

Symposium Resilient energy systems

Minutes of the table discussions

Table 1: Long term storage

Esther Alarcon Llado

For the purpose of the discussion, long-term storage was defined as storage with a duration exceeding 8 hours, extending from daily balancing to seasonal shifting. The panel agreed that such storage solutions are essential for enabling a reliable, low-carbon energy system by 2050. Long-term storage was seen as essential for balancing supply and demand across the Dutch energy network. By storing excess electricity during periods of high renewable generation and releasing it during shortages, storage systems can reduce grid congestion and enhance reliability.

1. Overview of Long-Term Storage Technologies

The panel structured the discussion around different categories of storage technologies, classified by the type of energy stored: chemical energy, heat, and hydro-based systems. A clear conclusion was that a diverse set of technological solutions is needed, as no solution fits all.

Chemical Energy Storage

A significant part of the discussion focused on chemical storage technologies. These included solid-state batteries (such as lithium- and sodium-based systems), flow batteries (liquid-based storage), CO₂ batteries (gas-phase storage), metal oxides (e.g., iron oxides), and hydrogen produced via electrolyzers.

Panelists noted that these technologies span a wide range of storage capacities and are generally at medium Technology Readiness Levels (TRLs). A key advantage identified was the possibility of transporting chemical energy carriers over long distances, enabling not only domestic balancing but also cross-border energy trade.

Hydrogen was discussed extensively. While recognized as a promising energy carrier, participants highlighted ongoing technical challenges. Hydrogen transport may lead to pipeline corrosion, and large-scale storage remains technically and socially complex. Underground storage in caverns was mentioned as a possible solution, but concerns about public acceptance and safety were raised. The panel agreed that chemical storage is particularly suitable for durations ranging from hours to several weeks, though it becomes less efficient for storage over multiple months.

Heat Storage

Heat storage solutions discussed included concentrated solar thermal systems, geothermal energy storage, and solid-state heat storage. Panelists emphasized the potential of geothermal storage for seasonal heat supply at a local level. However, they also noted that not all regions of the Netherlands have suitable geological conditions, limiting uniform nationwide deployment.

Pumped Hydro Storage

Pumped hydro storage was recognized as a technically mature and effective long-term (including seasonal) storage option. However, the panel acknowledged that its

implementation in the Netherlands would involve significant environmental impacts and spatial challenges. These factors must be carefully considered in national planning.

2. Materials Research and Circularity

Across all technology categories, the importance of materials innovation was repeatedly emphasized. Panelists stressed that advances in materials discovery are central to improving performance, durability, and cost-effectiveness. At the same time, they agreed that recycling and circularity must be embedded in technology development from the outset to ensure sustainability and reduce resource dependency.

3. System-Level Considerations

Beyond individual technologies, the discussion addressed broader system implications.

Integration of Renewable Energy

The panel agreed that high penetration of wind and solar energy will require substantial storage capacity. Long-term storage enables more efficient use of renewable generation and reduces curtailment, thereby strengthening overall system resilience.

Infrastructure Challenges

Participants noted that large-scale deployment of storage technologies will require substantial infrastructure investments. Spatial planning, grid reinforcement, transport networks for energy carriers, and public acceptance were identified as key challenges. Regional differences in geology, industrial activity, and population density further complicate implementation strategies.

Policy and Economics

A strong consensus emerged on the need for stable and long-term policy frameworks. Panelists emphasized that energy storage investments require regulatory clarity and robust economic assessment. Crucially, policy continuity should not depend on changing political leadership.

One proposal discussed was the creation of an “*Energieschap*,” analogous to the Dutch water boards (*waterschappen*). Such an institution could provide stable, regionally anchored governance of energy infrastructure, ensuring long-term oversight and local ownership while reducing political volatility.

4. Key Conclusions

The panel concluded that no single technology can meet all energy storage requirements—from hourly to seasonal timescales—nor can one solution serve the entire country. Instead, resilience will require a diverse portfolio of technologies tailored to regional conditions.

While many promising solutions and innovative ideas are emerging, panelists stressed the importance of **strategic focus**. They recommended that the government make clear choices regarding priority technologies and commit to sustained investment in research and development. A **long-term R&D commitment (~ 10y)** was considered essential to advance selected technologies to the required TRL levels and to ensure a resilient Dutch energy system by 2050.

Table 2: Energy Production

Gert Jan Kramer

Energy production is such a broad theme that we first selected a few topics on which a diverse group of physicists might have something useful to say. They were

1. The interplay between energy production and energy storage
2. The future primary energy mix
3. Carbon dioxide removal
4. “Take control”

Due to time constraints, we limited ourselves to exploring the second and fourth topic.

The future primary energy mix

We did a poll of participants’ expectations of the primary mix for the Netherland that would deliver climate neutrality. The choice was between solar, wind, nuclear and carbon-based primary energy sources (with the ration between fossil¹, bio and waste left unspecified). The outcome of this completely unscientific poll was this:

solar:	10 - 35%
wind:	20 - 45%
nuclear:	0 - 50%
carbon-based:	20 - 40%

We conclude that solar, wind and carbon-based are major and inevitable contributors to the future mix. But also that opinions of the role of nuclear vary enormously. These ranges are much wider than what is deemed plausible in expert reports. One might see this as a sign of experts’ tunnel vision or group think. But it could also be that even physicists have little intuitive grasp of what it takes to build a carbon-neutral energy system.

It was noted that the future size of the Dutch energy system is very much dependent on the future of Dutch industry, notably basic industry. This will presumably also affect the relative share of primary sources, but this was not discussed.

Take control

This was a *Cri de Coeur* from one of the participants: the case for change is clear. (And has been clear for a long time.) Much can be done. The technology is at the ready. Yet... the pace of change is below what is considered possible, let alone desirable. While the problem is clear and broadly recognized as a real problem, it proved difficult to come up with solutions. The opportunity space was scanned, bringing up the usual evergreens from *burgerberaad* to *draagvlak* and consistency of policy. What did transpire is that participants recognize a need for a greater role of government. Perhaps energy transition management can take clues from the time-honored institutions of water management, such as *waterschappen* and/or a *regeringscommissaris*.

¹ Since the condition is climate-neutrality, this assumes that fossil use is combined with CCS and any fossil emissions are offset by CRD.

Table 3: resilience.

Peter Hermans

This table responded to the question what messages from the discussions could be relayed back to the ministry.

1. First, more **clarification and information** would be appreciated that would give answers to the following questions:
 - If we discuss resiliency: what is the current baseline scenario and can we distinguish multiple scenarios?
 - If we focus on resiliency, what scale are we talking about then (national, regional, local)?
 - With respect to improving resiliency: who will need take what action? (at National, Regional and Municipal level)?
 - As there is a clear strategy for Wind and Solar, how would a focussed strategy on storage look like (batteries, WKO, etc.) also on geographical level, so that this, in combination with Solar and wind would contribute to the enhancement of resiliency? Can this strategy be stimulated via focussed subsidy schemes?
 - If we increase load on the existing infrastructure to mitigate the “waiting for connection lists” what would be the maximum norm for that; this is to enable that the regulator (ACM) can determine whether investments in grid capacity are too high or too low.
 - What bottom-up initiatives from the society would the ministry welcome to help mitigating congestion, and would the ministry be willing to assist in creating a more successful cooperation between local initiatives, municipalities and grid operators?
2. The advice to the ministry is to stimulate that **local energy sharing** becomes a success, both technically and financially, with the objective that it avoids excessive future grid tariffs and that it contributes to enhanced resiliency of the energy system (e.g. local balancing).
3. The advice to the ministry is to work towards a system and market set-up such that, in case of a national blackout, the **decentralized parts of the energy system** could remain functioning to supply energy at a lower energy volume level (dependent on what is locally or regionally available).

Table 3 also discussed the change management strategy and process that needs to be in place to arrive at a more resilient energy system.

4. The advice to the ministry is to come forward with a **clear and widely accepted vision** on where we want to go, what we would like to achieve (“world of B”) and the first steps today. This requires:
 - more own knowledge, independent from market actors, at the ministry (especially on digitalisation)
 - educational efforts towards the parlement and senate (as they have the final saying), to guide and support them in the change process.

- new and more “transition oriented” leadership styles at the ministry, including a more “risk taking and learning from doing” culture. Regulatory sandboxes (“*de experimenteer regeling*”) should be re-introduced.
5. The advice to the ministry is to create a process in which on national level the **vision and guardrails** (*kaders*) are established, which is augmented at regional level with “*planologie*” aspects (*ruimtelijke ordering*) and which then facilitates all bottom-up initiative from municipalities (in close cooperation with local energy communities and energy hubs).
 6. The advise to the ministry to take **strong control** (“*regie*”) over decisions which are made by the grid operators, including the final investment decisions of TenneT, and to steer that more information from grid operators is shared with municipalities, provinces, market actors, energy communities’ and energy hubs, so that this enables also viable solutions for mitigating congestion, which do not origin from the grid operators only.
 7. The overall concluding advise to the ministry is to **take control over this transition process which enables bottom-up contributions** to a more resilient, reliable and sustainable energy system and which rebalances societal versus market interests.

Table 4 Short Term Storage Technologies

Anja Bieberle

1. Definition:

- Short term storage solutions are defined at different time scale
- We refer here to short term as between ms and 1 week

2. Current short term storage solutions:

- (electro)chemical, such as battery
- Mechanical
- Physical
- Thermal

3. Needs to realize short term storage solutions and to get better in those.

- Most households in NL have short term storage already in house, e.g. through e-car, e-bike, etc., but it is not used continuously and efficiently for e.g. other applications when not in use for main application. For example, can the e-car battery be used for bidirectional charging (charging and discharging while the car is not used), communal grid? → more flexibility is needed for local usage of energy from short term storage technologies.
- More focus on steering and control of cycli, both for storage and usage
- Even more different short term storage solutions are needed than are available already now; many good ideas are not followed. Reason for diversity: scarcity of materials, processing capacity and knowledge.
- There should be a shift in thinking from energy units to how much power we need; Power = energy/time – this is a motivation to invest in short term storage solutions.
- A lot of solar cells are on the roofs of NL households. But in case of an electricity shortage the electricity cannot be used since it only works with an electrically driven converter – this is a fast and quick fix which will solve many problems for many in case of a black out.
- More general education is needed on energy usage and savings.
- Short term solutions bring instabilities of the grid – this needs to be better understood.
- Recycling and materials availability should be considered early in new developments; however, it is questioned whether scarce materials have to be fully banned, if they are e.g. available in Europe, or only very little material is needed or only for a niche product, it might be possible to use – the entire value chain has to be considered.

4. Thoughts in relation to companies

- Do we in NL support startups to work on alternative solutions seeing the need for diversity of solutions needed; also invest in niche solutions.
- What kind of industries should NL/Europe be a key player in? For our future resilience, also regarding materials availability.
- Autonomy and regulations are needed for making long term solutions for short term storage feasible.
- Europe should produce its own batteries; watch out for global dependences.

Tafel 5 - Scaling Challenges

Wouter Leibbrandt

Two key scaling challenges can be identified.

1. Scaling from proof of concept to large-scale production

Several challenges arise in this transition:

- **Technical challenges:** Moving from the technology of the product itself to the technology required for large-scale production.
- **Societal introduction:** Recognizing and addressing non-technical factors such as company culture, identifying early customers who are willing to adopt and take risks with new technologies, and establishing production and distribution chains.
- **Financing:** In the Netherlands and the EU, it is often difficult to secure the substantial investment required for scaling up. As a result, companies sometimes turn to the United States (e.g., Solvinty) or China (e.g., Nexperia) for financing and growth opportunities.

2. Scaling from limited deployment to mass deployment (e.g., home batteries, Energy Management Systems (EMS), and grid reinforcement)

This stage also involves several challenges:

- **Fragile long-term business cases:** For example, trading electricity on the imbalance market with home batteries may currently be profitable, but if adoption becomes widespread, profitability could decline significantly.
- **Spatial constraints:** A fivefold increase in 380 kV/150 kV substations in the Netherlands would require fundamentally different spatial planning compared with the current situation. The same applies to large battery parks and other infrastructure, while space in the Netherlands is already scarce.
- **Financing and workforce capacity:** Building a 200 MW electrolyzer at Maasvlakte is feasible, but meeting a total demand of 10 GW would require a vastly larger scale of investment and workforce capacity.

Recommendation:

The availability of skilled labor required to construct all components of the energy system should become a structural element in decision-making, prioritization, and planning. In practice, the same engineers, contractors, and construction companies are responsible for building hydrogen plants, nuclear power plants, and grid infrastructure—while also being needed for housing and defense infrastructure projects. Similarly, the same ICT specialists are required to develop EMS systems, automate energy markets, and ensure cybersecurity.

Resilience Considerations

These two scaling challenges also raise important resilience issues.

In the first case, the limited ability to scale up domestically developed technologies increases dependence on foreign actors, particularly the United States and China.

- **Recommendation:** Governments should ensure that investment decisions explicitly consider contributions to **strategic autonomy**. Dependencies on critical raw

materials and other supply-chain vulnerabilities should also be taken into account, potentially through financial incentives or regulatory instruments.

In the second case, the large-scale deployment of digital technologies may increase systemic risks, such as the possibility of coordinated cyberattacks. For example, if one million households use the same photovoltaic (PV) inverter and it is inadequately secured, this could create a significant vulnerability.

- **Recommendation:** Actively promote secure interfaces and enforce robust cybersecurity standards.
- **Recommendation:** Encourage **supplier diversity** to reduce systemic vulnerabilities.