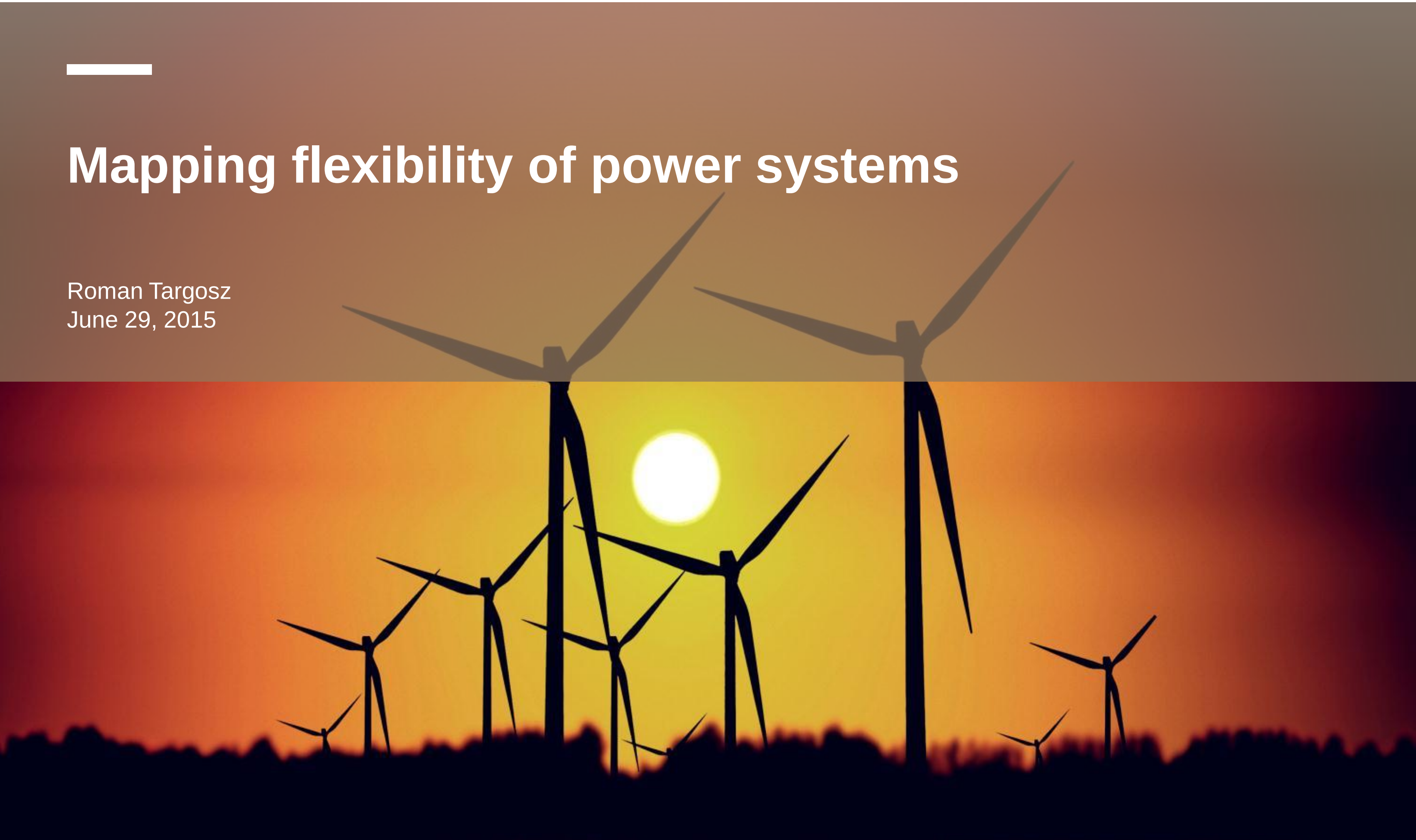
Copper Alliance



# Mapping flexibility of power systems

Roman Targosz
June 29, 2015

# Joint Industry Action on Energy Efficiency

**Coalition:**

- General advocacy to raise the profile of energy efficiency in EU Policy
- Represents 400 associations & 150 companies

**Industry Forum**

- Organises the industry voice on energy efficiency
- 10 associations representing 150 B€ of annual energy efficiency-related revenues

http://energycoalition.eu/

http://www.eeif.eu/

# Clean Energy Regulation Initiative

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CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY

Leonardo ENERGY

21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems

**Thought leadership reports**

**Ask an Expert**

**Webinar Program**

Providing network regulators around the globe with the necessary tools to prepare their systems for renewable electricity and energy efficiency

# Leonardo Energy Activities : E-learning

Copper Academy
DSM University
Energy Management
EU Energy & Climate Policy
Low Carbon Economy
Power Quality Academy

- Since 2009, 130+ learning units
- Training & certification for professionals
- www.leonardo-academy.org
- 7000+ users on Campus

# International Energy Agency Photovoltaic Power Systems Programme

## Participants

**WW communication / reputed source**

24 countries, 4 associations

## Copper Alliance contribution

**Environmental Analysis LCA-LCI**

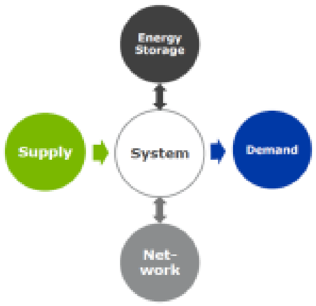
Task 12
CA provides inputs relative to copper (mainly addressing toxicity messaging)

**Bringing the economic and regulatory perspective**

Task 1
CA provides the Analysis of Self-Consumption Models

# Low-Carbon Energy Flexibility Roadmap for near 100% RE

## Mapping Flexibility Options



http://j.mp/flexreport

## Roadmap for near 100% RE

http://j.mp/flexroadmap

## Viability of near 100% RE

**Near 100% RE is possible**

**Requires significant changes in the design and operation of electricity systems**

**Major role for DSM**

Not published

In partnership with ECOFYS

# IEA Implementing Agreement Demand Side Management ( DSM )

- One of the 40+ Implementing Agreements in the IEA’s Energy Technology Initiative

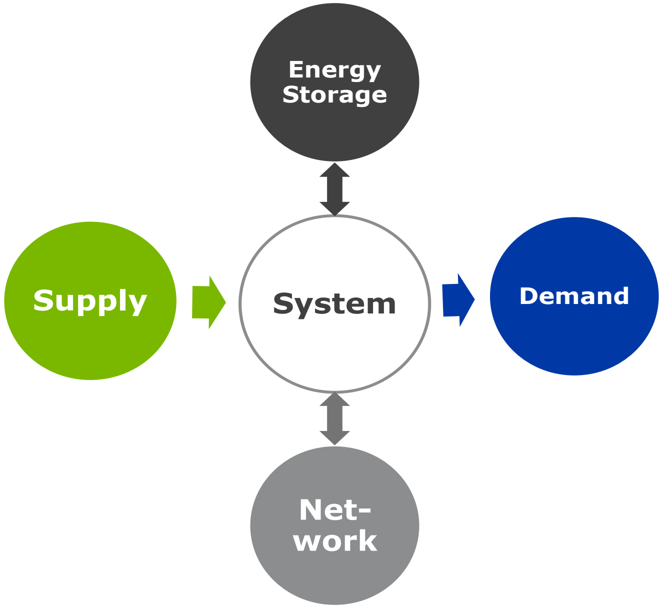
- Over 20 years of experience on DSM technology, programs and policy

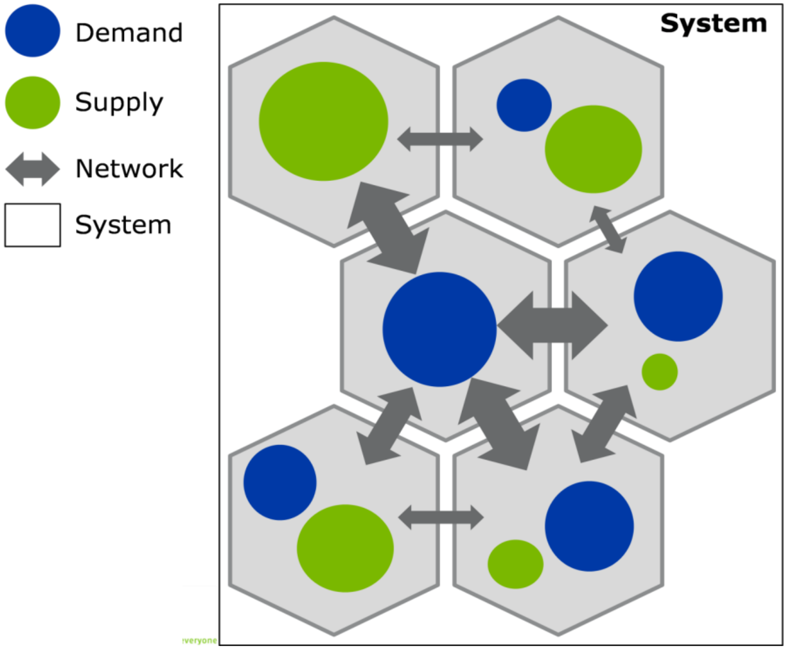
- Copper Alliance contribution:
  - Participation to task 17 – integration
  - Participation to task 25 – new business models
  - Organisation of the DSM University

www.ieadsm.org

# Flexibility

**Flexibility addresses variability of renewable energy systems providing ability of controllable power system components to produce or absorb power at different rates, over various timescales, and under various power system conditions**





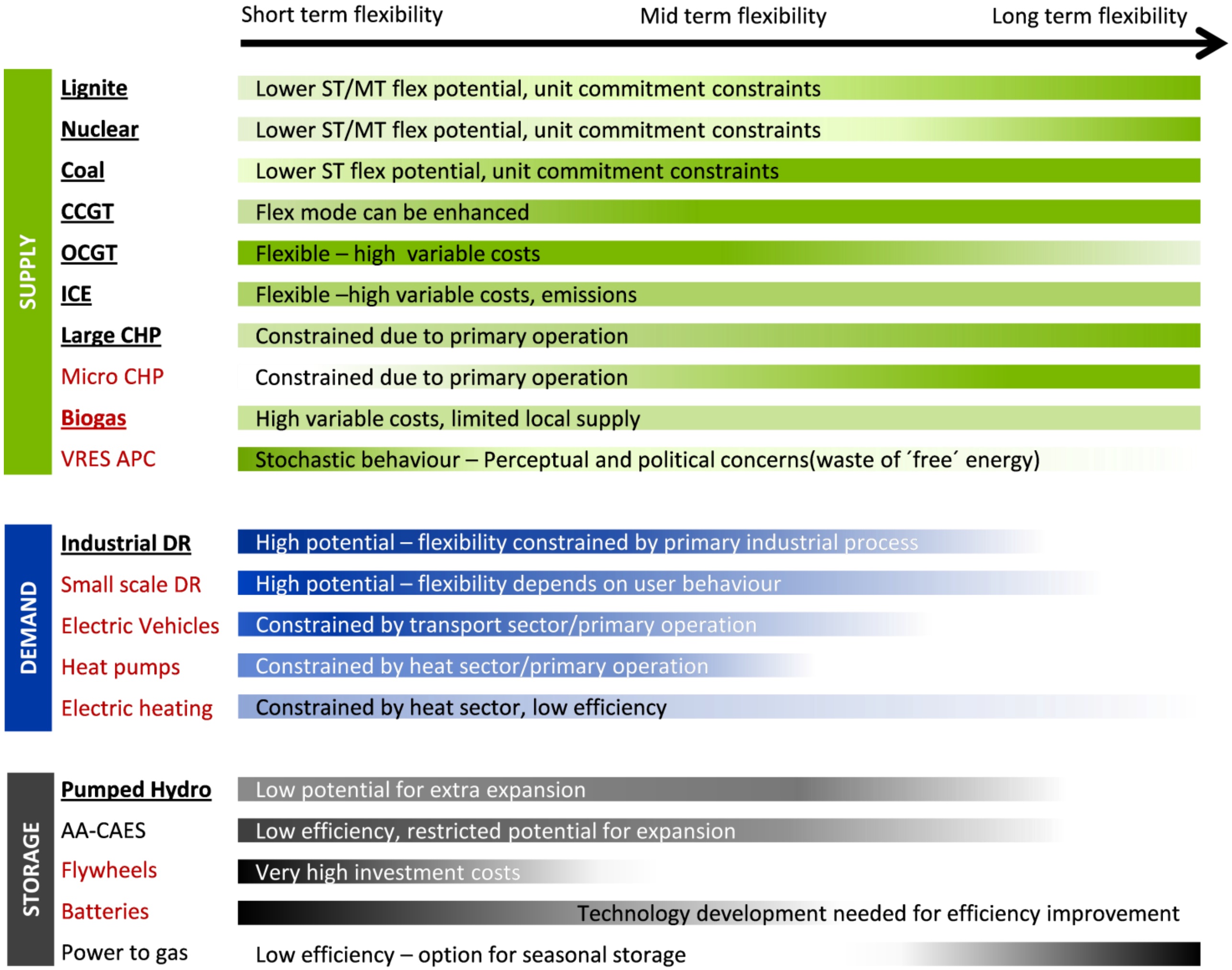
**System:** operational rules

**Demand:** partly controllable

**Network:** ability for spatial matching

**Supply:** controllable or intermittent (RES)

# Flexibility options mapping



Short term flexibility → Mid term flexibility → Long term flexibility

| Group | Option | Assessment |
|---|---|---|
| SUPPLY | **Lignite** | Lower ST/MT flex potential, unit commitment constraints |
| | **Nuclear** | Lower ST/MT flex potential, unit commitment constraints |
| | **Coal** | Lower ST flex potential, unit commitment constraints |
| | **CCGT** | Flex mode can be enhanced |
| | **OCGT** | Flexible – high variable costs |
| | **ICE** | Flexible –high variable costs, emissions |
| | **Large CHP** | Constrained due to primary operation |
| | Micro CHP | Constrained due to primary operation |
| | **Biogas** | High variable costs, limited local supply |
| | VRES APC | Stochastic behaviour – Perceptual and political concerns(waste of ´free´ energy) |
| DEMAND | **Industrial DR** | High potential – flexibility constrained by primary industrial process |
| | Small scale DR | High potential – flexibility depends on user behaviour |
| | Electric Vehicles | Constrained by transport sector/primary operation |
| | Heat pumps | Constrained by heat sector/primary operation |
| | Electric heating | Constrained by heat sector, low efficiency |
| STORAGE | **Pumped Hydro** | Low potential for extra expansion |
| | AA-CAES | Low efficiency, restricted potential for expansion |
| | Flywheels | Very high investment costs |
| | Batteries | Technology development needed for efficiency improvement |
| | Power to gas | Low efficiency – option for seasonal storage |

Red options are small-scale distributed technologies – communication & control infrasturcture key enabler

**Bold/Underscore options are mature technologies – maturity of most demand and storage options is low**

# Flexibility options characteristics comparison

| | | Flexibility potential | | | Economics | | | Lifetime | Maturity |
|---|---|---|---|---|---|---|---|---|---|
| | | Max Reaction times (%/min) | Shifting time (h) | Minimum Load / Must run | Max Efficiency | Variable cost (EUR/MWh) | Investment costs (EUR/kW) | | H/M/L |
| **Thermal generation** | Coal | 6 | N/A | 20 % - 40 % | 48 | 22-30 | 1300-1750 | 35-45 | H |
| | Lignite | 4 | N/A | | 44 | 3-5EUR | 1600-1850 | 45 | H |
| | CCGT | 8 | N/A | 15 % - 50 % | 60 | 40-60 | 680-1250 | 30-40 | H |
| | OCGT | 20 | N/A | 20 % - 50 % | 40 | 60-76 | 380-700 | 25-50 | H |
| | ICE | 20-100 | N/A | 0 | 45 | 260 (diesel) | 140-300 | 20 | H |
| **Nuclear** | | 4 | N/A | 50-60 | 33 | 10-15EUR | 3000-4000 | 50-60 | H |
| **Biogas** | | 100 | N/A | 0 | 40 | 0-60 (Fuel)<br>120-250 (w. CAPEX/OPEX)<br>135-275 (w. Flex) | 3000-6000 | 20 | H |
| **CHP** | Large scale | 5 | 12 | Mustrun | 46 | 3 | 1000 | 30-40 | H |
| | Micro | 20 | 12 | | 15 | 20 | 16000 | 20 | H |
| **Active power control of VRES** | | 100 | N/A | 0 | N/A | 0 | 1000-1800 (PV)<br>1000-1800 (Wind ON)<br>3400-4500 (Wind OFF) | 30-40 (PV)<br>20-25 (Wind Turbines) | M |
| **DSM Industry** | | 100 | 1-24 | N/A | 100 | 0 (no problem with process) - 2000 (Missed production) | 0 | N/A | M |
| **DSM small scale** | | 100 | 1-24 | N/A | 100 | 0 | 0 | N/A | L |
| **Electric Vehicles** | | 100 | 1-8 | N/A | 93 | | 0 | 5-15 | L |
| **Power2 Heat** | Heat Pumps | 100 | 2-24 | N/A | N/A | 0 | 530 – 2560 | 15 - 20 | L |
| | Electric Heating | 100 | N/A | N/A | N/A | 0 | 0 | | H |
| **Pumped hydro storage** | | 100 | 8 | N/A | 70-82 | N/A | 850-2000 | >50 | H |
| **(AA-) CAES** | | 20 | 8-20 | N/A | 40 (CAES) - 70 (AA-CAES) | N/A | 720 - 1000 | 25 | L |
| **Flywheels** | | 100 | 0,25 | N/A | 80-90 | N/A | 1500 - 1650 | 20 | L |
| **Batteries** | Conventional | 100 | up to weeks | N/A | 75-98 | N/A | 815 - 3675 | 5-15 | H |
| | High Temperature | 100 | up to weeks | N/A | 70-85 | N/A | | 10-15 | L |
| | Redox Flow | 100 | up to weeks | N/A | 60-75 | N/A | 1440-3700 $/kW | 5-20 | L |
| **Power to gas** | | 100 | years | N/A | 30-40 | N/A | 1080 - 2775 | 20 | L |

| | | Barriers | | | Role with RES | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Economic | Technical | Political/Environmental | 20% | 50% | 80% | Note | IT Infra |
| Thermal generation | Coal | High CAPEX (new+retrofit)- Flex mode increases OPEX | Endurance and degradation of materials on flex mode | CO2 Emissions<br>Flex mode leads to lower efficiency/higher CO2 | H | M | M | Traditionally Middle load | |
| | Lignite | High CAPEX (new+retrofit) - Flex mode increases OPEX | Endurance and degradation of materials on flex mode | CO2 Emissions<br>Flex mode leads to lower efficiency/higher CO2 | H | M | M | Traditionally Base load | |
| | CCGT | High OPEX | Endurance and degradation of materials on flex mode | Flex mode leads to lower efficiency/higher CO2 | H | H | H | Traditionally Middle load | |
| | OCGT | High OPEX | | | L | M | H | Peak load | |
| | Internal Combustion Engines | High OPEX | IT infrastructure needed for small units | High CO2 emissions, problem when units are situated in residential areas | L | M | M | Peak Load<br>Diesel engines used as emergency backup capacity could be used as distributed generation solution | x |
| Nuclear | | High hidden costs (accident risks and waste disposal) | Flex mode is not considered compatible with nuclear technology | Public opposition. Risks of radioactive contamination of areas in case of accidents. Nuclear waste disposal is also met with high public opposition | H | M | L | Base load | |
| Biogas | | High CAPEX | For flex mode additional storage tank is needed (extra CAPEX)<br>IT infrastructure needed | Public opposition due to impacts to food prices | L | M | H | The only RES option that offers flex operation as thermal gen<br>Upgrading to bio-methane can allow directly storing in the gas network | x |
| CHP | Large scale | Reduced efficiency in flex mode<br>Flex mode needs investments in thermal storage | E-Operation highly constrained due to the thermal duties (high mustrun capacity).<br>Heating networks are necessary for heat distribution for district heating CHPs | | H | H | H | CHP is politically supported due to high energy efficiency | |
| | Micro | High CAPEX | IT infrastructure needed | | L | M | H | micro-CHP is politically supported due to high energy efficiency | x |
| Active power control of VRES | | Opportunity costs due to lost RE production<br>High technical and administrative effort for pooling small units | IT infrastructure needed | Lack of public acceptance on wasting 'free' electricity | L | M | H | Role of APC should be increased with higher penetration levels. | x |
| DSM Industry | | Shifting timing of industrial processes incurs administrative costs.<br>If the process is disturbed there are extra costs due to missed production. | IT infrastructure needed | | L | M | H | High potential, easily realisable option<br>Key industrial processes are: electrolysis, electric arc furnaces and cement and paper production | x |
| DSM small scale | | The flex potential depends on the primary use of the equipment. Equipment often not designed for flex operation.<br>High costs for IT infrastructure | IT infrastructure needed | Data security issues | L | M | H | High potential, depends on the IT infrastructure development | x |
| Electric Vehicles | | Lack of business model | Charging infrastructure<br>Battery technology (low driving ranges)<br>IT infrastructure | Low public acceptance | L | M | H | EV are a parallel development, they do not correspond to power system investments.<br>Role in balancing and reserve power and for localised problems. Development depends on IT infra availability. | x |
| Power2 Heat | Heat Pumps | High costs of electricity<br>CAPEX (1300-1650 costs of HP) | IT infrastructure needed | Several fees, taxes and levies | L | M | H | Heat pumps installation is driven by the heat sector (high efficient solution) | x |
| | Electric Heating | Low efficiency, high OPEX | IT infrastructure needed | | L | L | L | Low efficiency option, mainly used in older installations | x |
| Pumped hydro storage | | Long RoI time | Low energy intensity (energy content of storage basins)<br>Geographical limitations (specific siting requirements) | Reservoirs destroy habitat and ecosystems<br>Low support for new systems | H | M | M | Lack of locations for new plants | |
| (AA-) CAES | | Long RoI time | Geographical limitations (specific siting requirements) | | L | L | L | Low potential for new plants | |
| Flywheels | | Long RoI time | High self discharge losses<br>Safety concerns<br>Cooling system needed for superconducting bearings | | L | L | M | Flywheels are used for frequency support of isolated system (inertia provision) | x |
| Batteries | Conventional | High investment costs, short lifetimes, often lifetime reduced by increased cycling | Recycling of chemical components needed | Contamination from toxic chemical components | L | M | M | | x |
| | High Temperature | | High temperature to keep the salt in molten state | | L | M | M | | x |
| | Redox Flow | | | | L | M | M | | x |
| Power to gas | | High costs and low efficiency | External source of C02 necessary for methanisation | | L | M | H | Seasonal storage | |
| Market Options | | | | | L | M | H | | |
| Network Options | | | | | L | M | H | Super-Smart grids needed for high VRES scenarios | x |

# Demand management in industrial installations

| **Efficiency** | **95 - 100%** | **Reaction time** | **20 – 100%/min (BET)** |
|---|---|---|---|
| **Investment costs** | Can be very low | Variable costs | Can be very low |
| **Installed capacity** | On average, nearly 120 GW of industrial consumption in EU-27 | Maximum energy content | N/A |
| **Lifetime** | N/A | Maximum period of shifting | 1 – 24 hours (BET) |
| **Maturity of technology** | High, some industrial customers already provide interruptible loads on balancing markets | | |
| **Environmental effects** | N/A | | |
| **Barriers** | Economic barriers: development of potential relies on electricity cost sensitivity and on price spreads in the electricity market. In most of the European markets, overcapacity prevents price peaks. In most of the industrial entities, the high organisational effort is not worth the cost savings by shifting demand to low price hours.<br>Technical barriers: potential barriers for specific implementations can be uncertain potential, quality losses in products, short period of shifting, structure of demand (efficient usage of production capacity).<br>Political barriers: some markets punish time differences in demand, e.g. by higher grid fees. | | |
| **Potential role** | Short-term and cost-efficient solution, additional potential for complete shut-down in minutes, but at much higher costs (value of lost load) | | |

# Demand management in services and households

| Efficiency | 95 – 100% | Reaction time | 100%/min |
|---|---|---|---|
| **Investment costs** | 300 – 370 € for meter, gateway and installation | Variable costs | 0 |
| **Installed capacity** | On average about 92 GW residential demand, and additionally about 92 GW from the service sector | Maximum energy content | N/A |
| **Lifetime** | N/A | Maximum period of shifting (h) | 1 – 24 hours |
| **Maturity of technology** | Low | | |
| **Environmental effects** | N/A | | |
| **Barriers** | Economic barriers: Necessary investments in IT infrastructure and data processing, few real time pricing tariffs available and market prices not visible to retail level. Accessing kilowatt-level for pooling loads can be very labour intensive, may have relatively high initial costs, and can take substantial resources to maintain, depends on the primary use of the equipment, which is not designed for flexible operation<br>Technical barriers: uncertain potential, missing communication infrastructure<br>Political barriers: Lack of acceptance or support, data security issues, coordinating utility interests and consumer interests can be a challenging paradigm shift. | | |
| **Potential role** | Demand management might turn out to be the game changer in electricity markets, when flexible demand sets the marginal price in wholesale markets. | | |

# Electric vehicles

| **Efficiency** | **93%** | **Reaction time** | **100 %/min** |
|---|---|---|---|
| **Investment costs** | N/A | Variable costs | - |
| **Installed capacity** | 6.5 kW/vehicle (Nissan Aaltra) | Maximum energy content | 29 kWh/vehicle (Nissan Aaltra) |
| **Lifetime** | 5-15 (battery) | Maximum period of shifting | Hours |
| **Maturity of technology** | The maturity of batteries used in EVs is high. However, there is low experience with using fleets of EVs for flexibility provision. | | |
| **Environmental effects** | The risks are related to the risks from the specific batteries used in EVs | | |
| **Barriers** | Economic barriers: no business model (yet)<br>Technical barriers: very few electric vehicles. Existence of sufficient charging infrastructure. Communication and control infrastructure. Battery technology (low driving ranges, high battery costs)<br>Political barriers: low public acceptance for system use of EVs | | |
| **Potential role** | Potential role for provision of balancing and reserve power. Also for solution of more localised problems. | | |

# Power to Heat

| Efficiency | Resistance Heating transfers 1 kWh of electricity to 1 kWh of heat. Efficient heat pumps with ground storage are up to 5 times more efficient. | Reaction time | 100%/min |
|---|---|---|---|
| **Investment costs** | 530 – 2560 €/kW for heat pumps | Variable costs | 1000 Euro/Liter – 50 Wh |
| **Installed capacity** | N/A | Maximum energy content | Storage facilities are designed for about 2 hours |
| **Lifetime** | 15 – 20 years | Maximum period of shifting | Depending on the isolation of the building – up to 24 hours |
| **Maturity of technology** | High | | |
| **Environmental effects** | | | |
| **Barriers** | Economic barriers: high costs for electricity if extracted from grid, especially for resistance heating (taxes and levies, grid fees). Efficiency of heat pumps a driver for their implementation<br>Technical barriers: constrained due to primary operation (temperature limits), efficiency dependent on ambient air temperatures, use limited to specific period of the year<br>Political barriers: fees, taxes, levies | | |
| **Potential role** | The electrification of the heat sector shifts demand from the heat to the power sector, and can simultaneously add significant flexibility to the system. Combining thermal storage with electric heat has the potential to vastly increase the flexibility of the power grid, builds an optional place to put | | |

# Market and System Operation Challenges

- **Dispatch Frequency**
- **Gate Closure Times**
- **Variable Resource Provision of Grid Support Services**
- **Variable Generator Power Management**
- **Ability of Variable Resources to Participate in Day-Ahead Markets**
- **Allowing Negative Price Bidding**
- **Imbalance Settlements and Penalty Structures**
- **Ancillary Services Market Structure**
- **Appropriate Minimum Bid Sizes**
- **Variable Resource Forecasting System**
- **Variable Resource Ramp Forecasts**
- **Provision of Peak Demand Adequacy**
- **Incorporating Demand Management**
- **Cross Balancing Area Trading and Provision of Ancillary Services**
- **Capacity Market Structure**
- **Treatment of Energy Storage**

# Energy Storage

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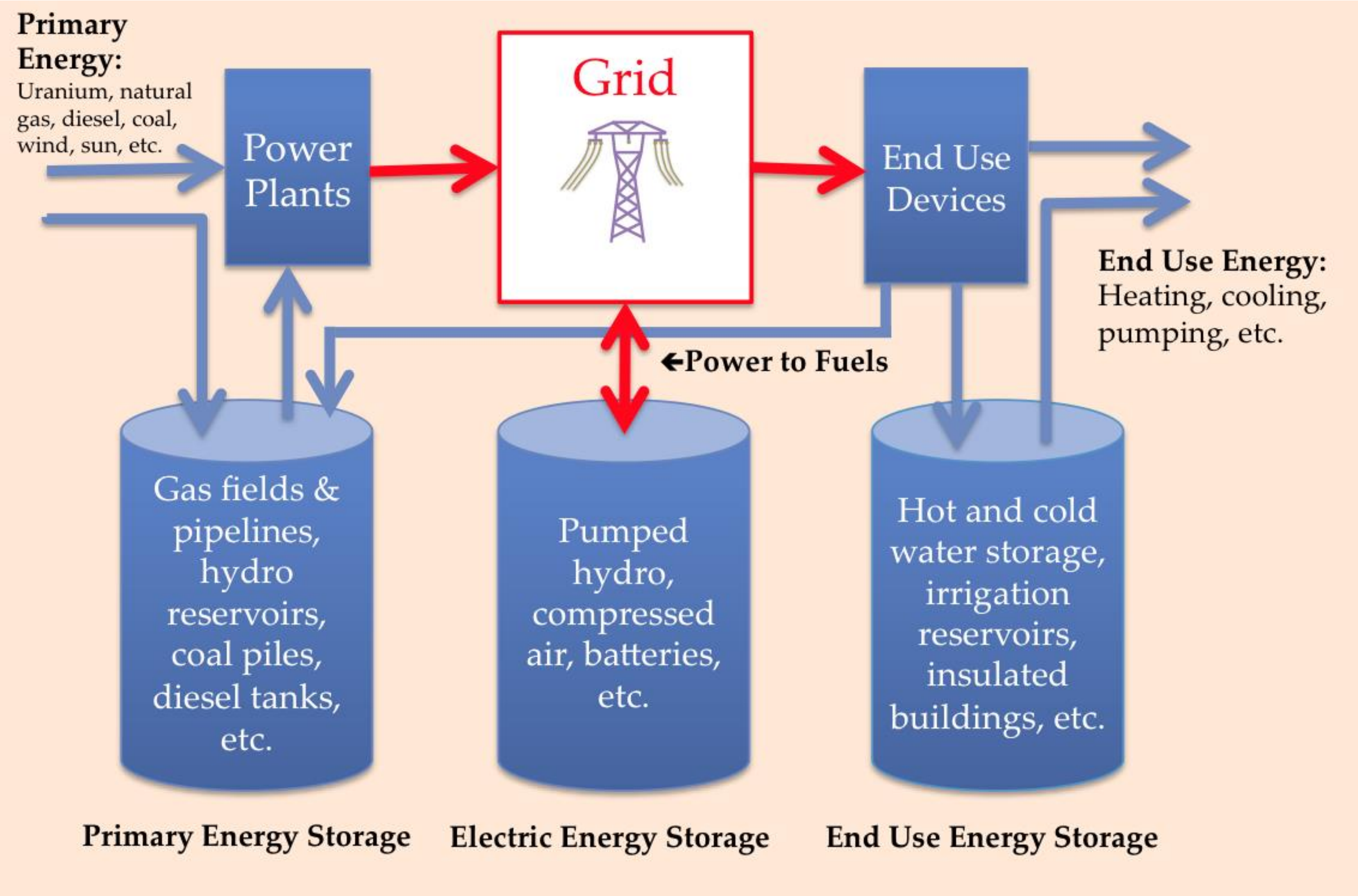


**Primary Energy:**
Uranium, natural gas, diesel, coal, wind, sun, etc.

Power Plants

Grid

End Use Devices

**End Use Energy:**
Heating, cooling, pumping, etc.

**←Power to Fuels**

Gas fields & pipelines, hydro reservoirs, coal piles, diesel tanks, etc.

Pumped hydro, compressed air, batteries, etc.

Hot and cold water storage, irrigation reservoirs, insulated buildings, etc.

**Primary Energy Storage**

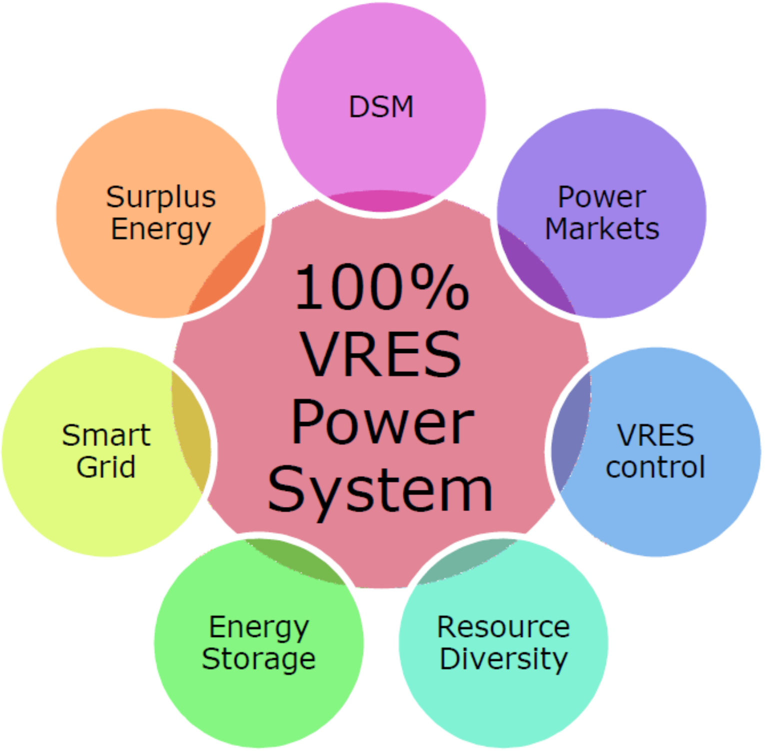
**Electric Energy Storage**

**End Use Energy Storage**

# Key elements of the flexibility vision

Ultimately, the transition to reliable, low-cost power systems dependent primarily on variable renewable resources involves a transformation in how power systems are planned and operated. How that transformation unfolds will depend on the conditions of the specific power system—the available renewable resources, availability of energy storage opportunities, composition of demand, interconnectedness to other power grids, etc. Nevertheless, there are certain characteristics that are likely common to all

1. Flexibility and energy storage inherent in **demand** will be more fully exploited, with today's power consumers becoming power system partners.
2. Wholesale and ancillary services **power markets** will become more liquid, operating closer to real-time and their geographic reach will be expanded in order to access existing sources of flexibility and exploit the diversity of distant variable resources.
3. Variable renewable generators will be **controlled** to provide grid support services and to reduce variability and uncertainty deriving from uncontrolled renewable resources.
4. Price incentives or other mechanisms will be instituted that appropriately **reflect diversity-related benefits** in the development of new variable resources.
5. **Bulk energy storage** will be instituted to cover longer periods (weeks to months) of low renewable energy supply.
6. More sophisticated communication and controls will be instituted to coordinate flexible resources across supply and demand, and across transmission and distribution grids—the "**smart grid**."
7. New electric energy uses will arise to capitalize on the occasional, but increasingly frequent **surplus energy events**.



# Near-Term Policy Flexibility Checklist

| Near-Term Objectives | Near-Term Policy Actions |
|---|---|
| **Minimize Conventional Generation Reserve Costs** | • **Balancing authorities begin looking to expand the geographic and technological sources of balancing services.**<br>• **Reducing operating period lengths or developing markets for sub-hourly dispatch.**<br>• Begin implementing or considering shorter gate closure times.<br>• **Quantifying and Valuing reserve requirements.** |
| **Lay Foundations to Address Mid-Term Objectives** | • Remove market practices that unduly penalize VER from full participation in the market (e.g., imbalance penalties, day-ahead under-performance penalties, etc.).<br>• Begin revising VER incentive structures to reduce penalties for providing balancing services.<br>• Begin developing robust grid codes.<br>• Begin developing institutional and technical frameworks for smart grid.<br>• **Begin developing dynamic/situational reserve requirements.**<br>• Evaluate the benefits and best use of VER forecasting systems.<br>• Encouraging VER to provide flexibility and grid support services.<br>• Developing frameworks for offering diversity incentives.<br>• Begin planning for phase out of inflexible baseload resources.<br>• **Begin developing market for demand resources—expand demonstrations.**<br>• Begin considering new business paradigms for utilities (e.g., decoupling).<br>• Develop VER ramp forecasts and incorporate into dynamic reserve assessments. |

# Mid-Term Policy Flexibility Checklist

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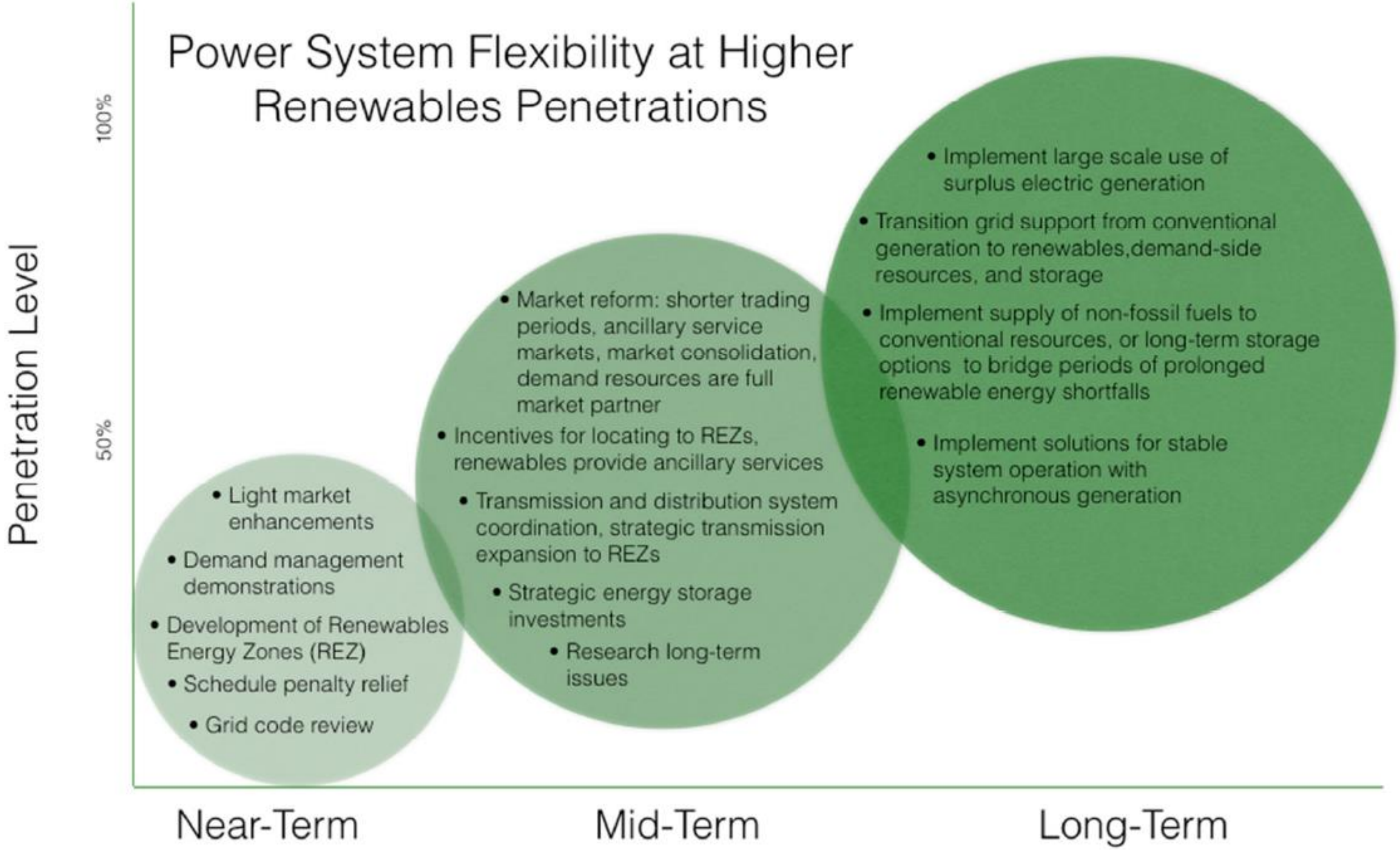
| Mid-Term Objectives | Mid-Term Policy Actions |
|---|---|
| **Increase Market Incentives to Promote Greater Resource Participation for Flexibility** | • **Expand markets for flexibility—more flexibility service types, as well as more institutional participants, and technology sources (e.g., demand).**<br>• **Reflect low wholesale market prices at the retail level (develop appropriate tariffs where needed).**<br>• Remove barriers to VER providing flexibility and grid support.<br>• **Allow negative wholesale market prices.**<br>• Remove any penalties that unduly restrict VER participation in markets.<br>• **Implement peak demand contribution assessments for all resources on comparable bases (conventional generators, VER, demand resources).**<br>• Modify VER production incentives to encourage diverse deployment of resources.<br>• Implement policies to encourage the retirement of baseload plants |
| **Allow Demand-Side Market Participation** | • **Develop institutions and/or incentives to promote development and aggregation of demand management.**<br>• **Comprehensive incentives and institutions to develop distributed generation resources.** |
| **Manage Distribution Grids** | • Transition of distributed generation to require communication and control equipment for system dispatch.<br>• **Implement aggregation and optimization of distributed generation and demand management—the smart grid.** |
| **Enhance Transmission Network Functions** | • Implement dynamic measurement, capability assessment, and control of transmission systems.<br>• Institute geographic granularity of (nodal) market prices capable of reflecting price implications of relevant congestion points. |
| **Increase Market Functionality** | • Liberalize flexibility markets to allow bids for shorter time periods (e.g., hours or minutes instead of years) and for more specific purposes (e.g., generation increases separate from generation decreases).<br>• Implement shorter gate closure times (no more than one hour).<br>• Implement shorter trading/dispatch periods (no more than ten minutes).<br>• **Consolidate balancing areas explicitly or virtually through other mechanisms (e.g., imbalance markets) to cover the largest practicable regions.**<br>• Implement capacity markets for resources that are needed for reliability but for which existing market incentives are inadequate. |
| **Lay Foundations to Address Long-Term Challenges** | • Begin retirement of inflexible baseload resources.<br>• Begin implementing new business paradigms and regulation for utilities (e.g., return on total system costs, decoupling, others).<br>• Implement grid codes capable of operating power systems without synchronous generation.<br>• Implement best practices for VER forecasting and use of forecasts in planning and operations.<br>• Implement VER ramp forecasts and incorporate into dynamic reserve assessments.<br>• **Implement system-based energy storage valuation methods, and institute mechanisms (e.g., capacity payments, or minimum acquisition levels) to develop cost-effective energy** |

# Long-Term Policy Flexibility Checklist

| Long-Term Objectives | Long-Term Policy Actions |
|---|---|
| **Able to Supply Power during Low Output Events** | • Implement incentives to ensure adequate resources under for low output events. |
| **Efficient Use of Power During High Output Events** | • Complete phase out of inflexible baseload resources.<br>• Implement policies develop optional uses of electric power (e.g., thermal energy storage requirements, dual fuel boiler capability, etc.). |
| **Full Smart Grid Implementation** | • Maximize use of transmission grid infrastructure and distributed generation and end-use flexibility options. |
| **Ensure Stable Operation with Non-Synchorous Generation** | • Require all VER (above a certain size and/or vintage) to be capable of providing needed ancillary services through markets and grid codes. |

# Changes needed for the transformation of the power system with growing VRES penetration levels.



- Light market enhancements
- Demand management demonstrations
- Development of Renewables Energy Zones (REZ)
- Schedule penalty relief
- Grid code review

- Market reform: shorter trading periods, ancillary service markets, market consolidation, demand resources are full market partner
- Incentives for locating to REZs, renewables provide ancillary services
- Transmission and distribution system coordination, strategic transmission expansion to REZs
- Strategic energy storage investments
- Research long-term issues

- Implement large scale use of surplus electric generation
- Transition grid support from conventional generation to renewables,demand-side resources, and storage
- Implement supply of non-fossil fuels to conventional resources, or long-term storage options to bridge periods of prolonged renewable energy shortfalls
- Implement solutions for stable system operation with asynchronous generation

# Flexibility technolgies over time horizon

## Mid Term Flexibility

Flexible coal, gas and ICE plants, while the potential of CHP depends on thermal storage and on primary operation constraints. Active power control of VRES is an option for mid-term flexibility, but risks perceptual and political concerns over lost clean energy.

**Pumped storage plants are a mature option in this respect, but their potential is restricted by geographic constraints, while AA-CAES present lower efficiencies. Large scale storage capacity for several hours is expensive for batteries and other small scale storage options.**

**Industrial demand management could offer a good demand shifting option with low variable costs. Small-scale DR presents a potential but this option requires enabling communication and control infrastructure. Options driven by developments in other sectors (electric vehicles and heat pumps) have the advantage of not presenting an power sector related investment, but are restricted by their primary operation.**

## Short Term Flexibility

OCGT and ICE, but at the expense of high variable costs. Active power control of VRES presents a potential, however hindered by the inherent operational uncertainty due to the stochastic prime mover.

**Storage options present a potential for short-term flexibility. Pumped storage is a mature and cost-effective option, however with a low potential for extra capacity due to the constraints on geographic siting. Imbalances of up to 15 minutes can be solved by flywheels and the technology is particularly suited for very short term flexibility requirements. Batteries (and EVs) offer the required technological characteristics.**

**Demand management could provide economical short term flexibility. Industrial DR is the low hanging fruit but should include management involvement for industrial customers while small-scale DR is restricted by primary operation and by the relative cost of control and communication infrastructure.**

## Long Term Flexibility

In the long run, only one storage technology competes with thermal power plants. Thermal power plants can be seen as facilities, that store electricity in form of fuels. Power to gas is the technology that transforms electricity back into a fuel (gas or hydrogen), however in the expense of low efficiency. This is only economical in systems with very high shares of VRES, and correspondingly high numbers of oversupply events. **On the demand side, no significant options appear, since shifting demand in longer periods is not generally applicable.**

# Conclusion

**Building power systems with sufficient flexibility that rely primarily on power from variable energy resources involves a significant system transformation. There is a plenty of flexibility options that can be used in this respect. In both near-term and mid-term challenges are largely institutional. They focus primarily on accessing untapped flexibility in existing infrastructure and improving efficiency of electric markets to correctly reflect the value of flexibility and reaching out to greater participation— including end use loads. The biggest institutional and policy changes are needed in the mid-term to access the inherent power system flexibility.**

**Relying almost entirely on variable renewable generation requires grid support services fully transitioning away from fossil generators to other sources, including the renewable generators, end use sources, and energy storage. Significant challenge will be to ensure the highest value use of occasional large power surpluses and to enable reliable and continuous service during periods of low renewable energy production. Renewable energy-sourced fuels for conventional generation can be part of the solution.**

# Thank you

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