“Energy Storage in 2050?”

JILLIS RAADSCHELDERS — DNVKEMA, Arnhem
Utrecht, donderdag 16 mei, 2013

KIVI NIRIA

KEMA DNV

Contents

Who we are

DNV KEMA Energy & Sustainability

- DNV KEMA Energy & Sustainability offers innovative solutions to customers across the energy value chain, ensuring reliable, efficient and sustainable energy supply, now and in the future.
- 2,300+ experts across all continents
- KEMA and DNV combined: a heritage of nearly 150 years
- Headquartered in Arnhem, the Netherlands
- Offices and agents in over 30 countries around the globe


Services across the Energy Value Chain

Policy & Strategy

Production

Trading

Transport & Distribution

Use

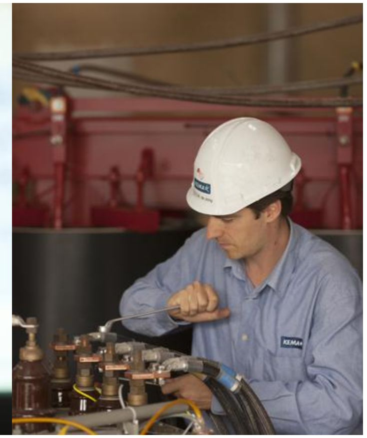
One company serving the needs of the energy marketplace

Our Services and Solutions along the energy value chain

- Business and technical consultancy, expert advice, operational services
- Testing, inspections , certification, verification
- Risk, performance, and quality management
- Research & innovation

2,300 Professionals in Energy & Sustainability



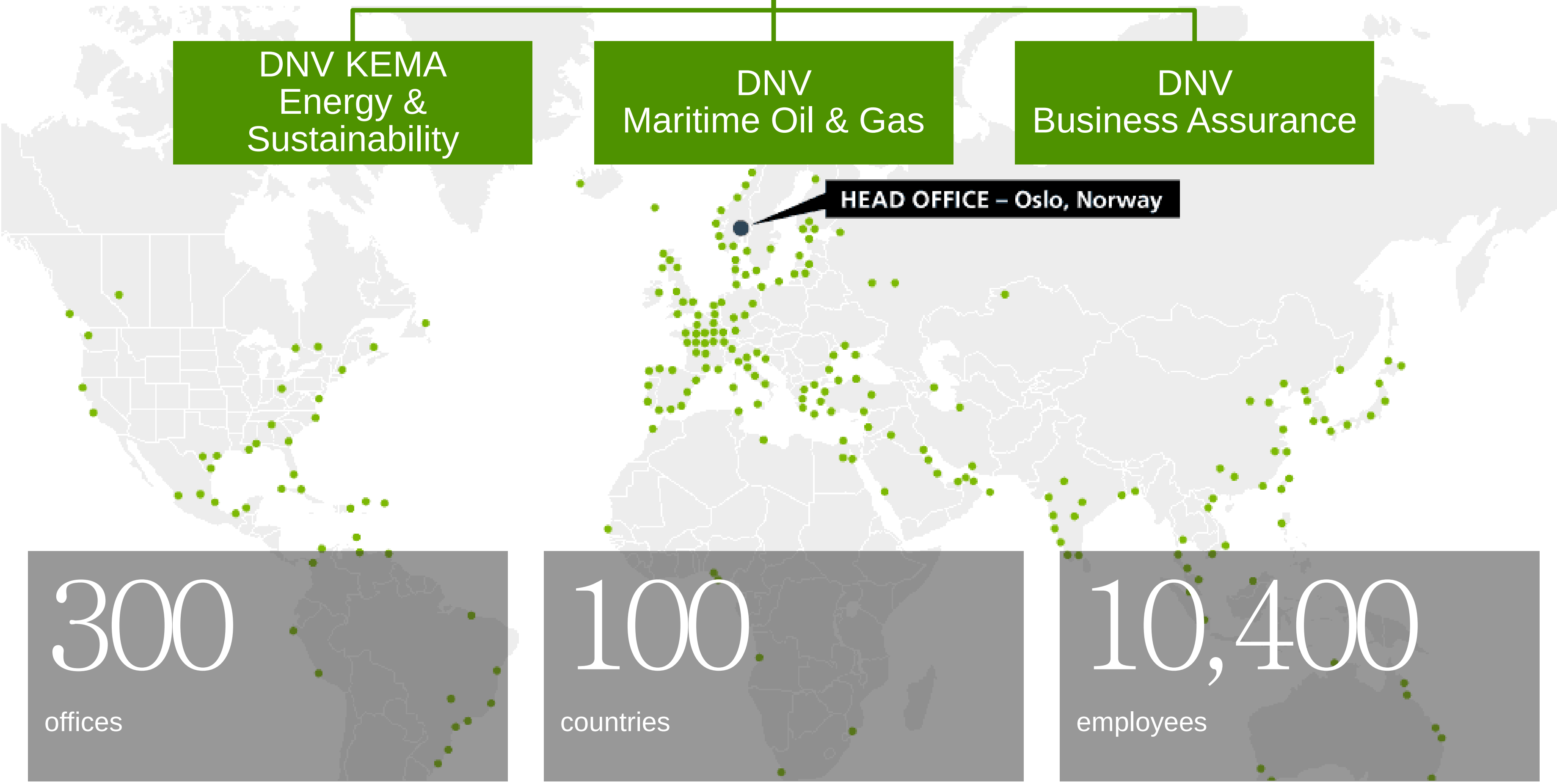


- Our passionate professionals work in multidisciplinary teams to enable our clients in finding the optimal solutions
- Their impartiality, high-level expertise, and experience are widely recognized
- They understand the business consequences of a technical decision and the technical consequences of a business decision
- They are present at major conferences and seminars and participate in international advisory boards, associations, and standardization committees to share knowledge and stimulate innovative thinking

The DNV Group

DNV Group

- DNV KEMA Energy & Sustainability
- DNV Maritime Oil & Gas
- DNV Business Assurance



300 offices

100 countries

10,400 employees

Summary

Summary

- Energy Storage means: Electricity but also gas, oil, heat & cold
- Storage on Transmission level & Distribution level
- "Storage" is not a value proposition, Flexibility or System Services are.
- Challenge is economical, not technical, value is differentiated over many stakeholders
- Storage needs to compete on Level Playing Field (not yet established)
- Storage adds cost to the energy system, but is required for 100% renewable
- Private Households may/will invest in DG-Storage combi.
- Technology development takes > 15 years, honoring the "10 times" rule-of-thumb

The changing world of energy, Key Driver for Storage

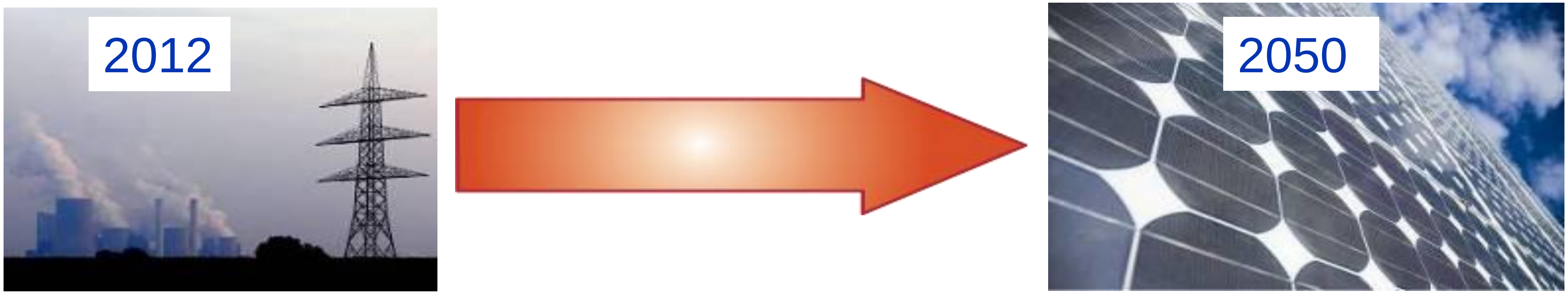
We need a radically new vision for the energy system

How do we get there from here?

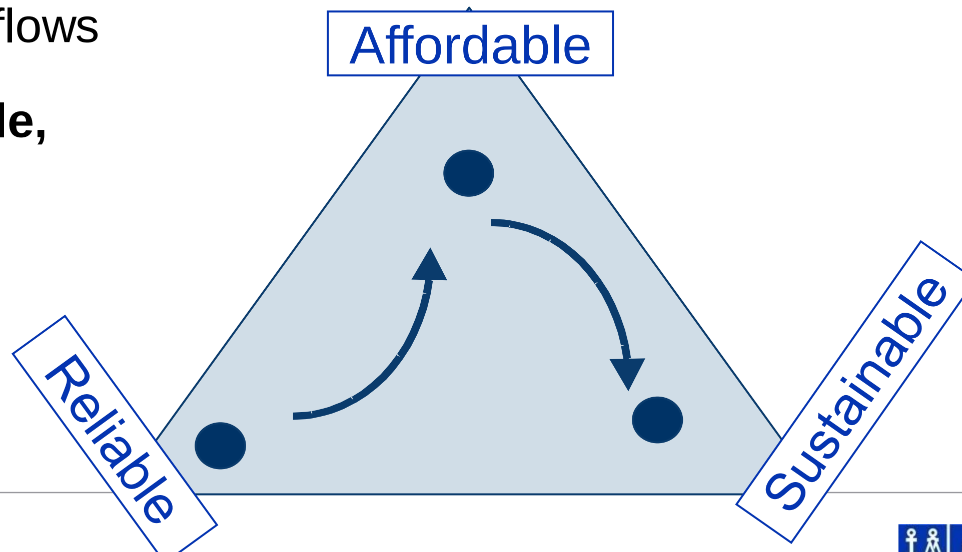
The World of Energy: Six major trends

1. Increased electricity demand
2. Environmental responsibility or stewardship
3. Declining fossil fuel supplies
4. Aging assets and workforce
5. Advancing technology, e.g. ICT
6. Maintaining reliability

Three parallel trends in European power sector



- **Decentralization**: large amounts of distributed generation (DG), new entrants in the energy market (often SMEs); new ways of cooperation; participating end-users
- **Europeanization**: mergers and acquisitions; power plants at remote distance from load centers; cross-border power flows
- Requirement to have an **affordable, reliable and sustainable** grid

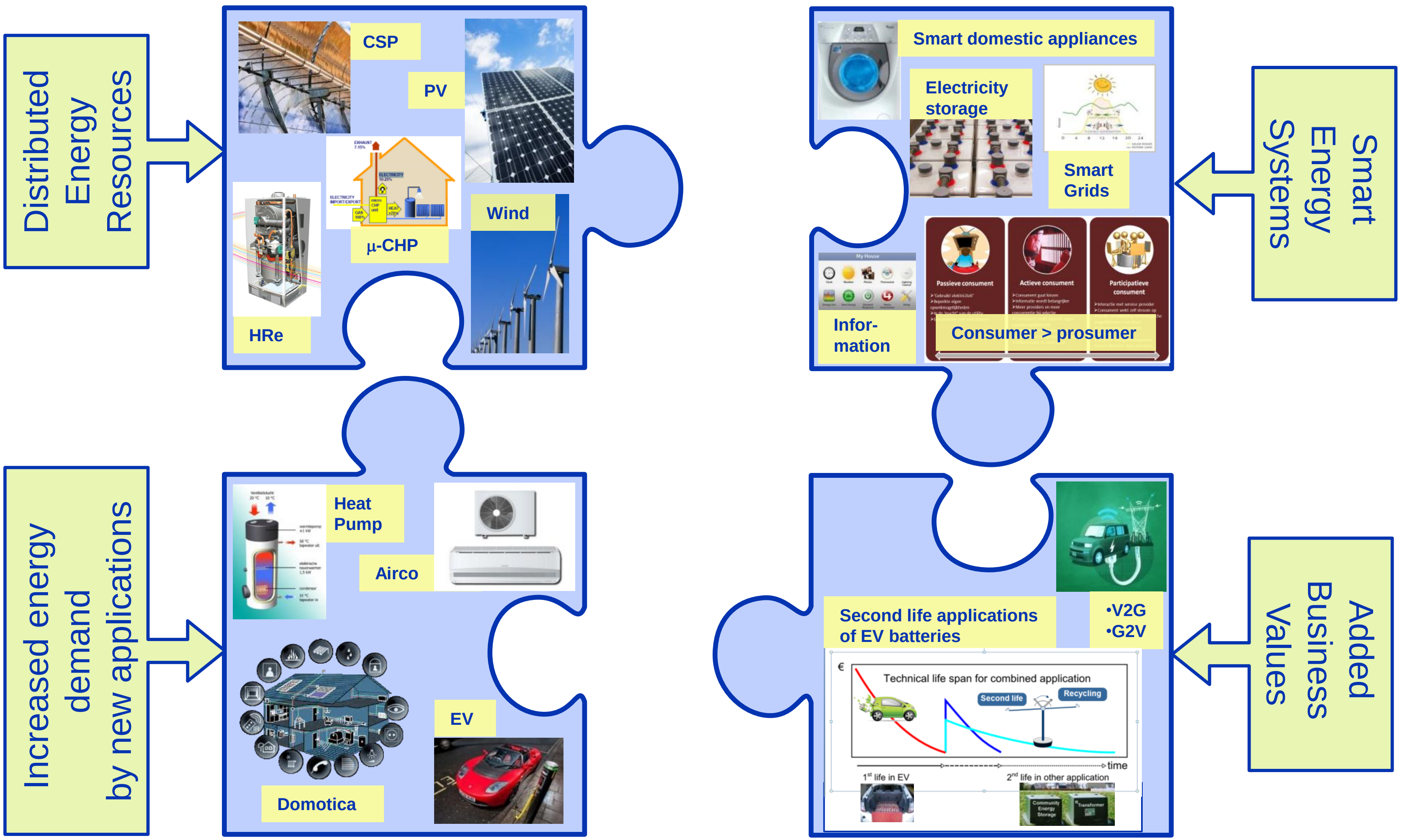


Power System Challenges

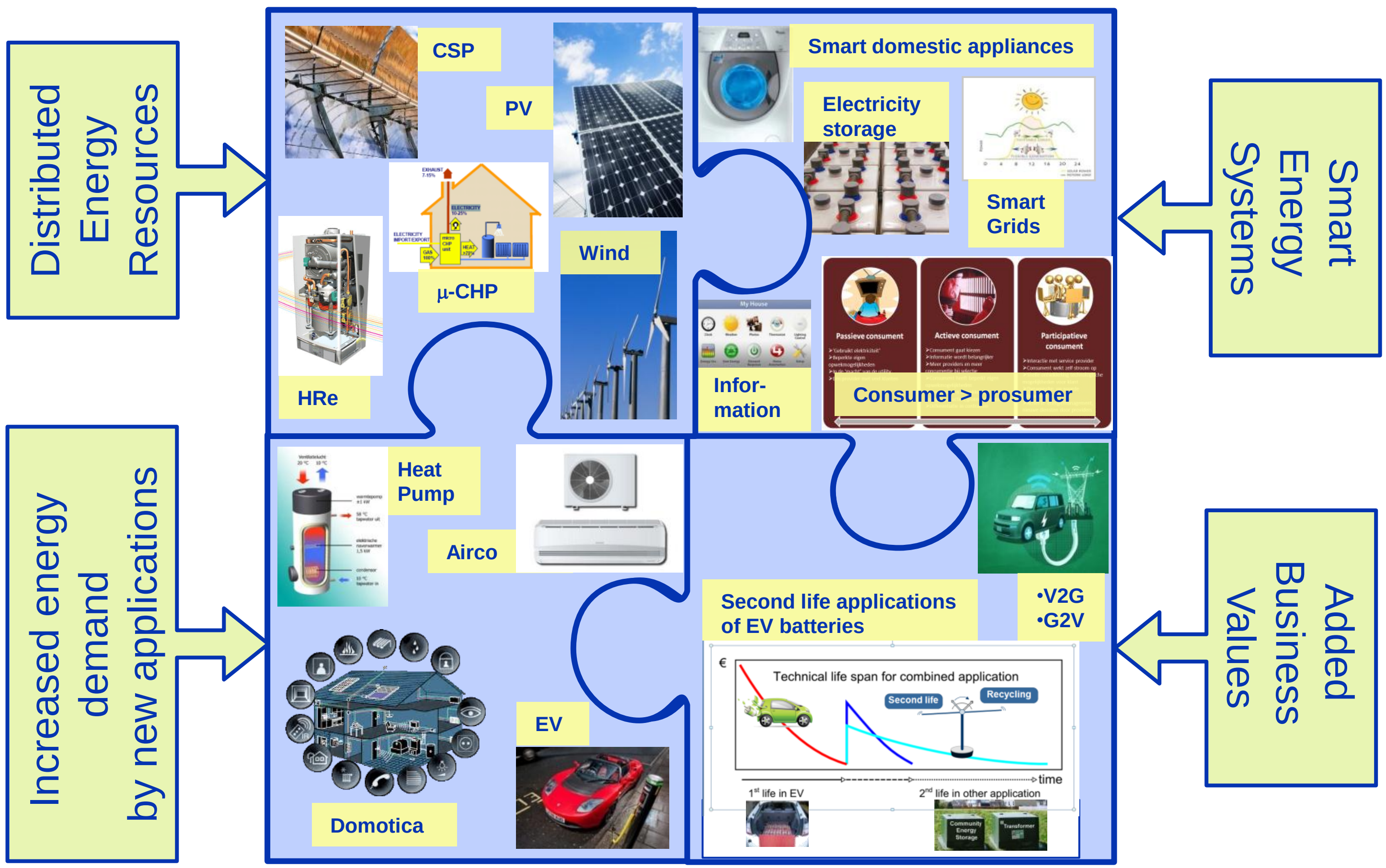
- Add new Engines, wiring;
- Add new equipment and functionality
- Introduction of Active Control

- And all this,………………………………………………….during flight !!!

Strengthen the business case for Smart Grids

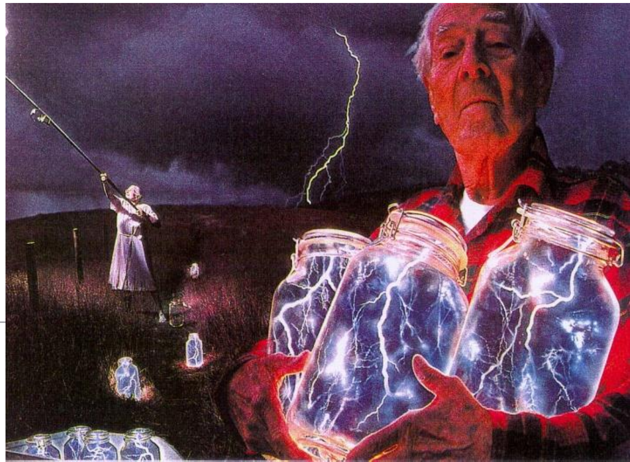


Strengthen the business case for Smart Grids

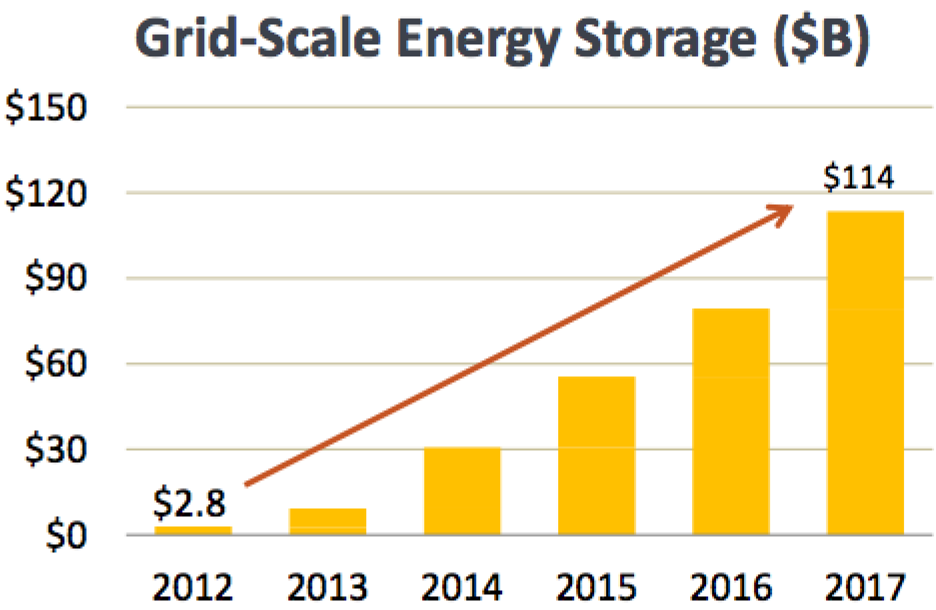


More flexibility is needed
some alternatives

1. Fast controllable power generation
   (and/or curtailment of e.g. wind power)
2. Increase interconnection capacity
3. Smart integration of DG, mainly small RES
4. Demand response, demand side management,
   and an active participation of end-users
5. **Energy storage**



Energy Storage Market Potential

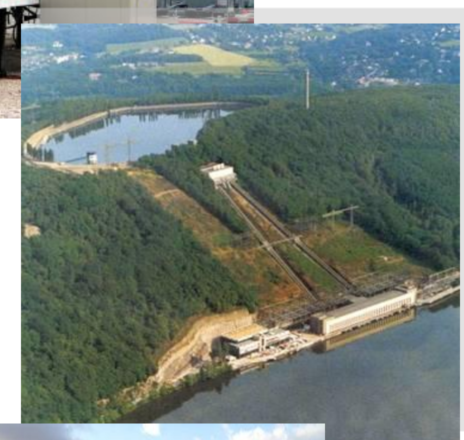


- Lux Research – $114 B by 2017
- Piper Jaffrey – $600 B market over 10-12 years
- Boston Consulting Group – $400 B market by 2020
- EPRI/DOE – annual savings of $50 billion/year via energy storage

Plenty of market potential… for the right product at the right price

The Energy Transition towards 2050, the role of storage

Why energy storage?



- ✓Electric infrastructure utilization factors are lowest of any commodities industry
  - <50% typically

- ✓We cannot afford to keep building to peak demand
  - (plus contingency factor)

- ✓Storage technologies are maturing in capability, durability, performance, and cost

Source pictures: Energy Storage Association

The balancing act of energy storage

Supply

- Increase of (varying) RES + DG
- Ageing assets (grids + power plants)
- Coupling of electricity, heat (and cold), and transportation

Demand

- Fuel shift due to electrical vehicles, heat pumps, etc.
- Increase of luxury resulting in higher peak loads
- Increasing dependency on delivery

Energy management

Physical

- Storage facilities (electricity, heat, gas) integrated at home/offices/…
- More need for preventing grid overloading, voltage support, frequency control, PQ

Market

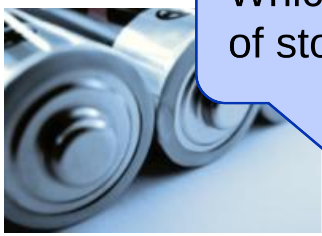
- Increase of energy trading, e.g. on the balancing market
- Uncertainty of dealing with energy storage in a regulated market

Energy storage at three levels

	Large scale	Medium scale	Small scale
Heat	• Heat and cold storage • Geothermal e-storage • …	• Soil heat exchange • Thermo-chemical storage • …	• Boiler • Mass of buildings • Phase change material • …
Electricity	• CAES • Pumped hydro • …	• Battery • Flywheel • …	• Battery • Flywheel • Super capacitor • …
Gas	• Gas-field • Gas grid • …	• Gas tank storage • …	• Gas tank storage • …

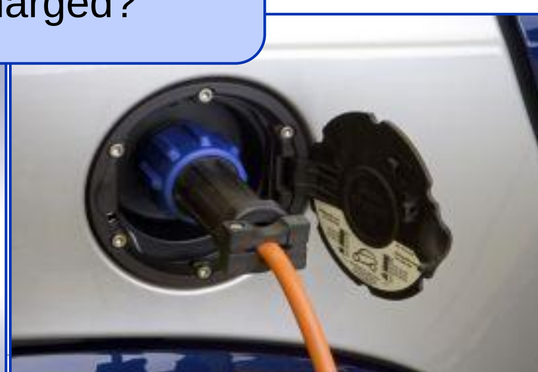
Which, where, when, what?

Which type and size of storage required?



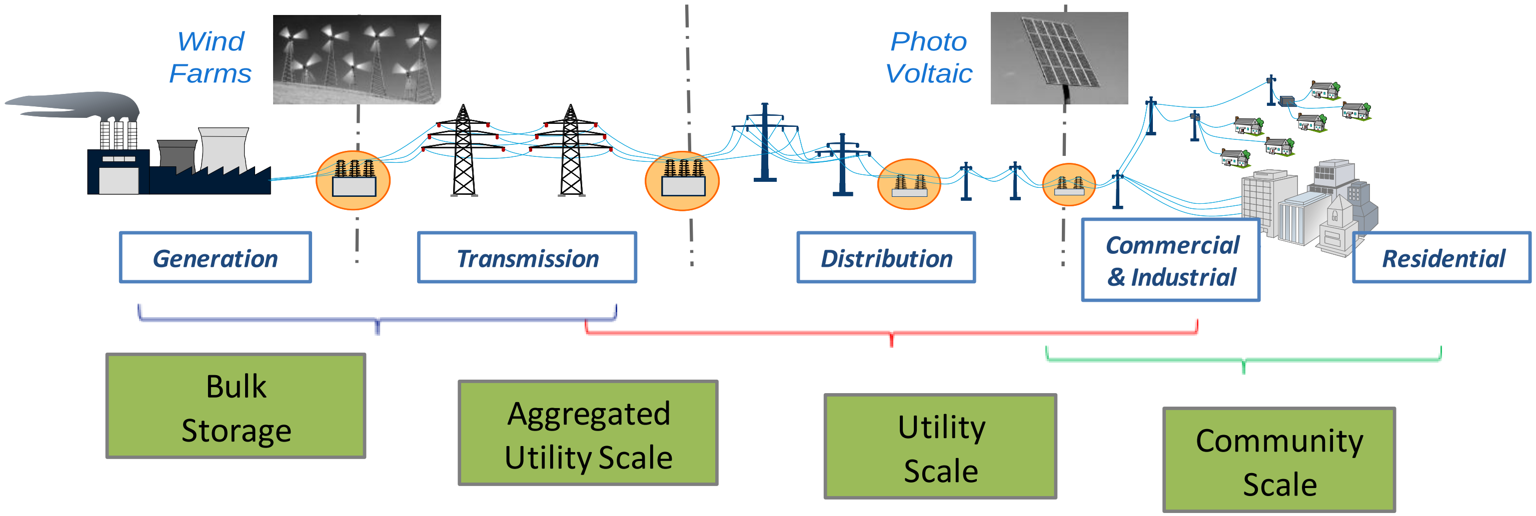
Where should storage system be located?

When should storage system be charged/discharged?



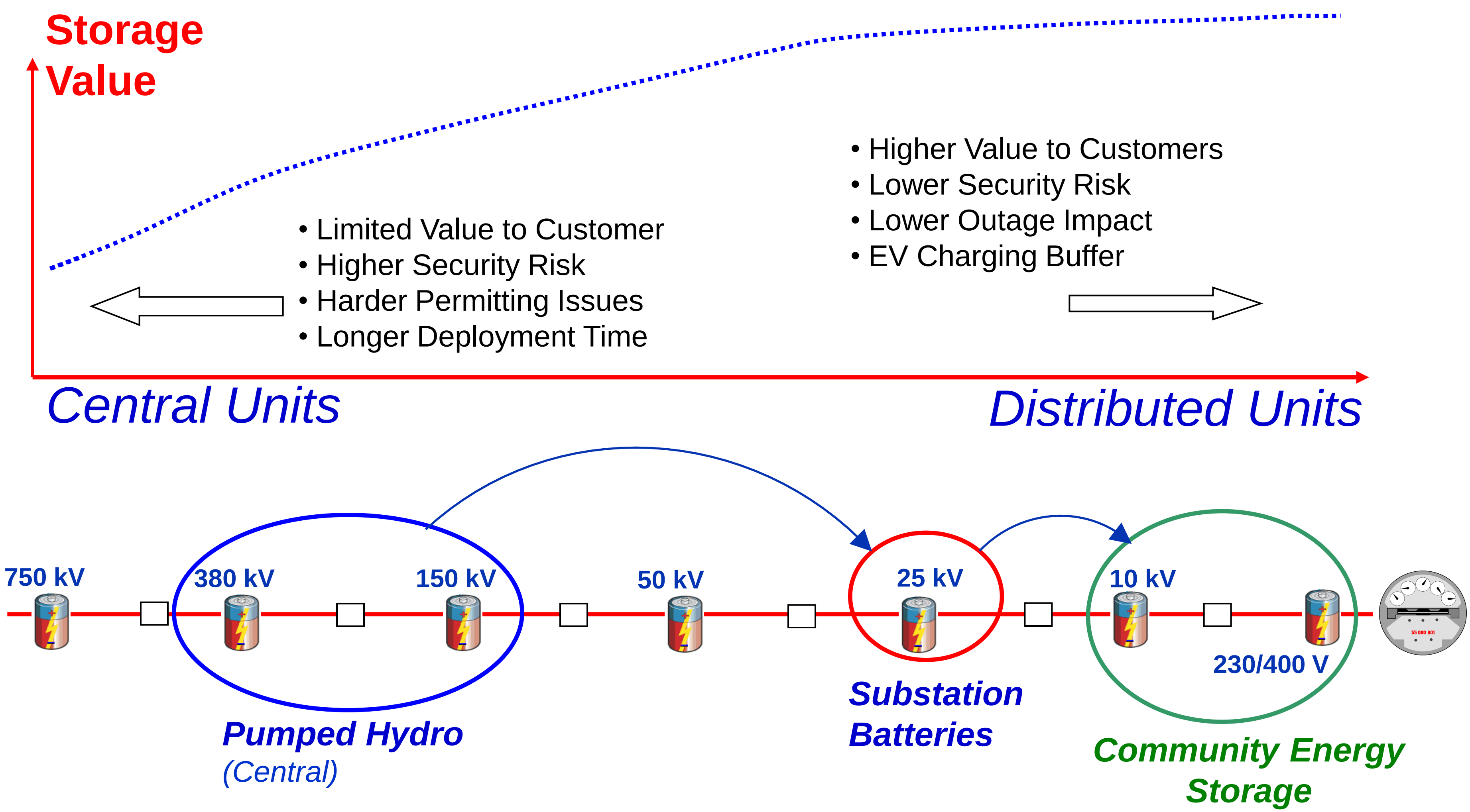
What are costs and benefits?

Need to Examine Storage Across the Grid



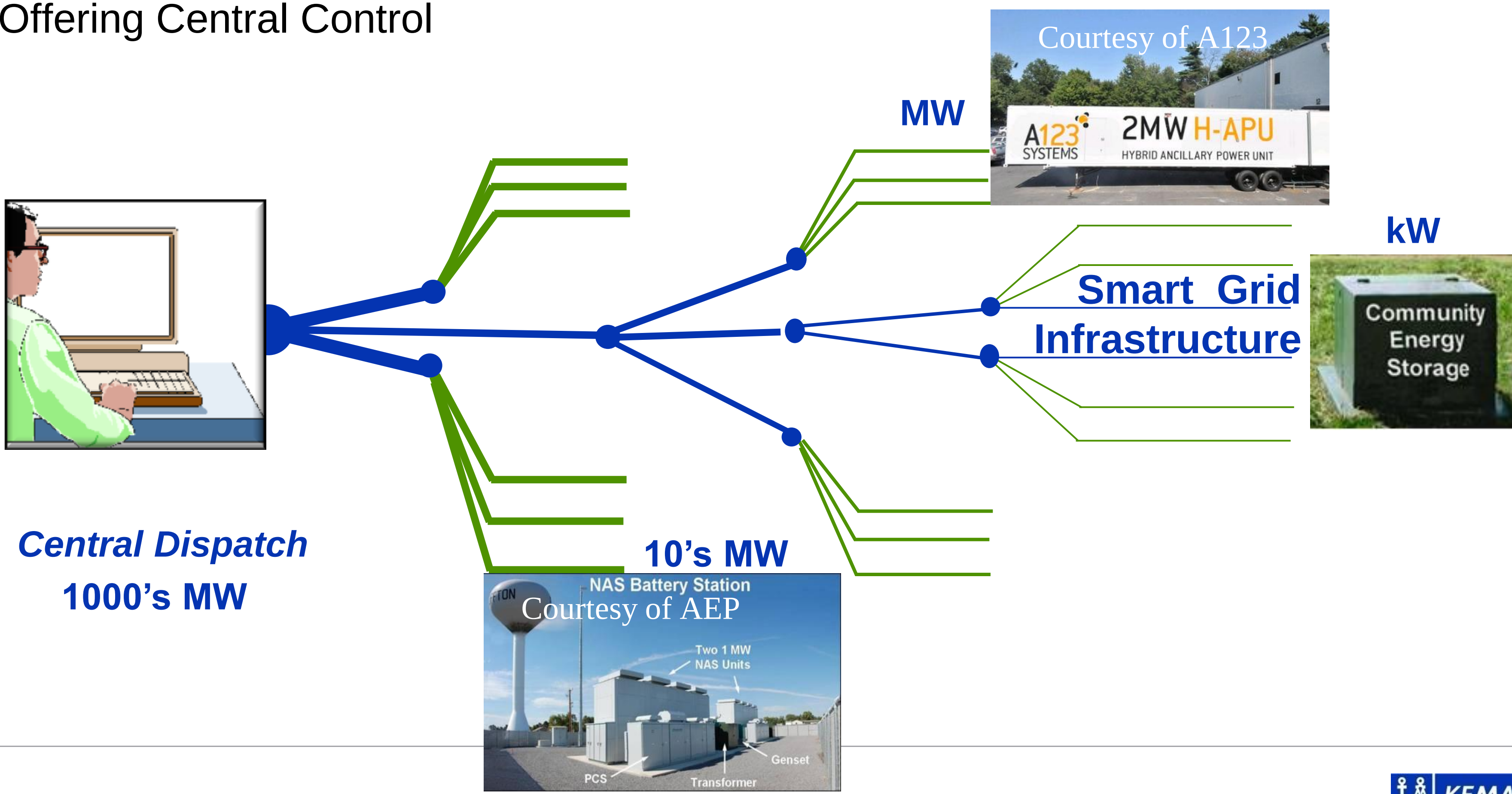
- Generation group focus on Bulk storage systems
- Power Systems group is able to assess the benefits storage can bring to transmission and distribution
- Energy efficiency group is able to integrate storage into building management and Demand Response

A Utility Perception of Storage Value



Distributed Bulk Storage !!

- Aggregation of Distributed Storage Units
- Realizing Distributed Value
- Offering Central Control



Regional Issues, medium- long term

The challenge is not the technical feasibility, but the economical feasibility.

- National Policy

EPC/SEP requirements for Private homes:

- Market developments:
  - Volume & Capacity Payments (Mileage-concept)
  - RES penetration
    - Centralised
    - Decentralised

Regional Issues

Technology

- Grid assets

Policy

Regulations

- E.E.G. (F.I.T.)

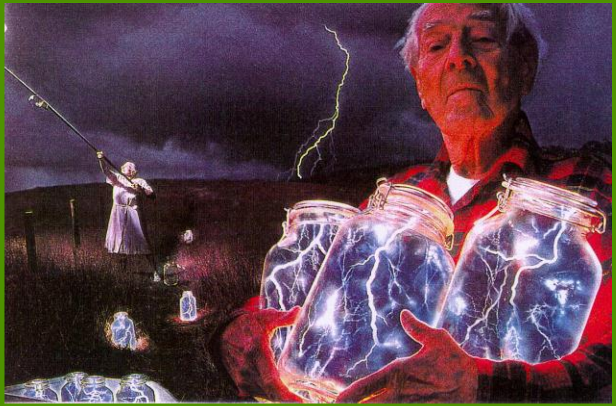
BDEW zweifelt an Regelung

Berlin (energate) – Netzbetreiber und Energieversorger rechnen wegen der geplanten Förderung dezentraler Solarstromspeicher mit höheren Kosten für die Stromkunden.

Mit dem angekündigten Programm würde die Bundesregierung den Eigenverbrauch von Solarstrom befördern, sagte die Hauptgeschäftsführerin des Bundesverbandes der Energie- und Wasserwirtschaft (BDEW), Hildegard Müller, bei einem Kongress im Bundeswirtschaftsministerium. Das klinge zwar „an sich gut“.

Tatsächlich würden sich die Speicherbesitzer damit aber dem Gesamtsystem der En… Kosten entziehen. Denn wer s… orgt, der zahle weniger Netzent… h weniger Steuern und Abgaben. … die anderen Verbraucher umgelegt … s sich derzeit zwar noch um … dem Gesamtsystem durch … chts Sinkender Preise für S… der … e werde die … Das … weltministe… en … speichern künftig mit 50 Mio. Euro pro Jahr unterstützen. … te sich der Bund im Zuge der letzten EEG-Novelle im … en Sommer mit der Solarbranche verständigt.

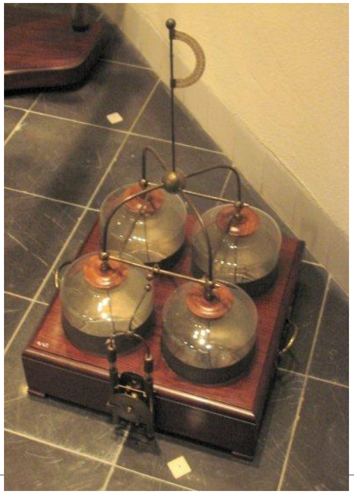
Storage Technologies



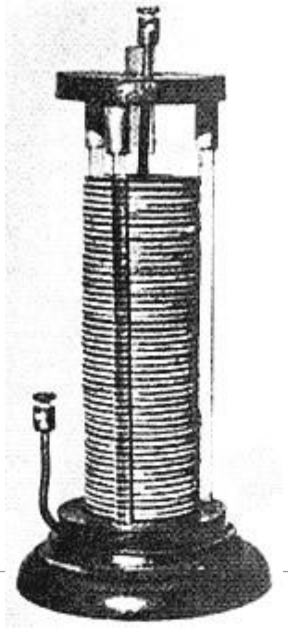
Energy Storage?

- **Global strategic petroleum reserves** ("GSPR") refer to crude oil inventories (or stockpiles) held by the government of a particular country, as well as private industry, for the purpose of providing economic and national security during an energy crisis. According to the United States Energy Information Administration, approximately 4.1 billion barrels (650,000,000 m^3) of oil are held in strategic reserves, of which 1.4 billion is government-controlled. (*source: Wikipedia)*

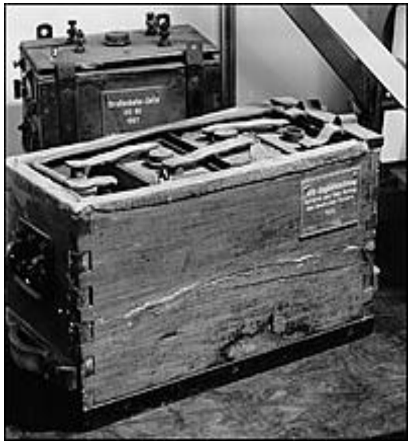
Bagdad Battery, 227 to 126 v. Chr.



Leidsche fles, 1746



Rittersche Säule, 1802



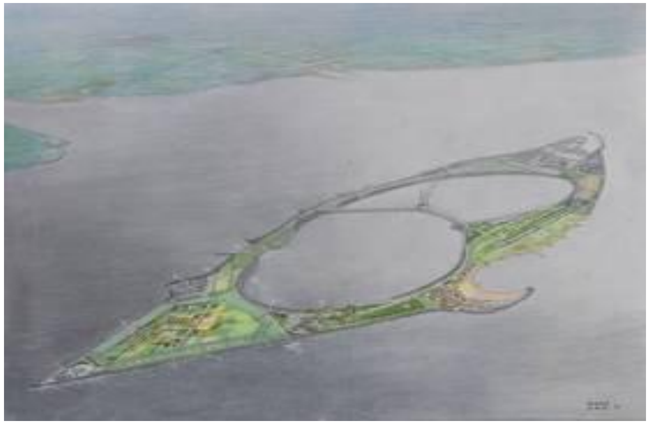
Varta Battery, 1907

Existing and new types of E-storage

- Electricity storage is well-established practice …

Okinawa, Japan, 30 MW (sea water)

- … but is developing fast in new markets



Specifications of storage systems

Checklist:

- ✓Energy capacity
- ✓Power capacity
- ✓Response time/start up time
- ✓Ramp up time
- ✓Cyclability and lifetime
- ✓Round cycle efficiency
- ✓…

Storage ***power*** applications

- <u>Output</u>: High Power/Energy ratio
- Fast reactive abilities
- <u>Power applications</u>
  - Ride through voltage dips
  - Voltage support
  - Load following small areas
  - Transmission support

Superconducting magnetic storage

Lithium-ion

Flywheels

Super capacitors

Storage *energy* applications

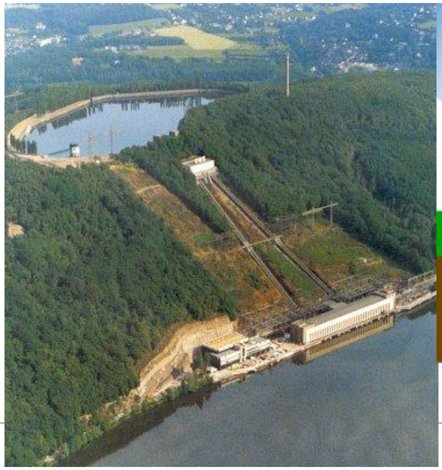
- Output: High Energy/Power ratio
- Long discharge times
- Energy Applications
  - Electric energy time-shift
  - Electric supply capacity, e.g. wind generation grid integration
  - Load following (frequency regulation)

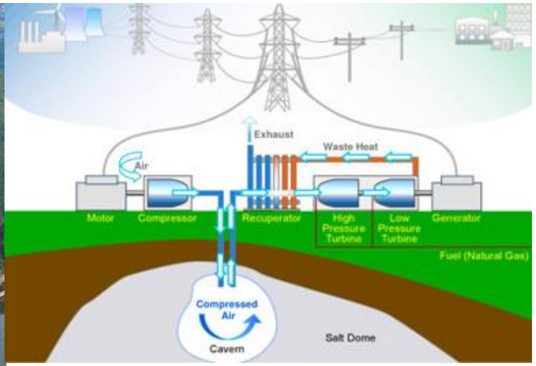
Lithium-ion

Lead-acid

Sodium-Sulfur battery

Pumped Hydro & CAES





Zinc-air

Is there a "Best" Technology Today?

- Many technologies offering variety of characteristics

  - **Power-2-gas -** will be utilized for "centralized" applications (North Sea P2G platform)
  - **Compressed Air Energy Storage –** will be utilized for "centralized" applications
  - **Above Ground CAES** Gen II, projected as 5MW, above ground (SustainX)
  - **Sodium Sulfur (NaS) battery** Long duration, Transmission back-up, but expensive

  - **(Vanadium) Redox Battery -** Long duration, flow battery, used for back-up applications
  - **Advanced Lead Acid Batteries -** 1 to 4 hours, used for renewable integration
  - **Sodium Nickel Chloride Battery -** Targeting vehicles and small backup (Telecom)
  - **Zinc-air -** 1 to 4 hours, used for renewable integration
  - **Li-ion – High Energy** Used for CES, renewable integration, maybe regulation

  - **Li-ion – High Power** used for frequency regulation, renewable integration
  - **Flywheels** 15 minute, many cycles, used for frequency regulation

Each application is finding its niche, but for one device that can serve all applications – not there yet?

- Need fast response, 2-4 hour duration, efficiency > 90%, cost competitive
- Generation II technologies are trying to fill 2-5 hours gap

Lesson learned – de Regenesys case

- Do’s and don’ts
- “Management of development risk within such a project is critical.”
- Total cost for this investigation of the Regenesys technology and demonstration at Little Barford was to be £1,962,916
- After laboratory scale, pilot plant of 1 MWe.
- Technology: Regenerative Fuel Cell
- Very broad scope: large-scale design and manufacturing processes in parallel
- Result: door technische obstakels is project nooit afgemaakt, werd er geen overname klant gevonden en is het project en fabriek gestopt.

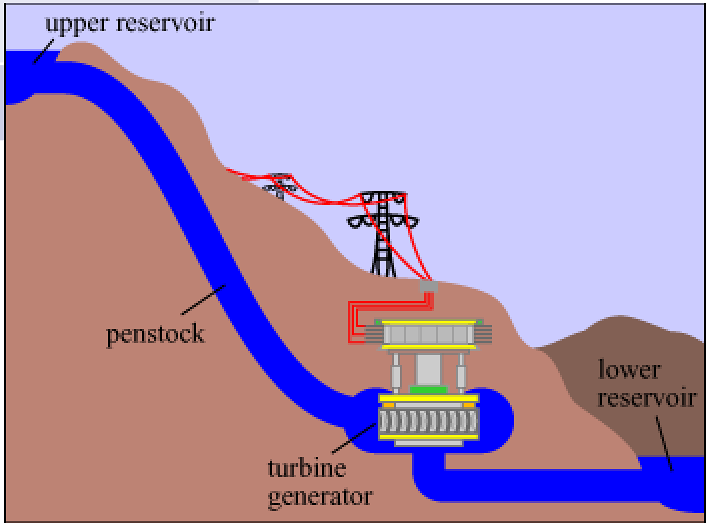
Exterior view of Regenesys Technologies Ltd pilot utility scale energy storage plant at Little Barford, Cambridgeshire, UK, July 2003.

Interior view of the plant – stream of XL modules.

Technologies

Specifications Pumped Hydro Power Storage (PHS)

Pumped Hydro Power Storage	
Response time	seconds
Ramp time	4% of power capacity per sec <3 min
cyclability	Capacity does not depend on cycling
round trip efficiency	75-85%
Power capacity	Multi MW
Energy capacity	Depends on size of reservoir
lifetime	decades



The Energy Island

Innovative plan for large-scale energy storage

Characteristics:

- Artificial island in North Sea, 15 km from the coast, size of 10x6 km^2, water depth of sub surface inner lake is -32 to -40 m
- Storage capacity of 20 GWh, able to provide about 1.500 MW
- Enabler for other functionalities, e.g. 300-500 MW wind turbines, marina for maintenance offshore wind farms, other harbour facilities, substation, aquatic biomass, tourism, nature, agriculture, fish farming,

Specifications Compressed Air Energy Storage (CAES)

Compressed Air Energy Storage	
Response time	minutes-hrs
Ramp time	<15 min
cyclability	
round trip efficiency	65-70
Power capacity	Multi MW
Energy capacity	Depends on size of reservoir
lifetime	decades

- **1978 Germany 320 MW** **(Upgraded 2008)**
- **1991 Alabama 110 MW**
- **Plan: Ohio 2700 MW**

Specifications CAES

	400 MW CAES[1]	180 MW CAES[1]	15 MW CAES[2]
Power [MW]	420	180	15
Storage duration [hrs]	10	10	4
Capital costs [$/kW]	850-900	850-900	1.200
Capital costs [$/kWh]	85-90	85-90	400-450

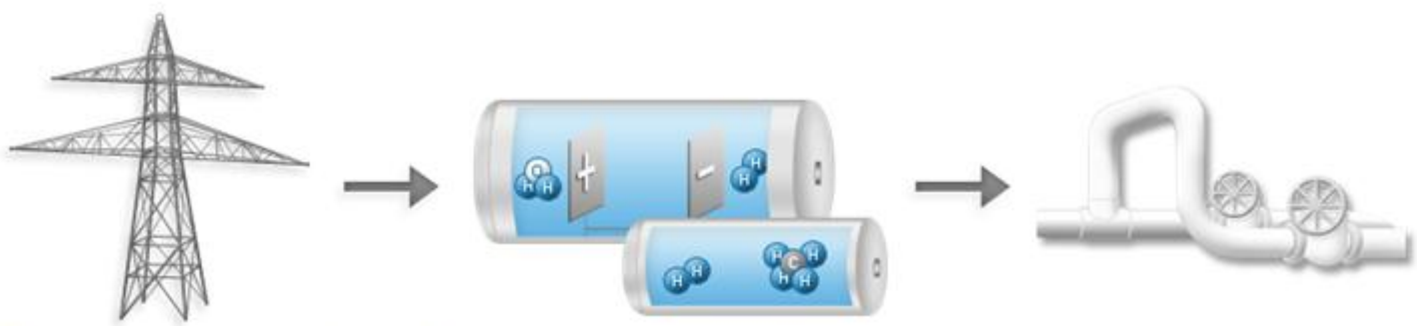
Compressed Air Energy Storage
115MW, 26 Hour System

(1) below ground storage; (2) above ground storage

The concept of Power-to-Gas

Conversion of electrical power into:

- Hydrogen (H_2) by electrolysis
- Methane (CH_4) by methanation of H_2 and CO / CO_2



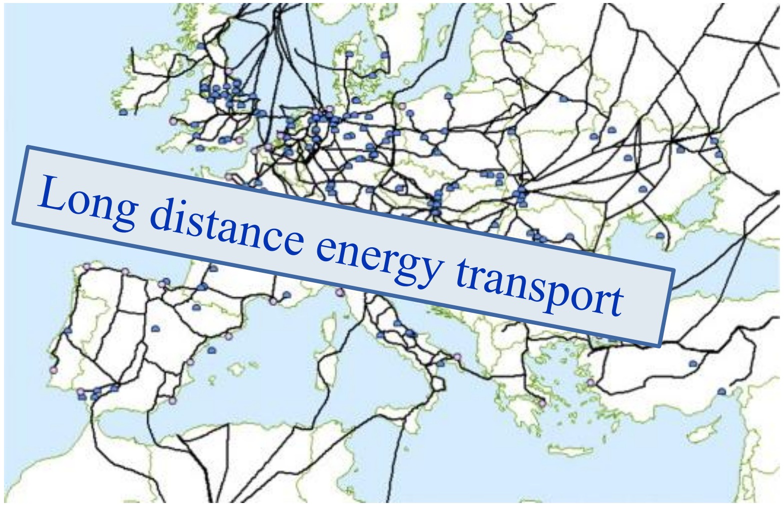
Illustrations from www.powertogas.info

Additional info:

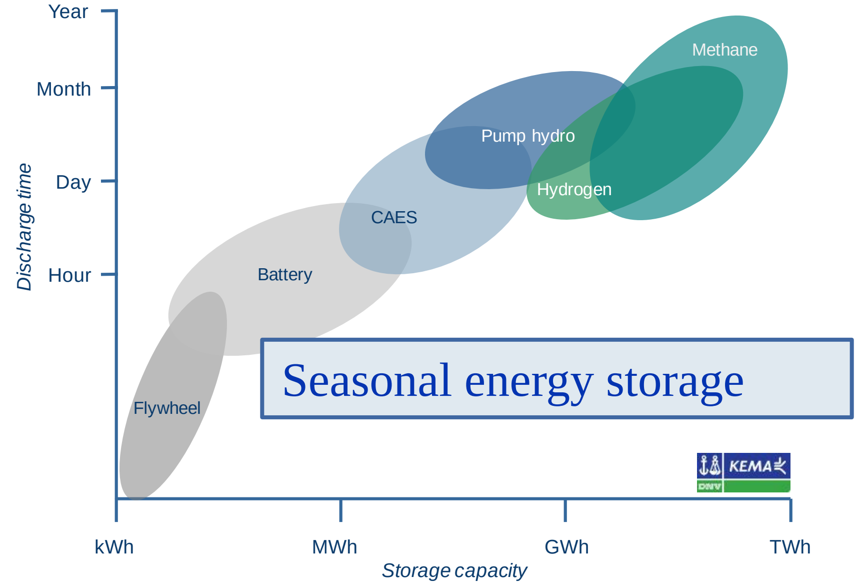
Hydrogen can be limitedly added to the natural gas infrastructure, converted into methane or used in the chemical industry (to produce e.g. methanol)

Methane can unlimitedly be added to gas infrastructure. Methanation is a catalytic reaction, firstly presented by Paul Sabatier in 1902.

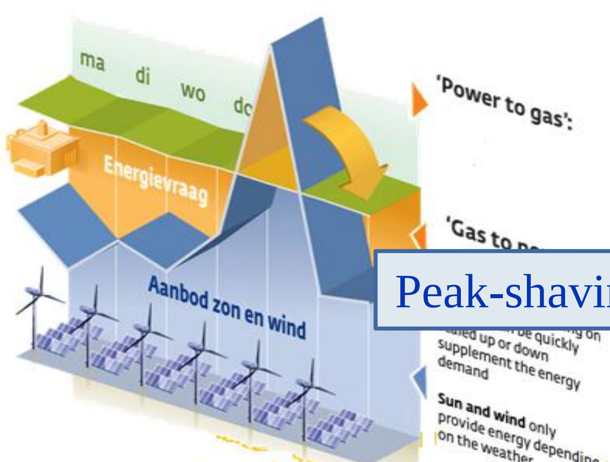
Why Power-to-Gas?



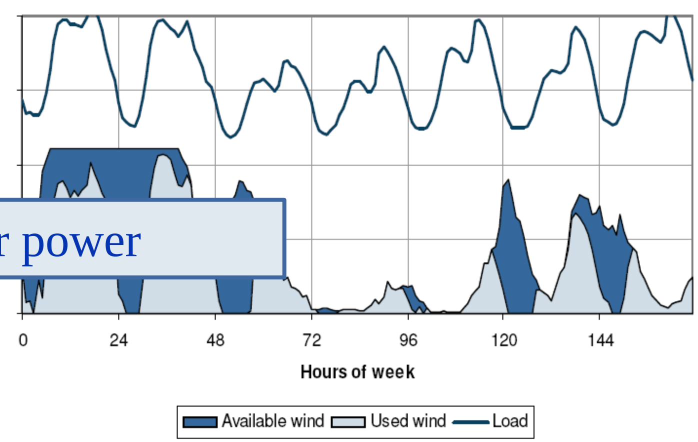
Long distance energy transport



Seasonal energy storage

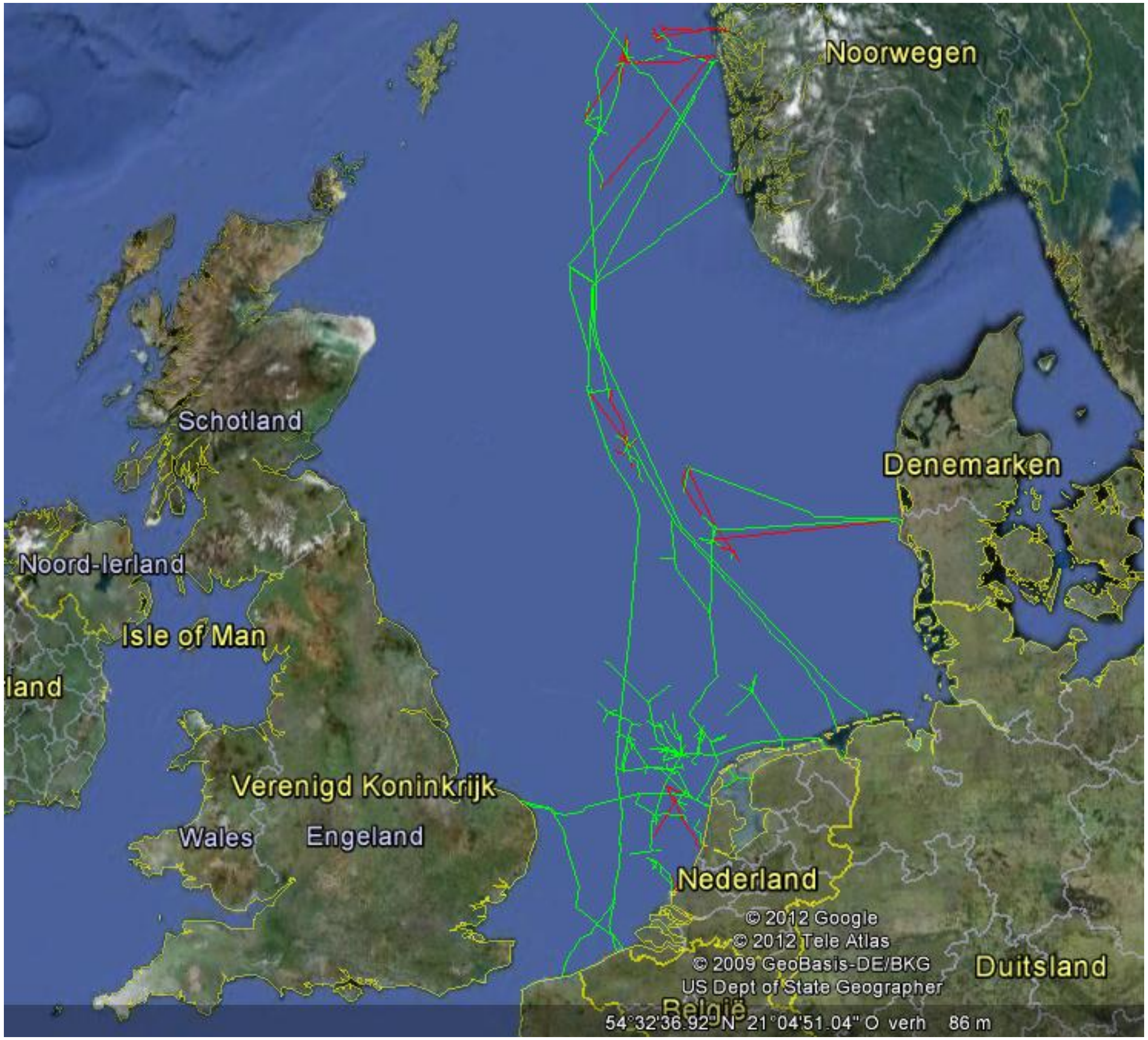


Source: NV Nederlandse Gasunie

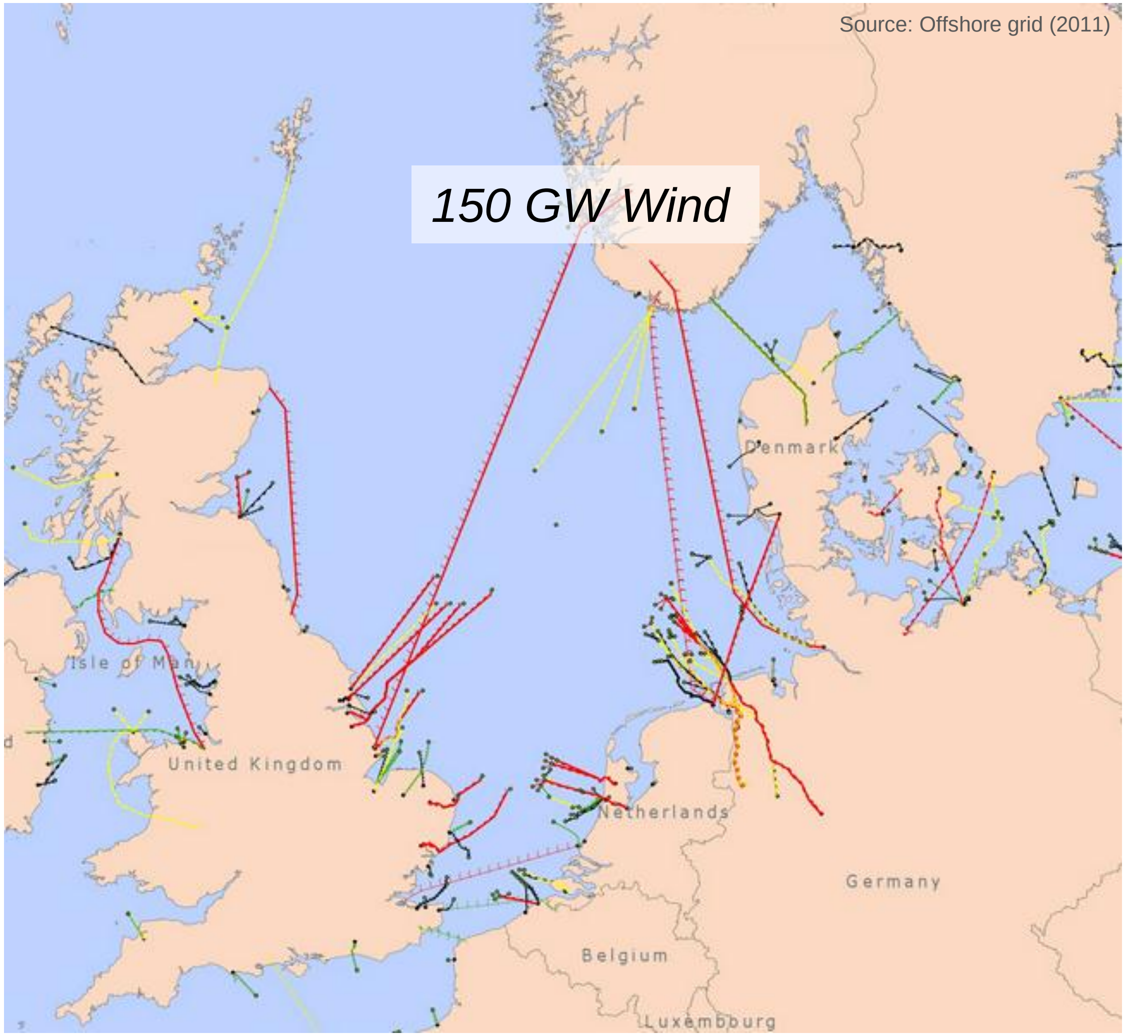


Peak-shaving excess wind/solar power

North Sea Power to Gas – Gas infrastructure



North Sea Power to Gas – Planned Wind Farms



McPhy Energy INGRID Project

Italy

Comments

- 39 MWh Grid Connected Renewable Energy Storage
- Solid-state high-density hydrogen storage system
- 1.2 MW hydrogen generator
- provides balancing support for the local grid managed by Enel Distribuzione

Lithium-ion Battery

1.0MW, 15 min ancillary service

Source: Energy Storage Association – www.energystorage.org

Lithium-ion Battery Storage System

Siemens lithium-ion rechargeable battery

Italy

Comments

- 500 KWh storage system
- For the use of ENEL
- Modular power storage system called as ‘Siestorage’
- Based on lithium-ion rechargeable battery technology

SAFT lithium-ion battery storage plant

Spain

Comments

- Lithium-ion batteries
- Capacity of 1.1 MW and 560 kWh of power
- supplied by SAFT
- Acciona incorporates energy storage into a grid-connected PV solar plant

ABB DynaPeaQ® energy storage installation

UK

Comments

- Static var compensator (SVC) Light® technology with a highly scalable lithium-ion battery
- Eight stacks of 13 Saft lithium-ion battery modules
- Stores up to 200 kWh
- Rated power and storage capacity is typically about 20 MW for approximately 15–45 minutes
- Connected to UK Power Networks

Van klein…naar groter…..en groot

Standaard formaat 18650 (18x650mm)

Capaciteit: 40 Ah
Energie: 128 Wh
Cycles: 2000
Gewicht: 1.53 kg
Max. stroom: 120A

Capaciteit: 1000 Ah
Energie: 3200 Wh
Cycles: 2000
Gewicht: 32 kg
Max. stroom: 3000A

1.0-MW, 7.2-MWh NAS Battery

Source: Energy Storage Association – www.energystorage.org

Distributed Energy Storage
34 MW, 7 Hour Battery with 51 MW Windfarm

Source: Energy Storage Association – www.energystorage.org

Flywheels

- Kinetic Energy Systems
- Steel Flywheels
  (up to 8,000 RPM)
- Composite Flywheels
  (up to 60,000 RPM)
- Magnetic Bearings
  (Levitated Rotor)
- 100 kW for 15 minutes (typical)
- Very high efficiency (> 90%)
- Long life (up to 20 years possible)

Beacon Power's
25 kWh Gen4 Flywheel

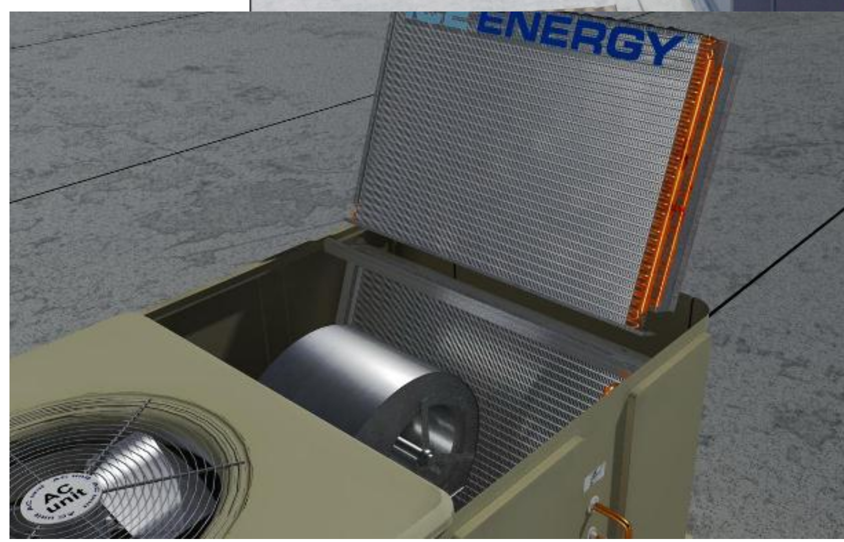
Flywheel Distributed Energy Storage Systems

- Operational 24X7
- Provide ancillary services to ISO (faster response)
- Minimal operation and capital costs
- Liquid process cooling system to cool 200 flywheels and electronics
- Electrical System
  - One 20 MVA transformer
  - Ten ~2 MVA transformers

Source: Beacon

Thermal Storage Systems

- Technology has been available for many years, but new package systems are providing a resurgence in the application
- ICE-Energy, ICE Bear Technology, Glen-dimplex


Lead – Acid Battery

OLD:

- **Low Capital Cost**
- **Short Cycle Life**
- **Low Efficiency**

NEW:

- **Low Capital Cost**
- **improved Cycle Life**
- **Good Efficiency**

Advanced Power Systems

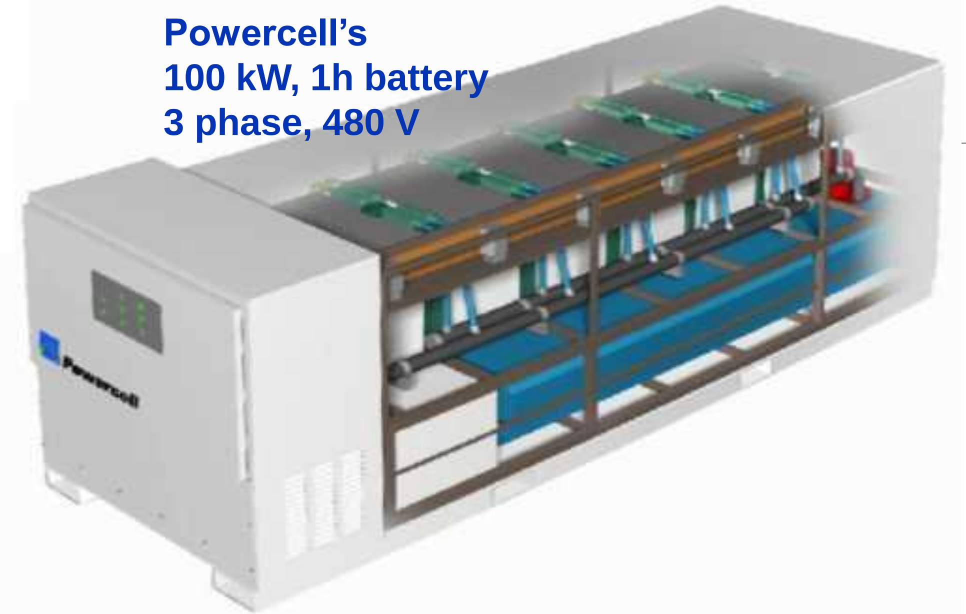
- Technologies have been advanced into devices that are safe, and can conduct multiple charge/discharge cycles

- Currently being demonstrated in the field today for Renewable applications

- Capable of multi-MWh applications

Courtesy: Xtreme Power

Flow Battery Systems



Powercell's
100 kW, 1h battery
3 phase, 480 V

ZBB's 4x50kW, 2.5 hour flow battery in a shipping container

Highview cryogenic energy storage plant

UK

Comments

- The world’s first liquid air energy storage plant (LAES)
- 300kW/2.5MWh pilot plant
- Hosted by Scottish and Southern Energy
- Located in Slough, UK

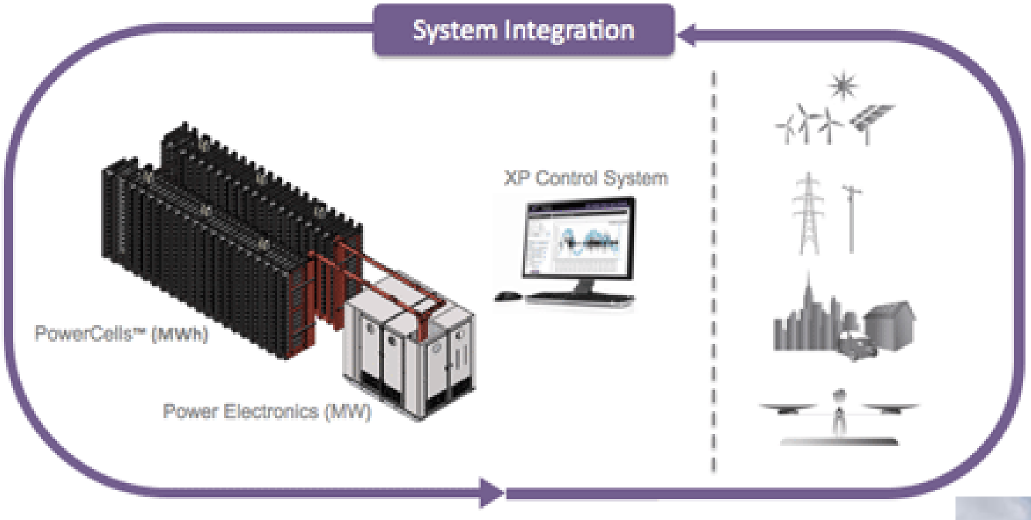
Alternatives, “gravitational” storage

- Advanced Rail Energy Storage, or ARES

- Energy Cache

(http://www.youtube.com/watch?v=G3nz_kU604s&feature=youtu.be)

Netgekoppelde opslag



Wereldwijd in batterij (chemische) opslag
al circa 14 GW netgekoppeld (2012)

Xtreme Power 10 MW opslag bij 30 MW windpark op Hawaii

Nu ook een feit in Nederland!

Enexis Smart Storage Unit – Etten-Leur
Chemie: Li-ion
Laden: 100 kW
Ontladen: 400 kW
Capaciteit: 230 kWh

Summary

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- Energy Storage means: Electricity but also gas, oil, heat & cold
- Storage on Transmission level & Distribution level
- “Storage” is not a value proposition, Flexibility or System Services are.
- Challenge is economical, not technical, value is differentiated over many stakeholders
- Storage needs to compete on Level Playing Field (not yet established)
- Storage adds cost to the energy system, but is required for 100% renewable
- Private Households may/will invest in DG-Storage combi.
- Technology development takes > 15 years, honoring the “10 times” rule-of-thumb

Thank You.

Questions?