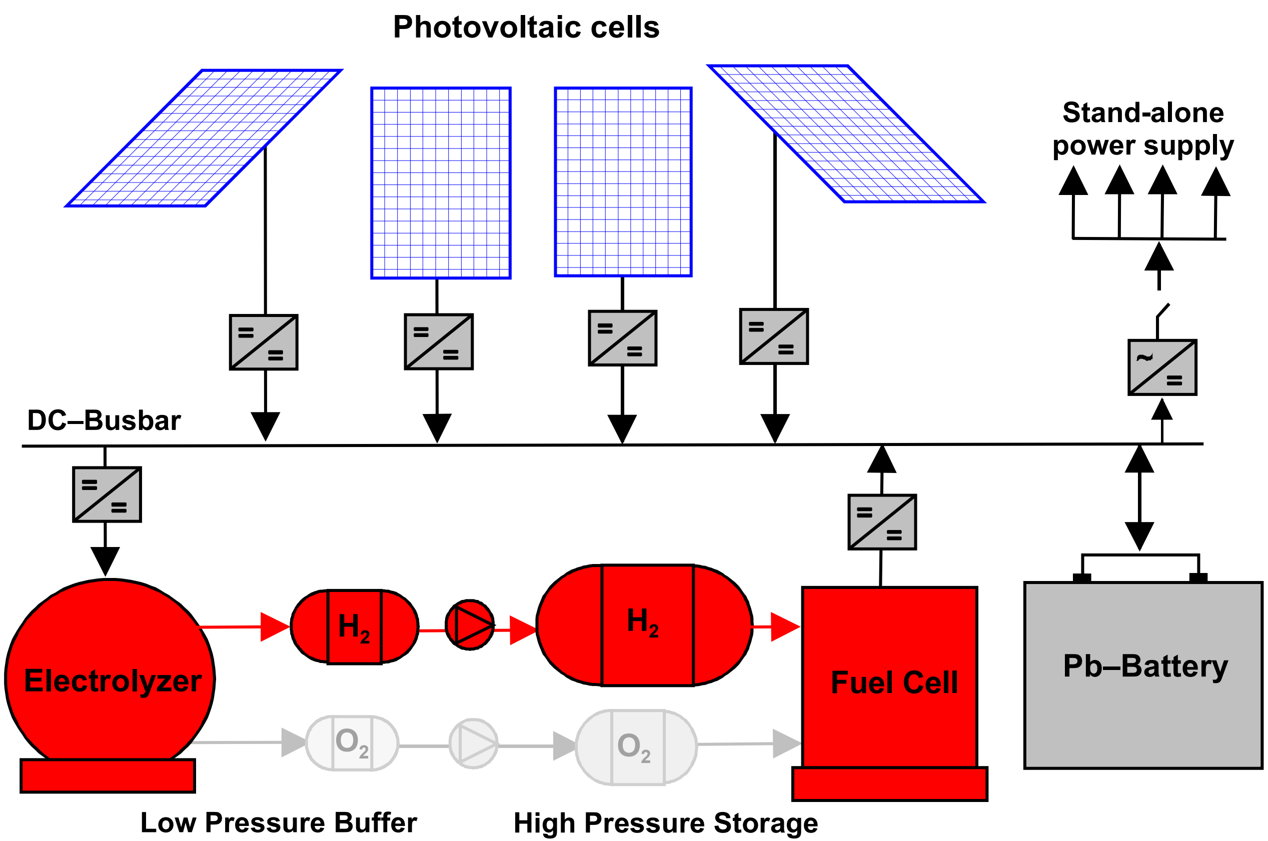
Source: IFE

Vision – Hydrogen as an Energy Carrier



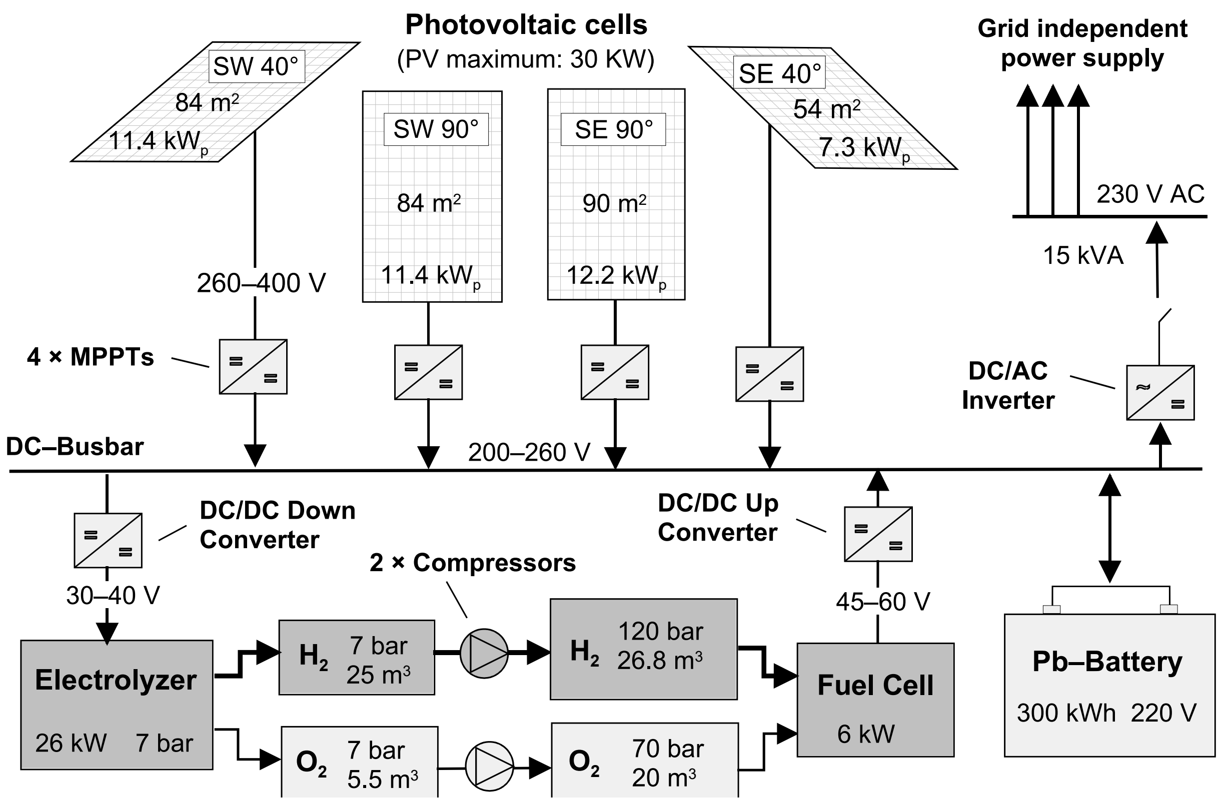
Source: IFE (1995)

Solar PV / Hydrogen System – Stand Alone System



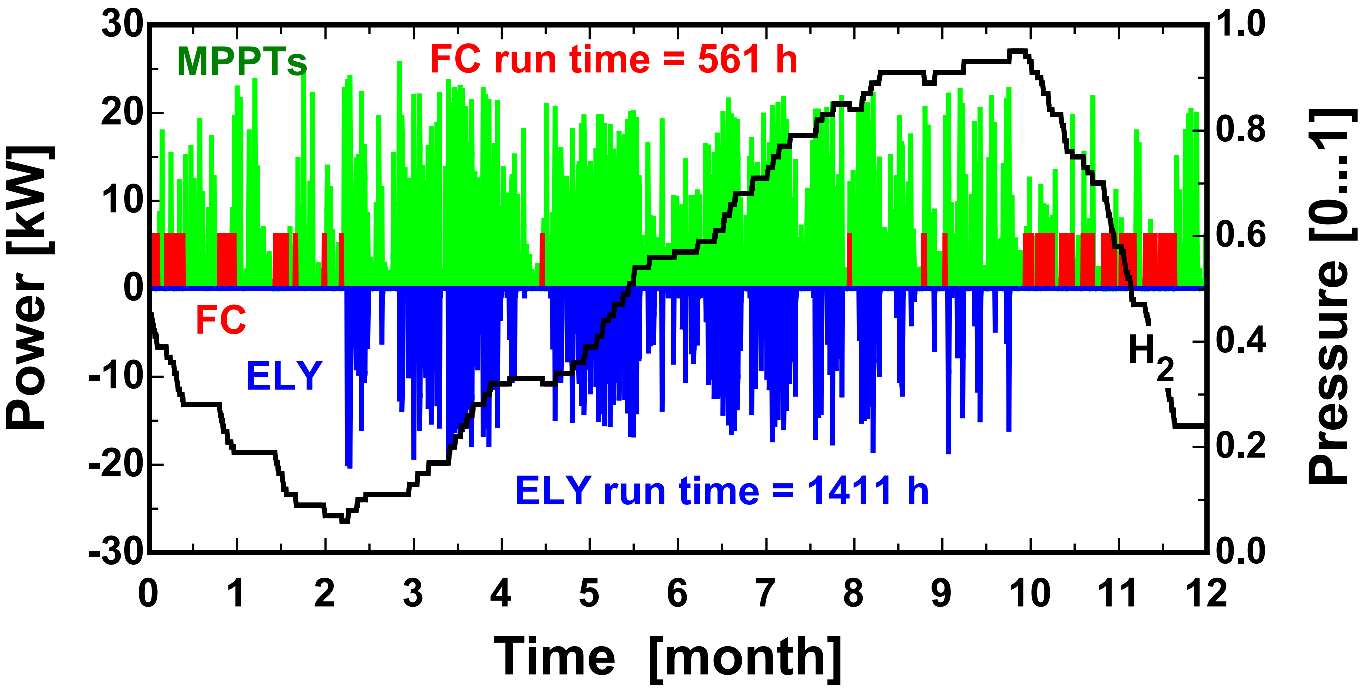
Source: Ulleberg (2003)

Solar PV / Hydrogen System – Specifications



Source: Ulleberg (2003)

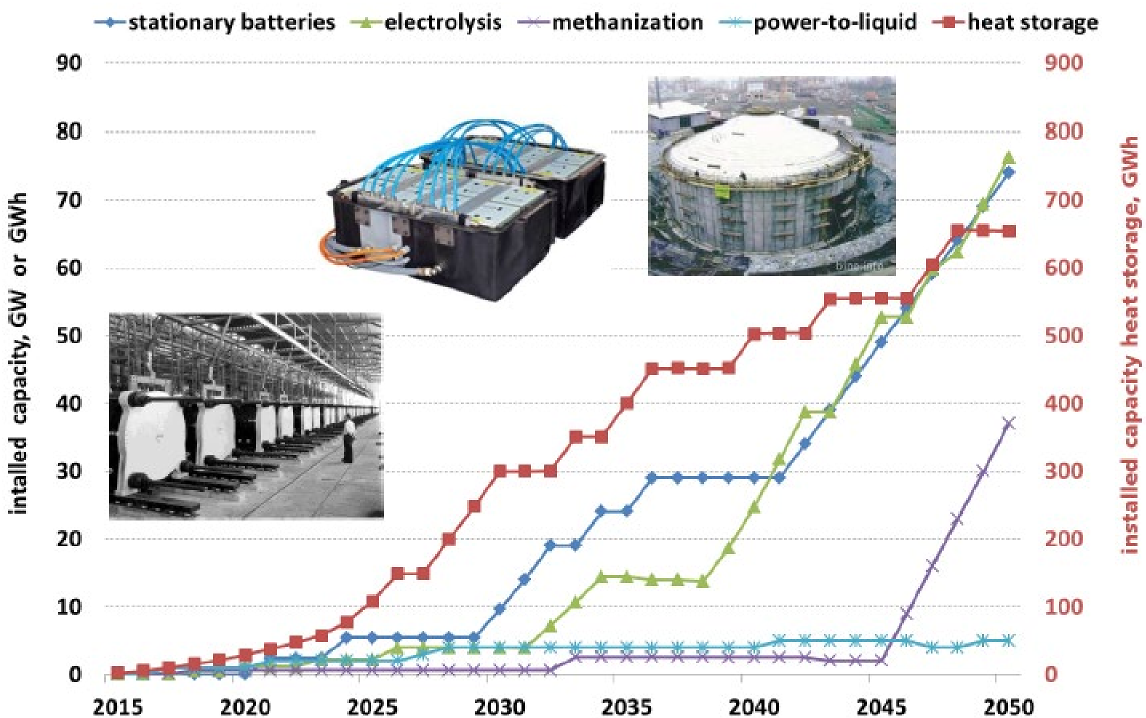
Solar PV / Hydrogen System – Performance



Source: Ulleberg (2004)

Energy Storage Systems

Large Scale Options for the Future – Case Study on Germany



Source: Fraunhofer ISE (2016)

Summary & Conclusions

- Renewable Energy Systems
  - Distributed Power Systems
  - Energy & ICT – *Energy Informatics* & *Smart Grids*
  - Integrated Energy Systems – *Electrons ↔ Molecules*

- Energy Storage
  - Batteries: *short-term* energy storage, high efficiency
  - Hydrogen: *long-term* energy storage, low efficiency

Thank you for your attention!

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