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# Report on:
# Renewable Mini-Grids Innovation Outlook


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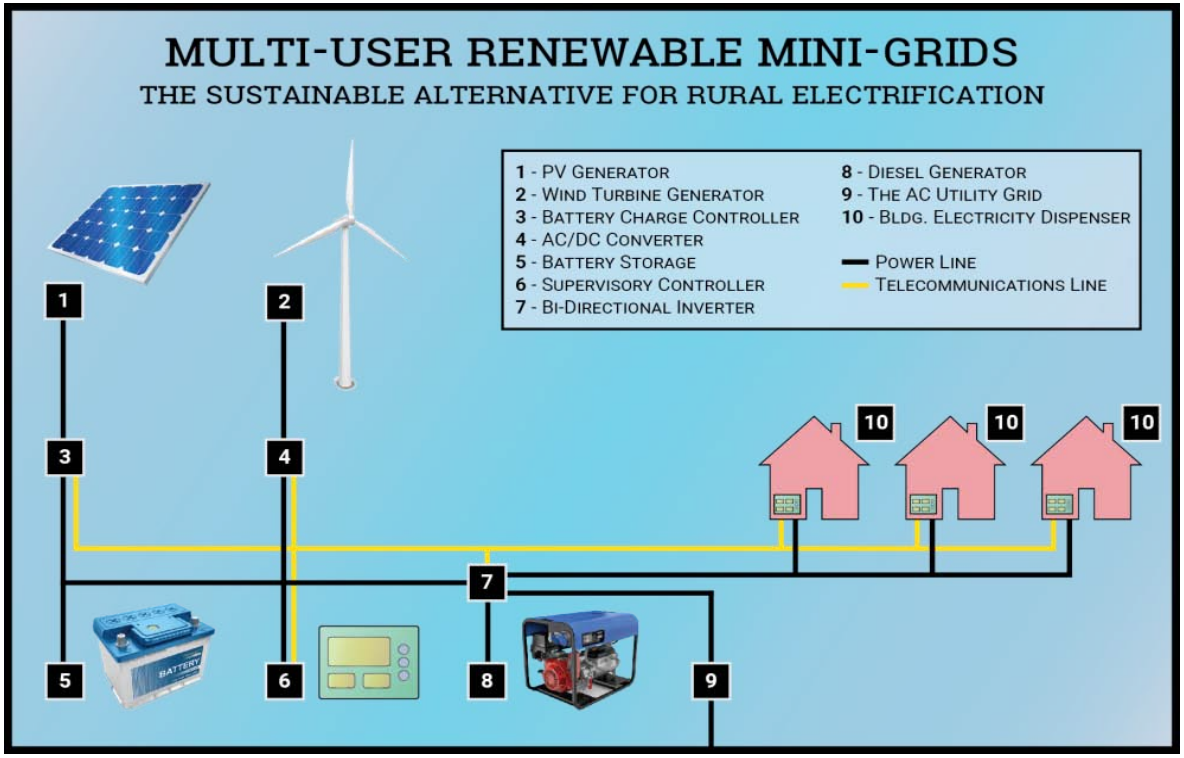
# What is a renewable mini-grid?

Mini-grids* that derive a majority of their primary energy from renewable sources to generate electricity

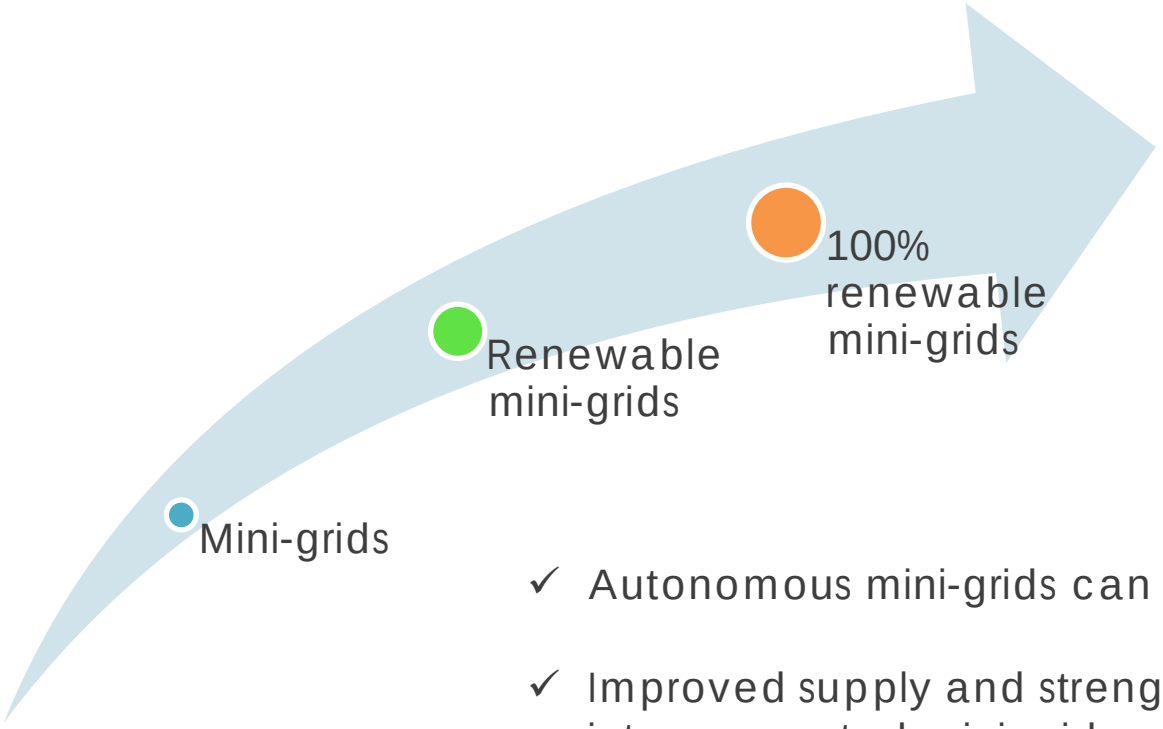



* Mini-grids are integrated energy infrastructures with loads and energy resources, including generators (*e.g.* PV, wind turbines), energy storage devices (*e.g.* lead-acid batteries), power conversion equipment (*e.g.* inverters), and control, management and measurement equipment (*e.g.* battery supervisors, data transfer, meters, among others).

# Mini-grid types

| | Lower Tier of Service | Higher Tier of Service |
|---|---|---|
| Autonomous | **Autonomous Basic (AB mini-grids)**<br>**Generation Sources:** PV, hydro and biomass<br>**Tier of service:** less than 24 hour power<br>**End-users:** Remote community without major commercial or industrial activity<br>Added value:<br>• Enable enhanced energy access<br>• Alternative to grid-extension<br>• Improve quality of life | **Autonomous Full (AF mini-grids)**<br>**Generation Sources:** PV, hydro and wind<br>**Tier of service:** 24/7 power<br>**End-users:** Remote communities, islands, with major commercial or industrial requirements; Industrial sites disconnected from grid<br>Added value:<br>• Alternative to expensive polluting imported fuels<br>• Diversification and flexibility of supply |
| Interconnected | **Interconnected Community (IC mini-grids)**<br>**Generation Sources:** PV, wind and biomass/biogas<br>**Tier of service:** High critical/ interruptible<br>**End-users:** Medium to large grid- connected community (*e.g.* university campus)<br>Added value:<br>• Community control<br>• Improve reliability<br>• Response to catastrophic events | **Interconnected Large Industrial (ILI mini-grids)**<br>**Generation Sources:** PV, wind and biomass/biogas<br>**Tier of service:** Very high: Critical/ uninterruptible<br>**End-users:** Data centres, industrial processing or other critical uses<br>Added value:<br>• High reliability for critical loads<br>• Enhance environmental performance<br>• Resiliency |

# Why a renewable mini-grid?




- ✓ Autonomous mini-grids can be cost-effective in remote areas
- ✓ Improved supply and strengthened neighboring grids of interconnected mini-grids
- ✓ Increase reliability and resiliency to the main grid
- ✓ Diminished environmental impact through high use of renewables
- ✓ Increased local control and choice in the energy mix

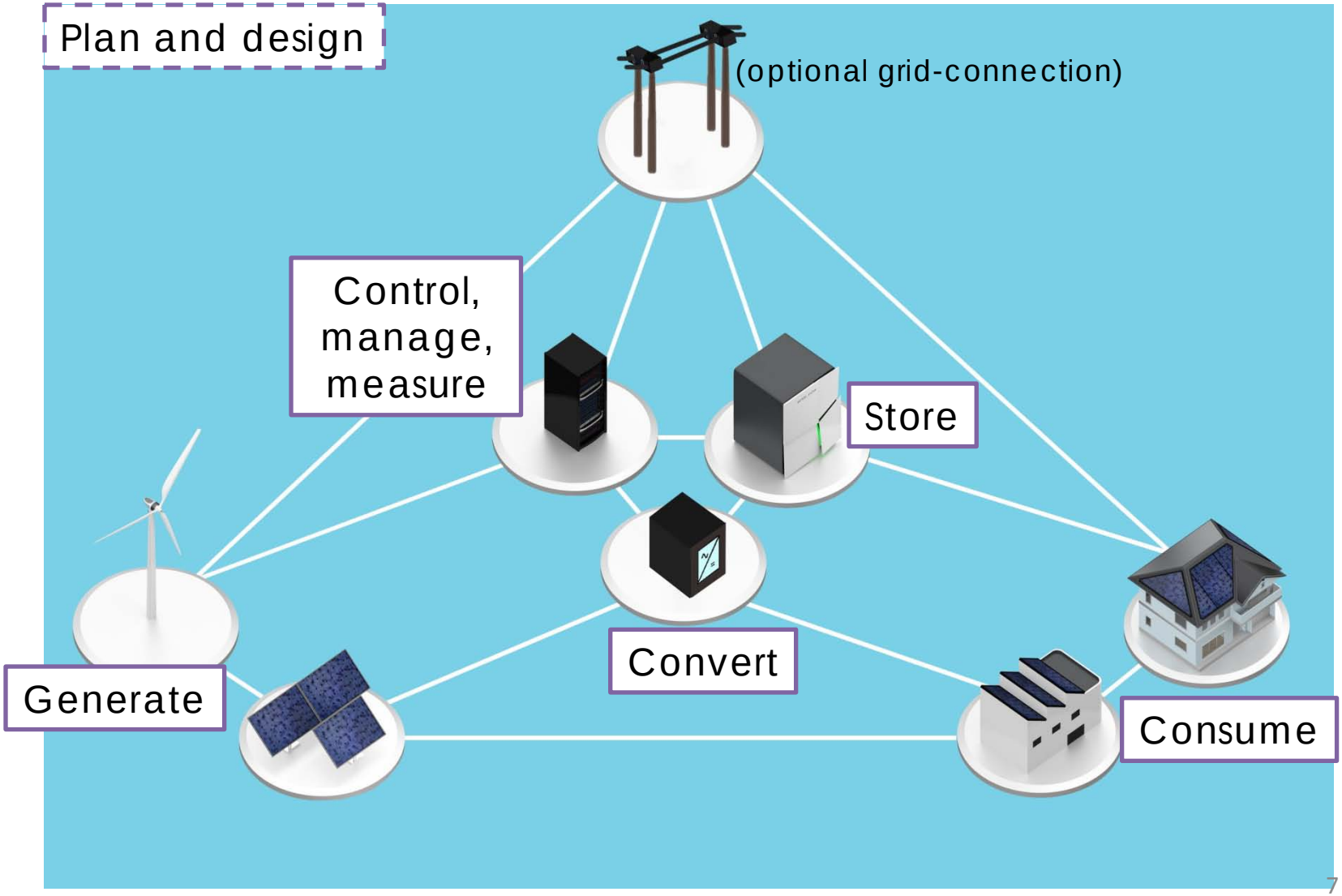
# Deployment today


| Region | Autonomous Basic | Autonomous Full | Interconnected Community | Interconnected Large Industrial |
|---|---|---|---|---|
| Canada and USA | ● | ● | ● | ● |
| Caribbean, Central America, Mexico | ● | ● | ● | ● |
| South America | ● | ● | ● | ● |
| Europe | ● | ● ● ● | ● | ● |
| North Africa | ● | ● | ● | ● |
| Sub-Saharan Africa | ● ● | ● | ● | ● |
| Central and North Asia | ● ● | ● | ● | ● |
| East and South Asia | ● | ● ● ● | ● | ● |
| Middle East | ● | ● | ● | ● |
| Oceania | ● | ● ● | ● | ● |
| Antarctica | | ● | | |

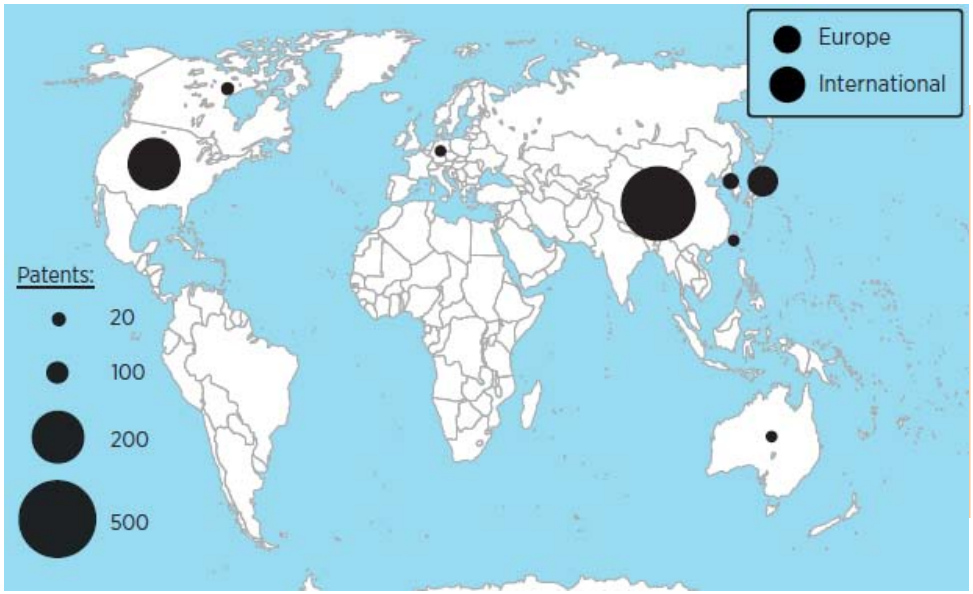
# Methodology

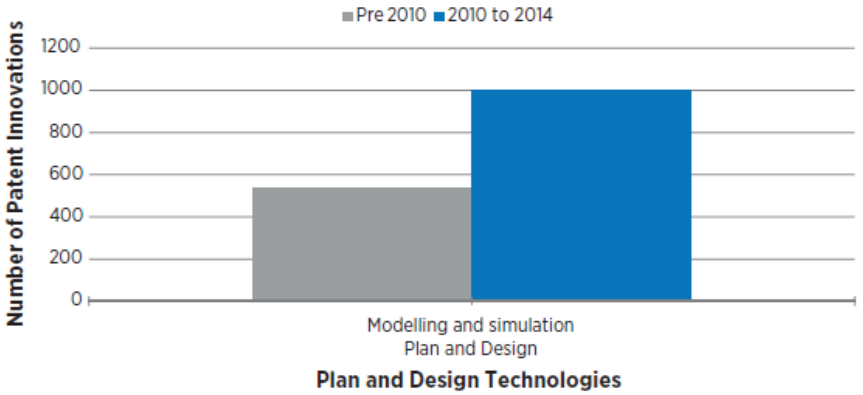
- Patent review
- Literature review (outlooks, scientific papers, etc.)
- Interviews with experts from industry, academia, research centres, NGOs
- Case studies

# Functionalities



# Plan and Design patent review

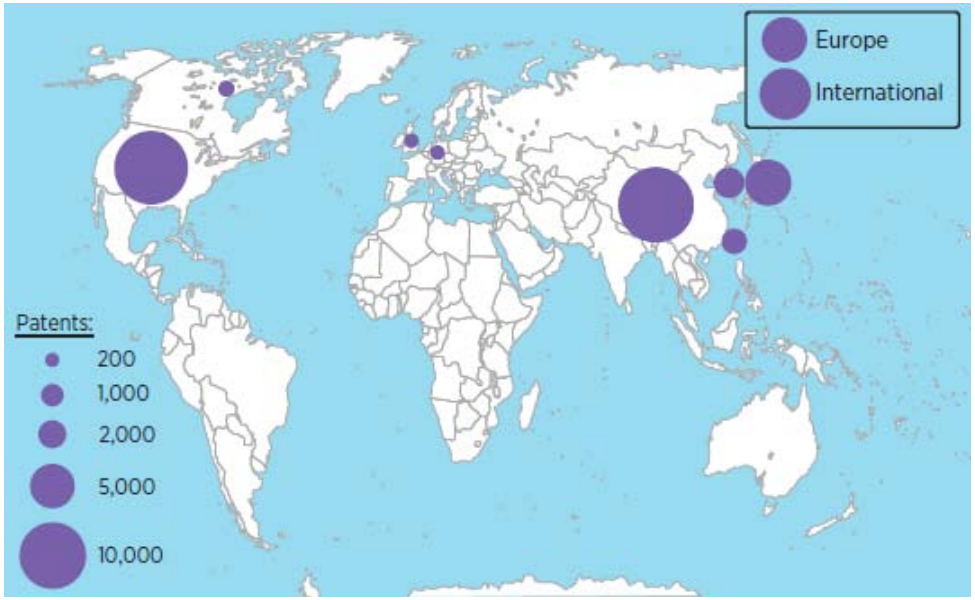


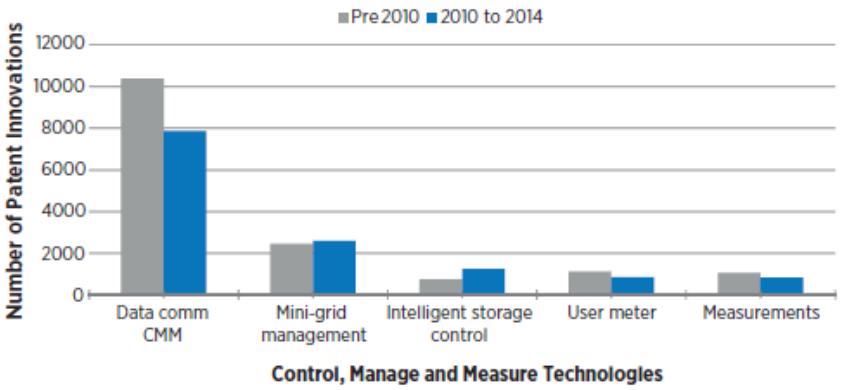




Trending topics on patents:

- The plan and design patent review focused on tools for modelling and simulation
- The most trending technology modelling and simulation is for computer aided design (CAD)

# CMM technologies patent review

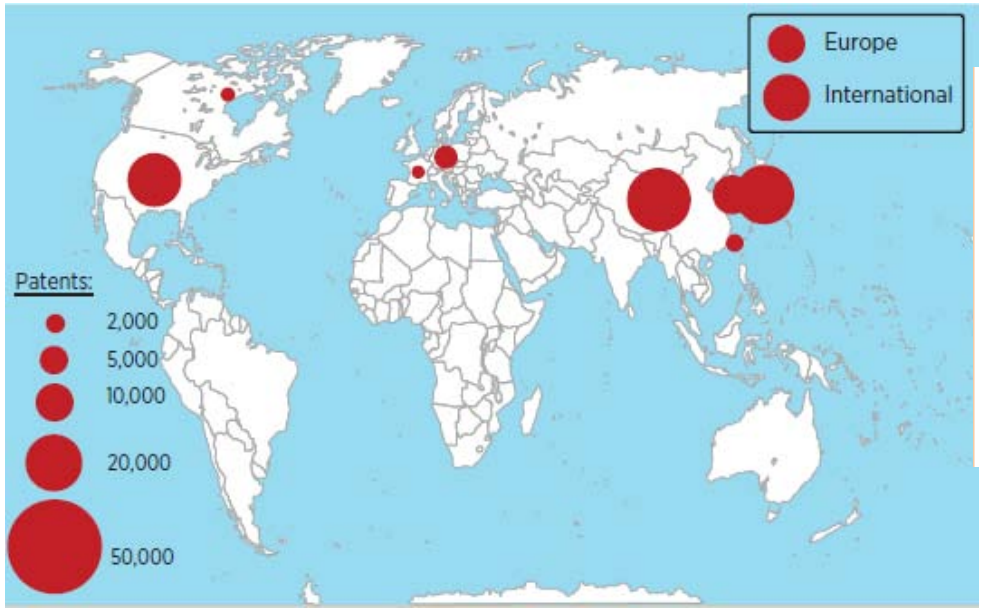


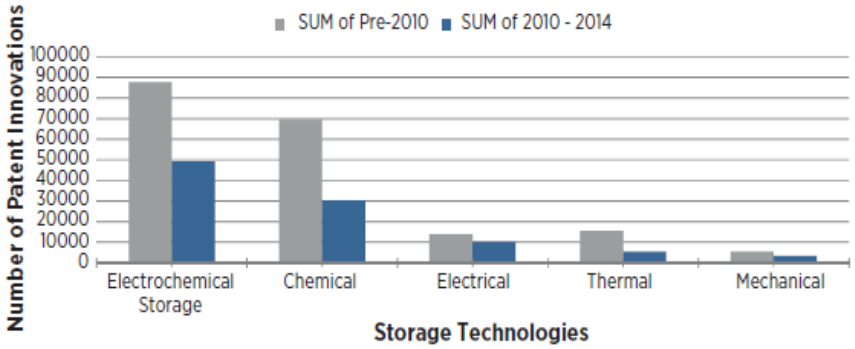




Trending topics on patents:

- **Data communication technologies**: power network operations, communications and information technologies, distribution or generation.
- **Mini-grid management:** technologies for reduction of losses (e.g. zero current switching or soft switching converters, zero voltage switching or non-dissipative snubbers).
- **Intelligent storage control**: uninterruptible or backup power supplies integrating with renewable energies.
- **User meters:** utility meters which are networked together (e.g. interconnection within a single building)
- **Measurements**: equipment characterised by state monitoring, e.g. fault, temperature monitoring, insulator monitoring, and corona discharge.

# Storage technologies patent review

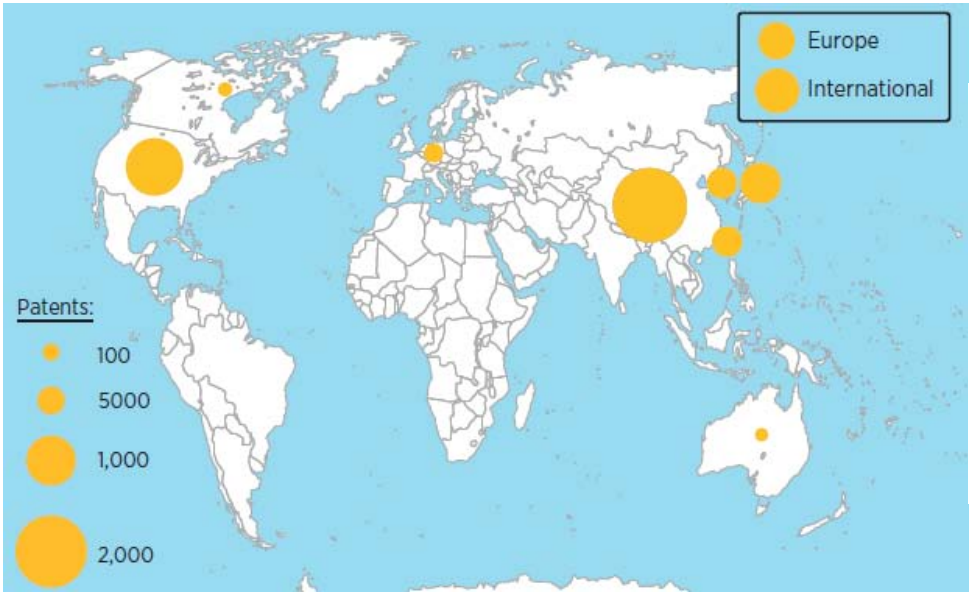


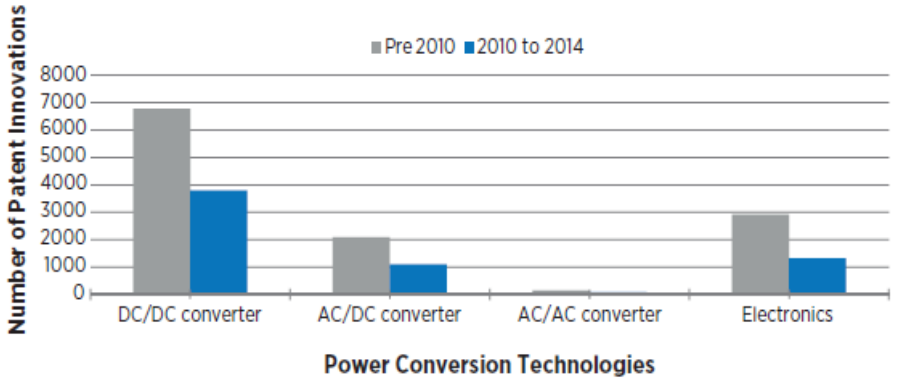




Trending topics on patents:

- **Electrochemical:** lithium ion batteries and lead acid batteries in the past 5 years. Lithium technologies and flow batteries are the most cited and published. Most patents for sodium-sulphur and lead-acid batteries patents are old.
- **Chemical:** Proton Exchange Membrane Fuel Cells and hydrogen technologies (liquified, solidified or compressed)
- **Electrical:** ultracapacitors, supercapacitors, and double-layer capacitors.
- **Thermal:** research is focused primarily on sensible and latent heat storage.
- **Mechanical:** research in pressurized fluid storage, internal combustion engines and fluidic energy storage (e.g. pressure accumulators).

# Convert technologies patent review

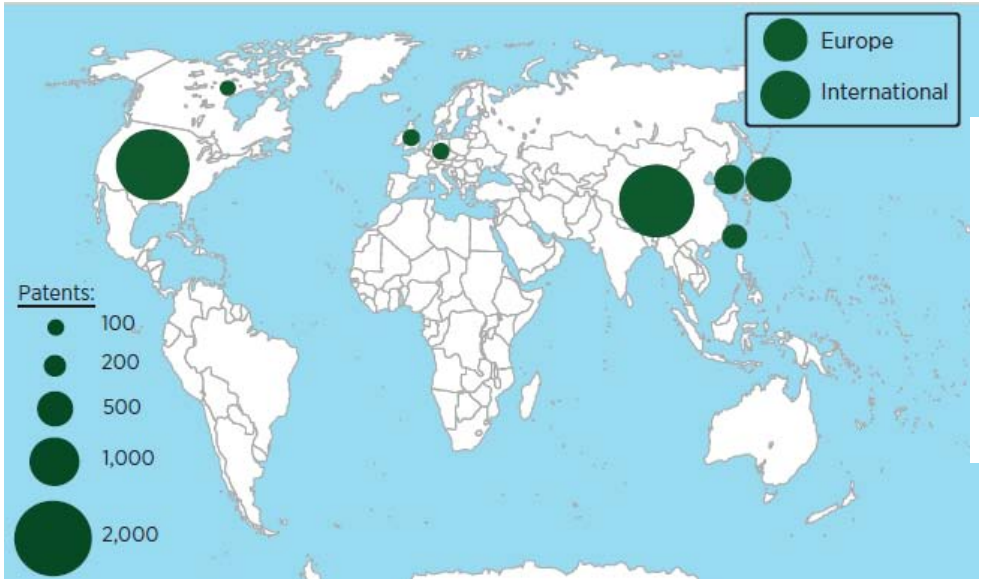


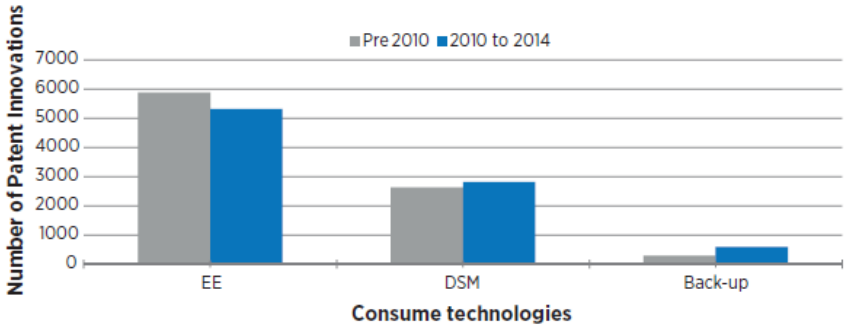




Trending topics on patents:

- **DC-to-DC conversion**: galvanically and non-galvanically isolated DC/DC converters in the past 5 years. Most focus is on low power applications, which has some applicability to renewable mini-grids.
- **Conversion between AC and DC:** DC/AC or AC/DC conversion and technologies which use wide band gap based power semiconductors, i.e. power converters integrating silicon carbide, gallium arsenide, gallium nitride or diamond power switches
- **AC-to-AC conversion**: AC/AC converters

# Consume technologies patent review




Trending topics on patents:

- **Energy efficiency:** elements or equipment involving protection devices and home appliances involving heating ventilating or air conditioning units.
- **Demand side management**: energy saving modes or efficient standby (e.g. detecting absence of load or auto-off), and demand response devices (e.g. load shedding and peak shaving).
- **Backup:** elements or equipment involving energy storage, UPS equipment or standby emergency generators involved in the last stages of power distribution.

# Plan and design

| Opportunity for Innovation | Cost | Reliability | Ease | Environment |
|---|---|---|---|---|
| Standardised planning and design | ★★★★ | ★★ | ★★★★ | ★★ |

## STATE OF THE ART TODAY

- Requires renewable mini-grid specialist for all stages of design, including conceptual design
- General solar resource data is of sufficient quality; however wind and hydro data require on-site measurements to validate and data can be costly.
- Load planning is based on ad-hoc and site-specific approaches for estimating loads

## FUTURE

- Early stage design of renewable mini-grids does not require a specialist, and there are robust tools for a complete design, based on proven off-the-shelf components
- Resource planning is supported by robust tools that accurately predict resources without on-site validation. Detailed, local resource data is affordable and readily available.
- Smart load planning tools provide accurate, proven estimates on expected load based on readily available data at a site

# Control, manage, and measure

| Opportunity for Innovation | Cost | Reliability | Ease | Environment |
|---|---|---|---|---|
| More intelligent controls | ★★★ | ★★★★ | ★★★★ | ★★ |
| Improved communications and standards | ★★ | ★★★★ | ★★★★ | ★ |
| Improved metering and monitoring | ★★ | ★★★ | ★★★★ | ★★★ |
| Simplify connecting equipment together | ★★ | ★ | ★★★★ | ★ |

## STATE OF THE ART TODAY

- Specialized and expensive controls
- Non-economic, non-predictive controls
- Moderate plug-and-play capability
- High utility interest, but limited to pilot projects
- Numerous competing standards
- One to two hours renewable resource prediction with high accuracy

## FUTURE

- Low cost modular controls
- Economic and predictive controls
- Seamless plug-and-play capability
- Standard interconnection terms for utilities
- Common, open-source standards
- Day-ahead renewable resource prediction with high accuracy

# Store

| Opportunity for Innovation | Cost | Reliability | Ease | Environment |
|---|---|---|---|---|
| Use less expensive, more abundant, and less resource intensive materials | ★★★★ | ★★ | ★ | ★★★ |
| More robust, lower maintenance technologies to reduce lifecycle costs for storage | ★★★ | ★★★★ | ★★★ | ★★ |
| Improvements in long-term storage capability | ★★ | ★★ | ★★ | ★★★★ |
| Improvements in high power output capability | ★★ | ★★★ | ★★ | ★★★ |

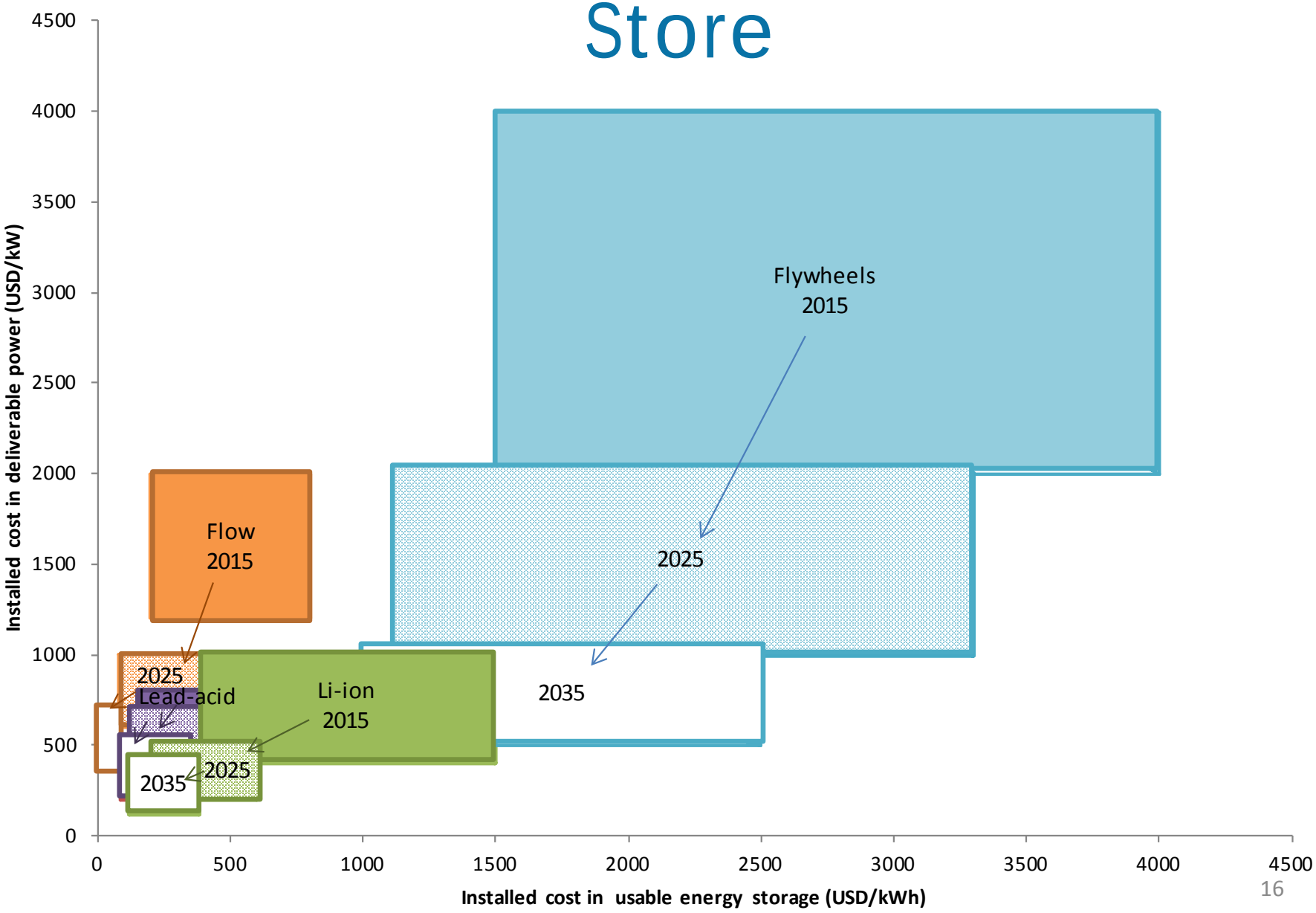
## STATE OF THE ART TODAY

- Expensive
- Most deployments use lead-acid batteries
- Limited options for long-term and seasonal storage
- Increasing numbers of projects that use flywheels, lithium ion, and flow batteries

## FUTURE

- Significantly decreased costs
- More technologies used, particularly lithium-ion
- Enhanced battery chemistries and solar fuels enable better long-term and seasonal storage
- Multiple, diverse storage technologies are commonly used in projects

# Store


Installed cost in deliverable power (USD/kW)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Installed cost in usable energy storage (USD/kWh)
Flywheels
2015
2025
2035
Flow
2015
2025
Lead-acid
2035
Li-ion
2015
2025

# Convert

| Opportunity for Innovation | Cost | Reliability | Ease | Environment |
|---|---|---|---|---|
| Lower capital costs of converters | ★★★★ | ★ | ★★ | ★ |
| Combine diverse function into inverters | ★★ | ★★ | ★★★★ | ★ |
| Improve efficiency, particularly at partial load | ★★ | ★★ | ★ | ★★★ |
| More converter options for diverse renewable mini-grid markets | ★★ | ★★ | ★★★★ | ★ |

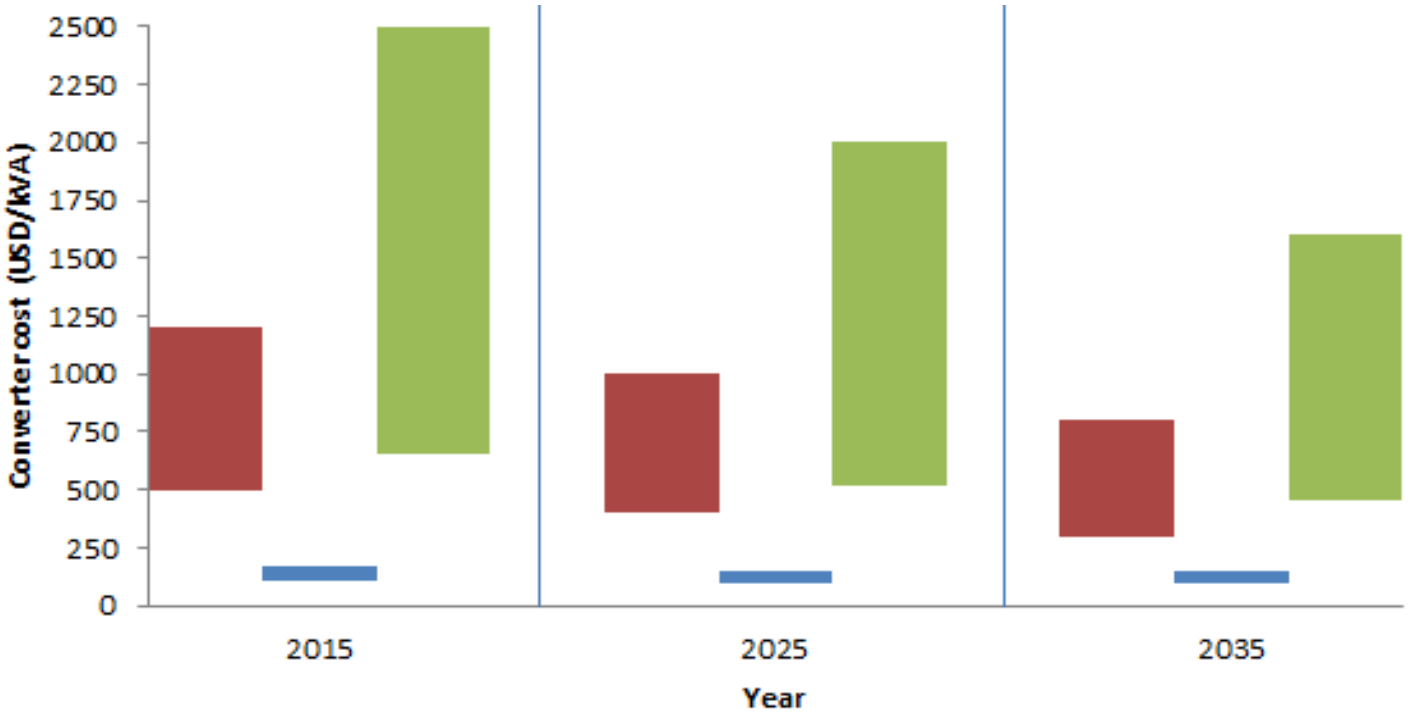
## STATE OF THE ART TODAY

- Grid-following inverters have achieved considerable price drops in the past decade
- Dual-mode inverters are starting to become common for interconnected mini-grids, as they are coming into the main grid market for distributed generation in unreliable grids that can operate interconnected or islanded

## FUTURE

- Converters are Increasingly using new nanomaterial semiconductors, such as CNT.
- Dual-mode inverters with smooth shifts from grid to island mode in black start with innovative droop control methods to avoid transient fluctuations of voltage and frequency.

# Convert


2500
2250
2000
1750
1500
1250
1000
750
500
250
0
Converter cost (USD/kVA)
2015
2025
2035
Year
Grid-forming
Grid-following
Dual-mode


Grid-forming inverter
Grid-following inverter
Dual-mode inverter

# Consume

| Opportunity for Innovation | Cost | Reliability | Ease | Environment |
|---|---|---|---|---|
| Increased commercial availability of efficient end-uses | ★★★★ | ★ | ★★ | ★★★★ |
| Better user tools for adapting consumption to energy supply (DSM) | ★★★★ | ★★ | ★★★ | ★★★★ |

## STATE OF THE ART TODAY

- Mini-grids are currently feeding mostly AC loads
- The use of DC power is primarily explored in commercial buildings and in smaller energy access applications/mini-grids

## FUTURE

- Increasing use of high-efficiency and DC appliances reduce electricity costs for home owners and businesses.
- High-efficiency and DC appliances are standard, further reducing electricity costs for home owners and businesses

# Generate

| Opportunity for Innovation | Cost | Reliability | Ease | Environment |
|---|---|---|---|---|
| Lower capital costs for generation | ★★★★ | ★ | ★ | ★★ |
| Reduce maintenance needs | ★★ | ★★★ | ★★★★ | ★★ |
| Improved efficiency and increased energy capture | ★★★ | ★ | ★ | ★★★★ |
| More converter options for diverse renewable mini-grid markets | ★★ | ★★ | ★★★★ | ★ |

## STATE OF THE ART TODAY

- Low cost silicon-based polycrystalline solar PV is main renewable generation technology used in mini-grids.
- Small wind is used less due in large part to competition from solar PV and the high cost of resource assessment
- There are some new small hydro power turbines for low head and low flow applications,
- Increased availability of biomass gasification that is able to handle more feedstock, although they are plagued with maintenance issues.

## FUTURE

- Solar remains the dominant energy generation source in mini-grids. Solar PV price reductions continue, driven by advancements in DSSC, nanomaterials and organic chemistries.
- Wind, hydro, and biomass are strong options when suitable resource is available. Advancements in resource tracking, together with lower-maintenance designs have made these more viable.
- It is cost-effective to get near 100% energy from renewables in a mini-grid.

# Renewable mini-grids as a whole

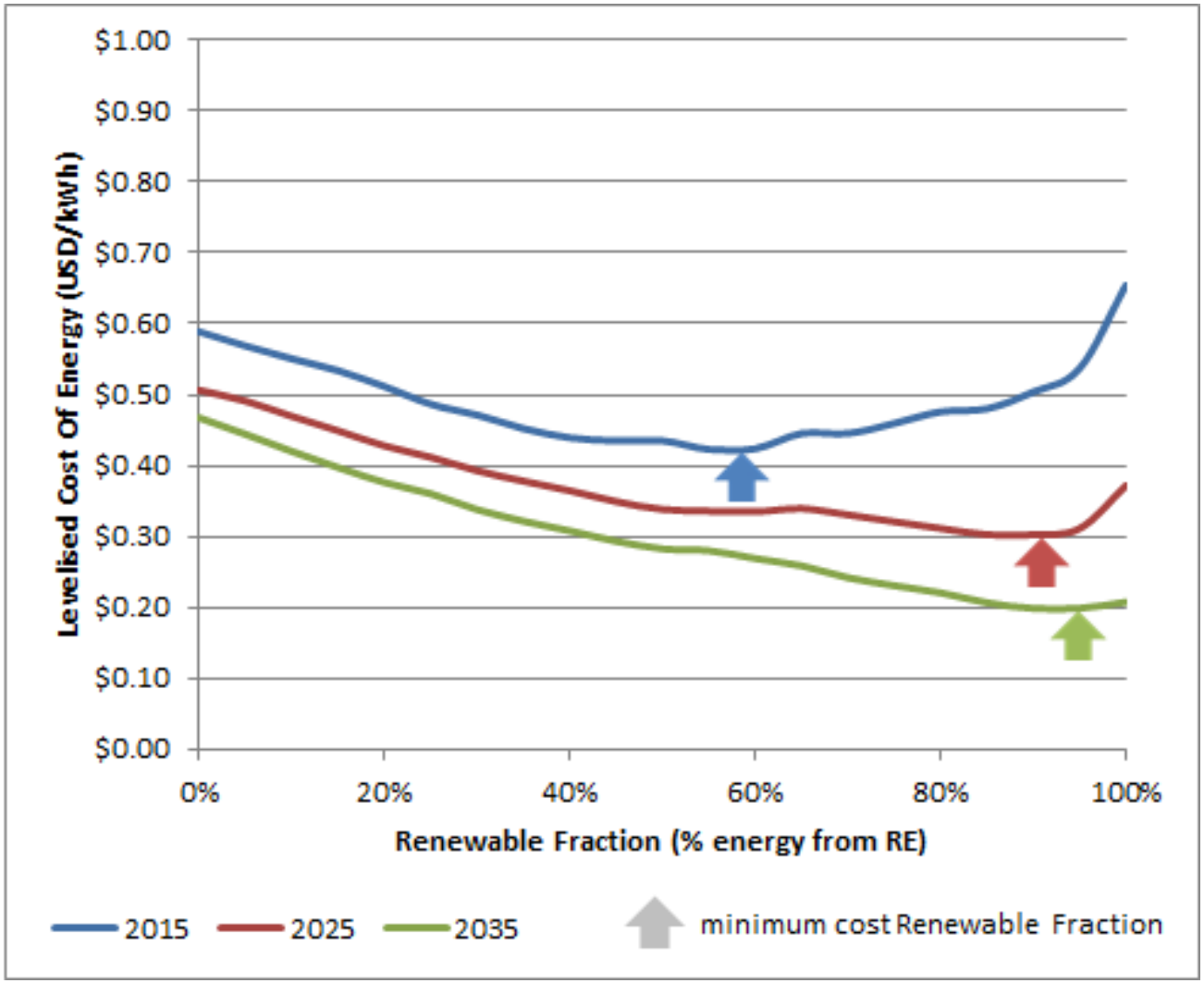
## STATE OF THE ART TODAY

- **Autonomous:** Most of the autonomous mini-grid based on renewable energy are small. Larger autonomous mini-grids are increasingly using renewables to displace a part of their diesel generation.
- **Interconnected:** Interconnected mini-grids use storage for reliability during short duration main grid outages. Renewables are used primarily in mini-grids interconnected with unreliable main grids and in areas that have renewable incentives or expensive main grid power. Many interconnected mini-grids use fossil generation for back-up, along with combined heat and power.

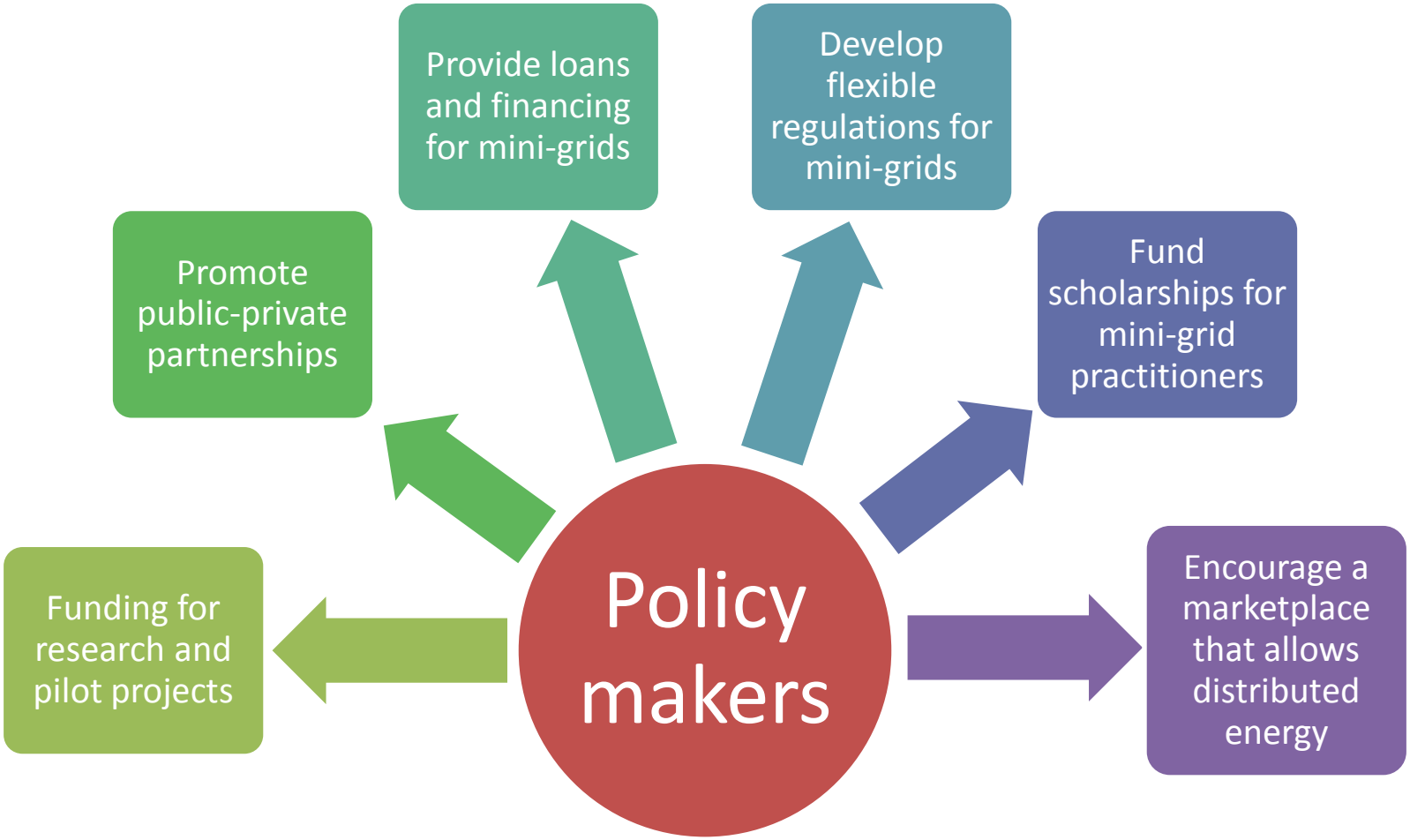
## FUTURE

- **Autonomous:** Renewables are used in all mini-grids. There are many DC mini-grids. Leveraging low cost storage, low cost RE generation and intelligent controls, mini-grids are widespread. Energy access renewable mini-grids are commercially viable, while higher reliability renewable mini-grids are increasingly commercially viable.
- **Interconnected:** Mini-grids with medium-penetrations of RE are commonplace, with uptake driven by need for resilient disaster response. Spurred by decreasing costs, many communities have adopted renewable mini-grids for local control of energy. Broader utility acceptance of mini-grids in their networks reduces costs for resilient operation for both main and mini-grid.

# Renewable mini-grids as a whole



# The role of policy makers

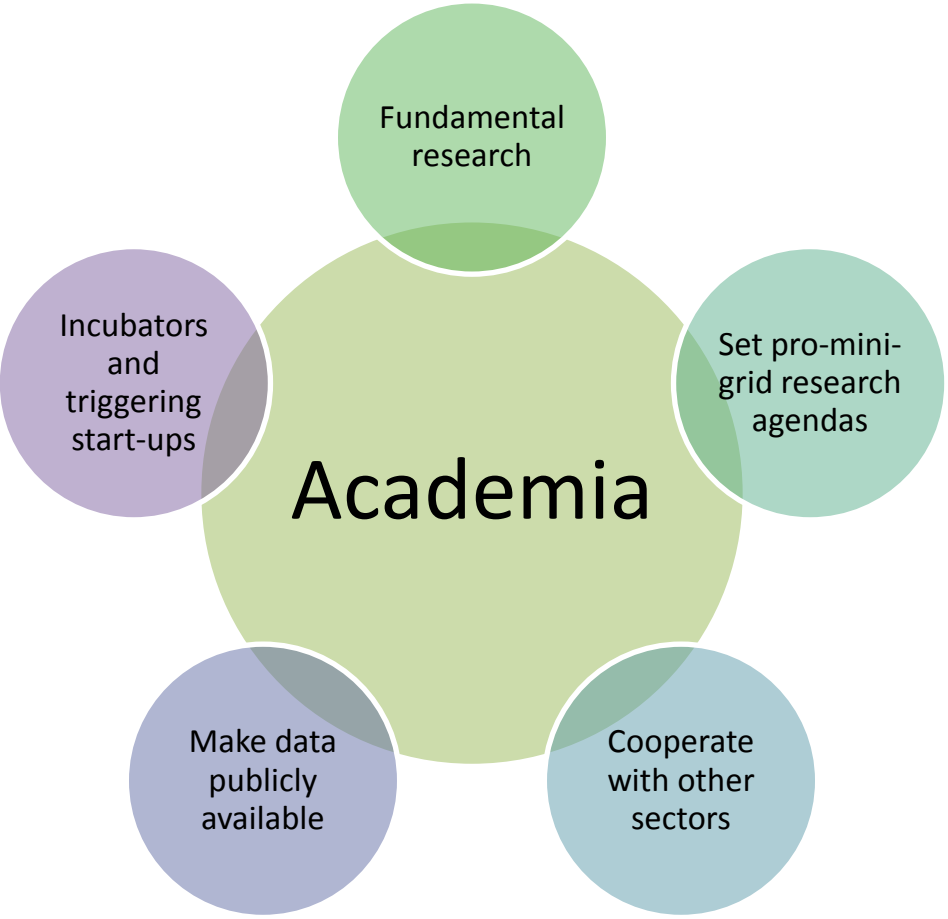


# The role of the private sector

## Private sector

- Undertake fundamental research
- Pilot projects
- Deploy mini-grids
- Technology transfer
- Industry standard groups

# The role of academia and NGOs



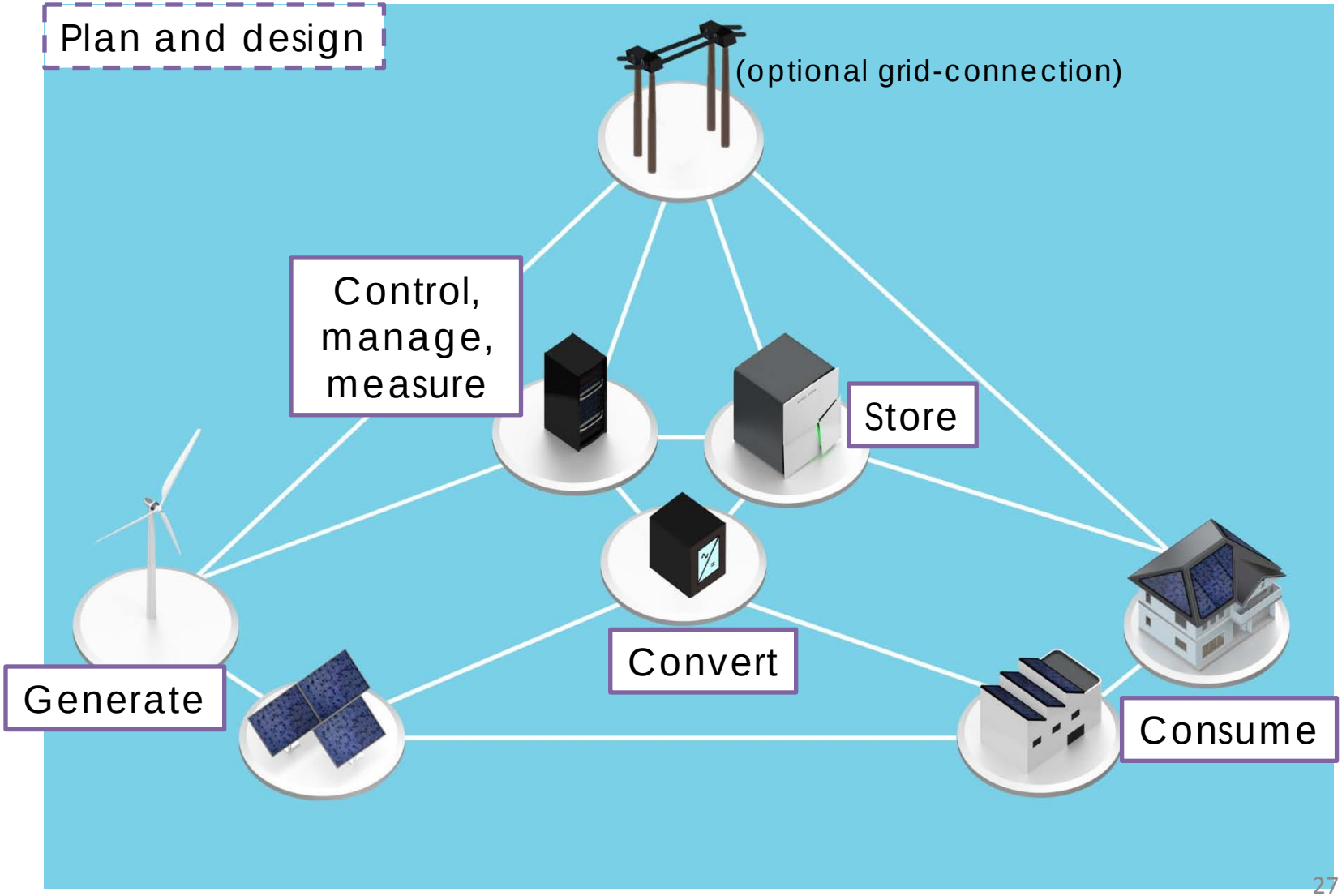

# Conclusions

- Innovation in renewable mini-grids will span many functionalities, technologies, and industries.

- Technological innovations continue to happen in all six of the core functionalities.

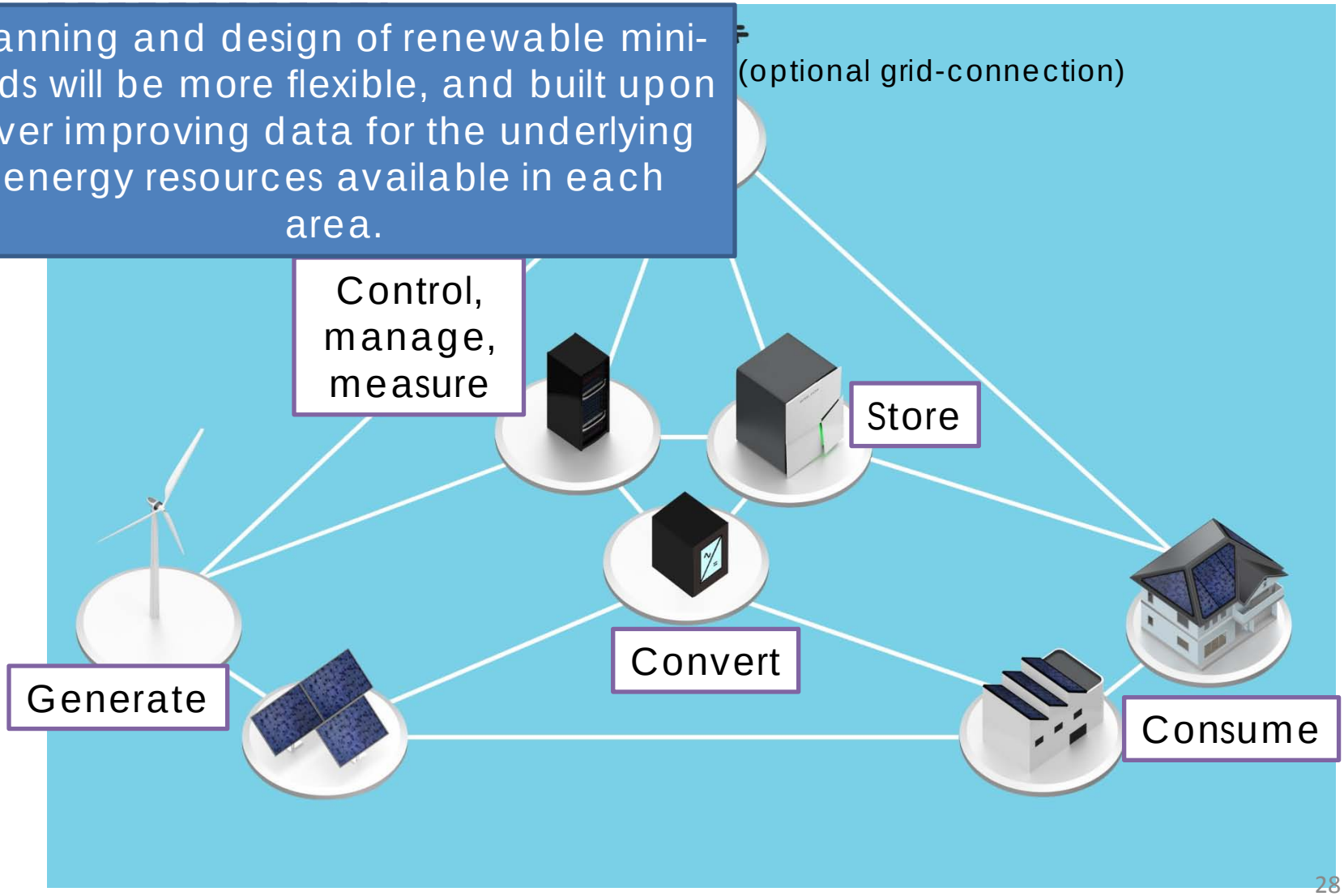
- In the next two decades innovations will:
  - decrease costs of energy from mini-grids,
  - drive an increase of renewable energy penetration in mini-grids, and
  - make mini-grids an increasingly attractive alternative to traditional centralized grid planning and SHS.

# Conclusions



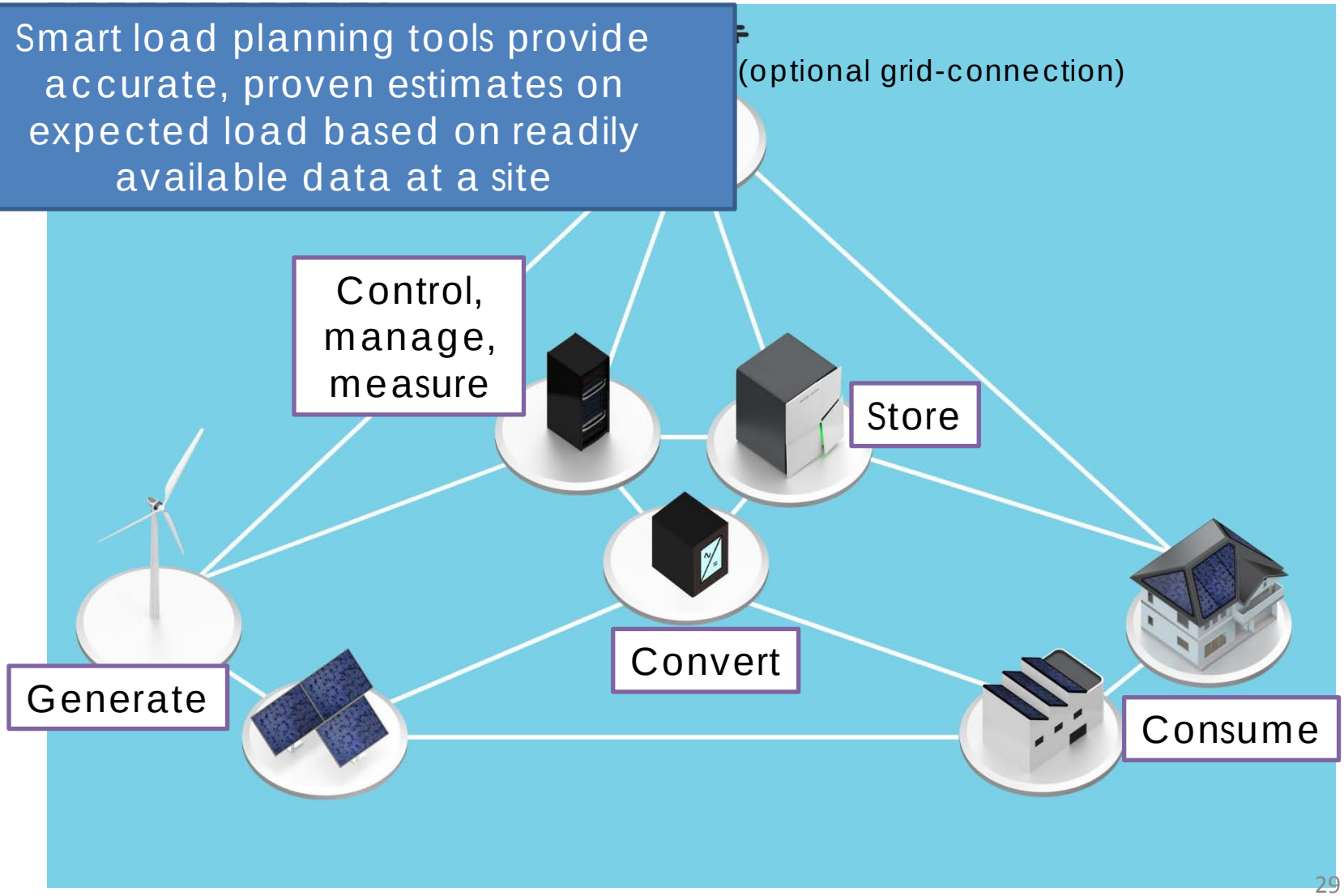
# Plan & design – 2025

Planning and design of renewable mini-grids will be more flexible, and built upon ever improving data for the underlying energy resources available in each area.

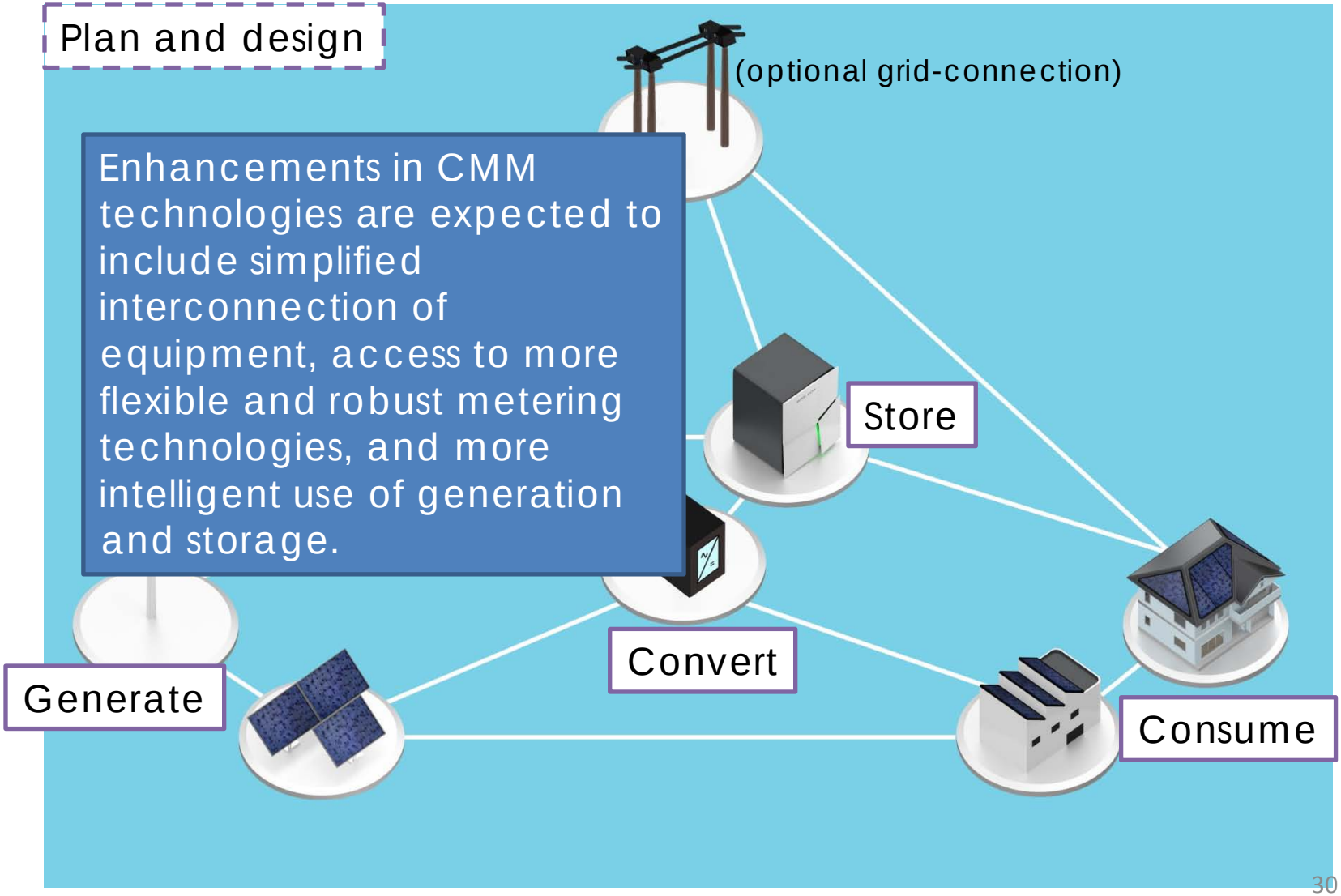


# Plan & design – 2035

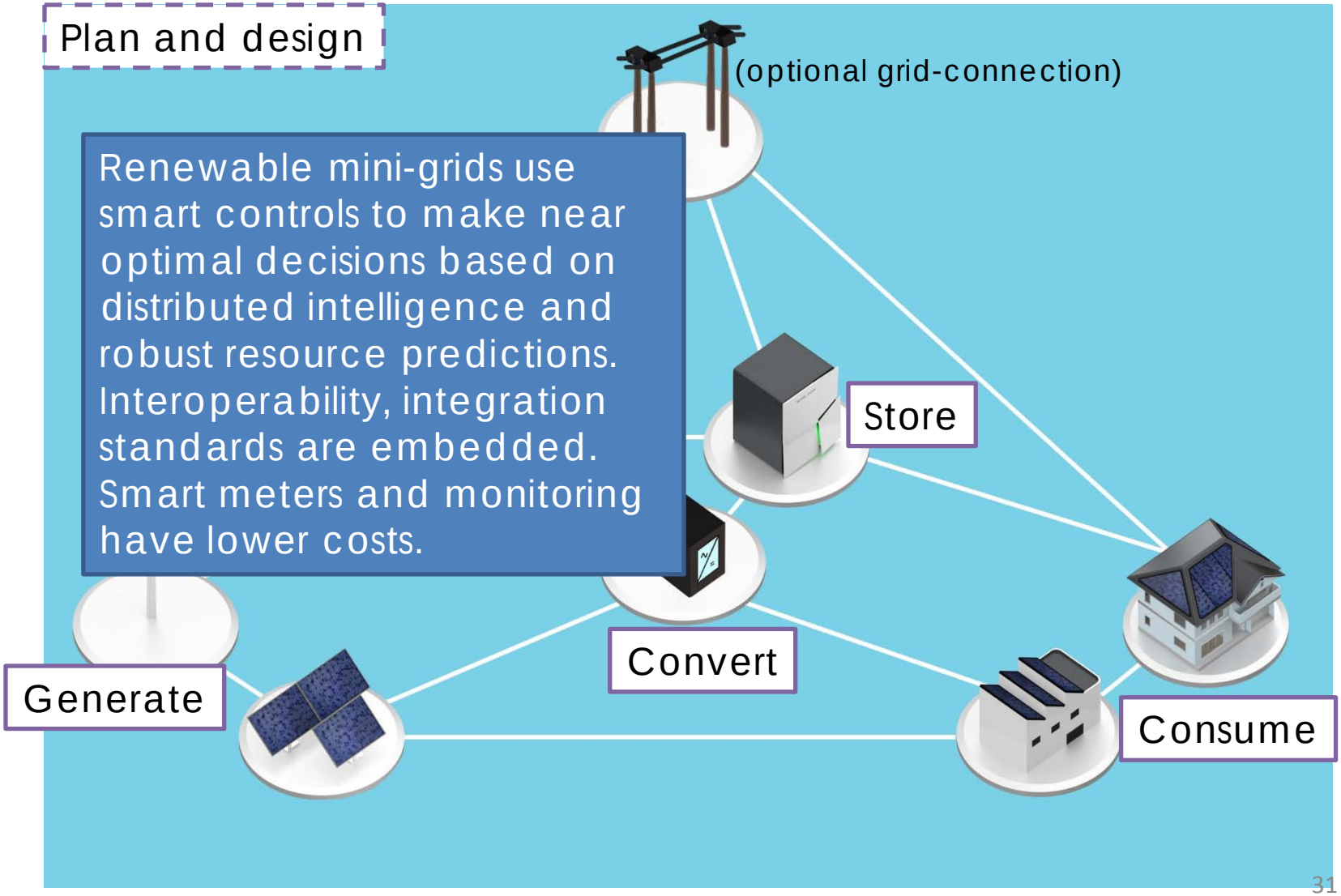
Smart load planning tools provide accurate, proven estimates on expected load based on readily available data at a site



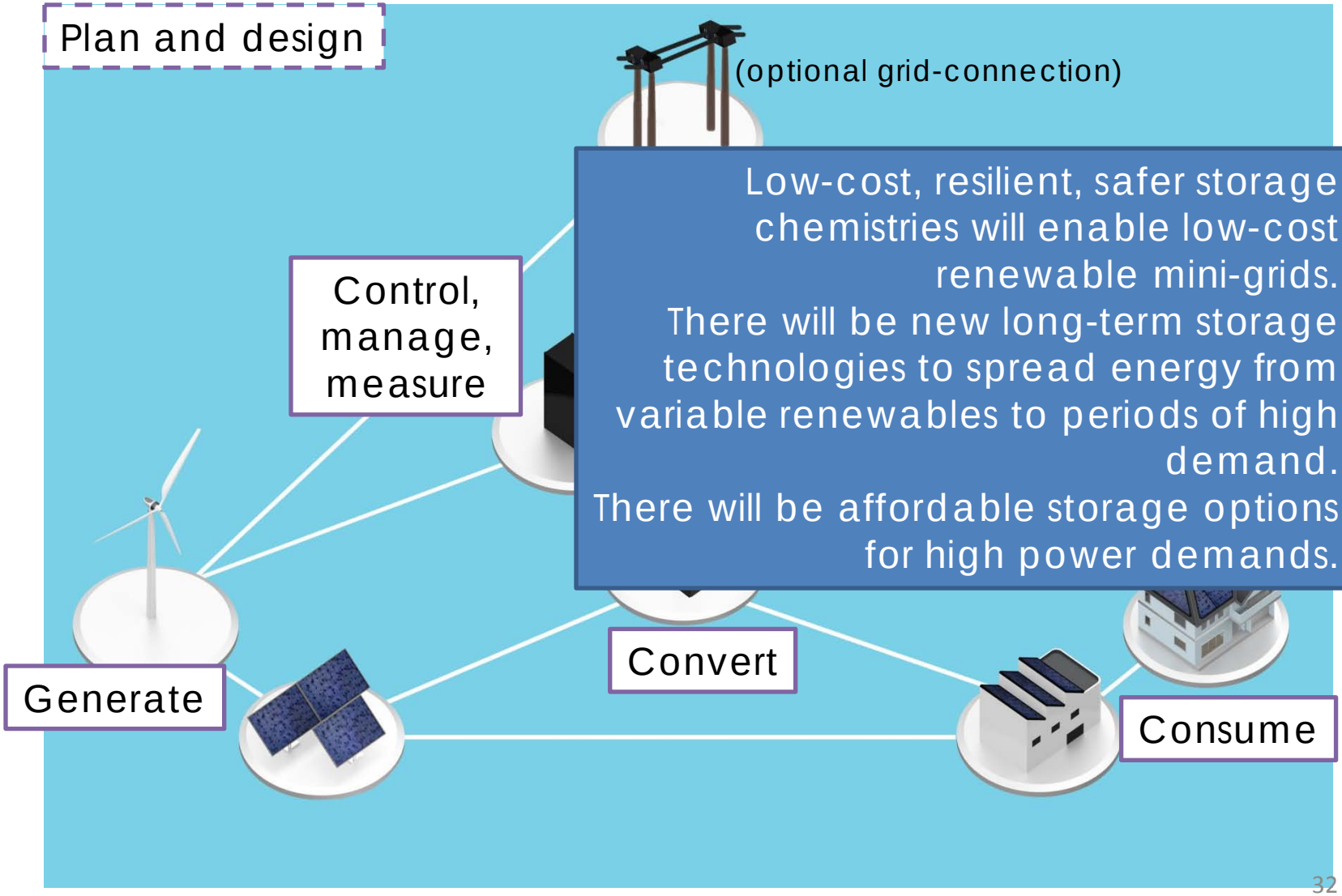
# CMM – 2025


Plan and design
(optional grid-connection)
Enhancements in CMM technologies are expected to include simplified interconnection of equipment, access to more flexible and robust metering technologies, and more intelligent use of generation and storage.
Store
Convert
Generate
Consume

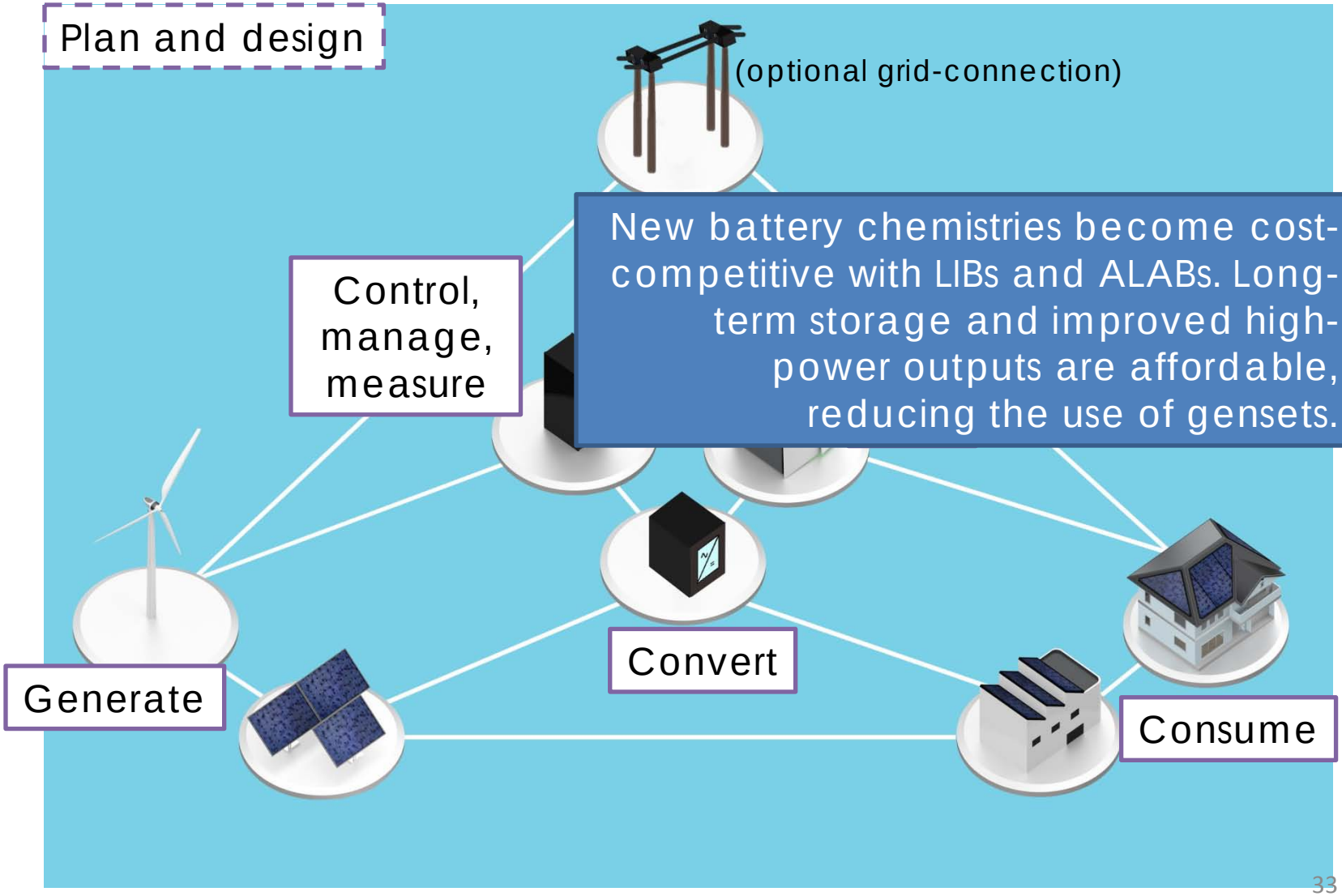
# CMM – 2035


Plan and design
(optional grid-connection)
Renewable mini-grids use smart controls to make near optimal decisions based on distributed intelligence and robust resource predictions. Interoperability, integration standards are embedded. Smart meters and monitoring have lower costs.
Store
Convert
Generate
Consume

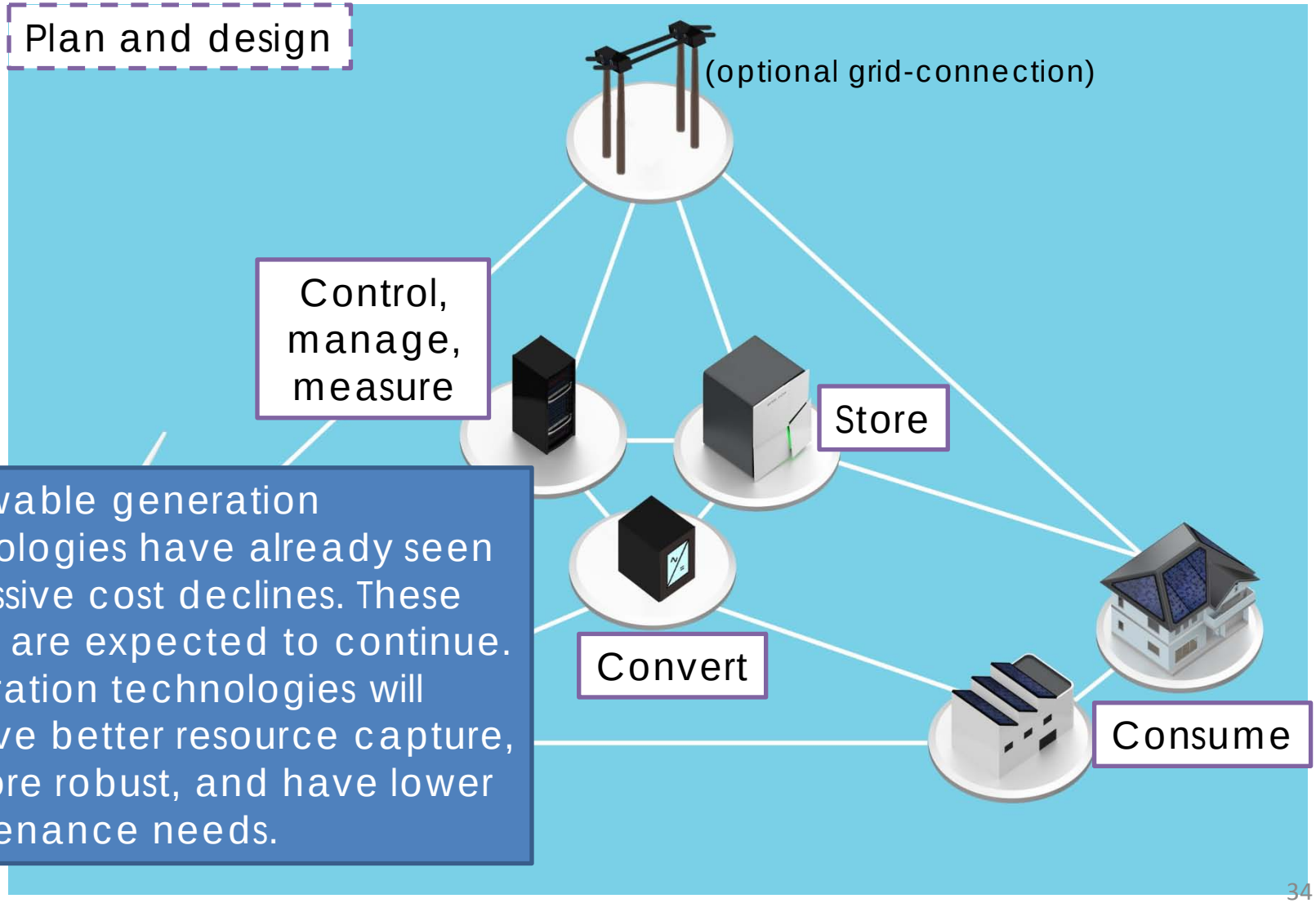
# Store – 2025


Plan and design
(optional grid-connection)
Low-cost, resilient, safer storage chemistries will enable low-cost renewable mini-grids.
There will be new long-term storage technologies to spread energy from variable renewables to periods of high demand.
There will be affordable storage options for high power demands.
Control, manage, measure
Generate
Convert
Consume

# Store – 2035

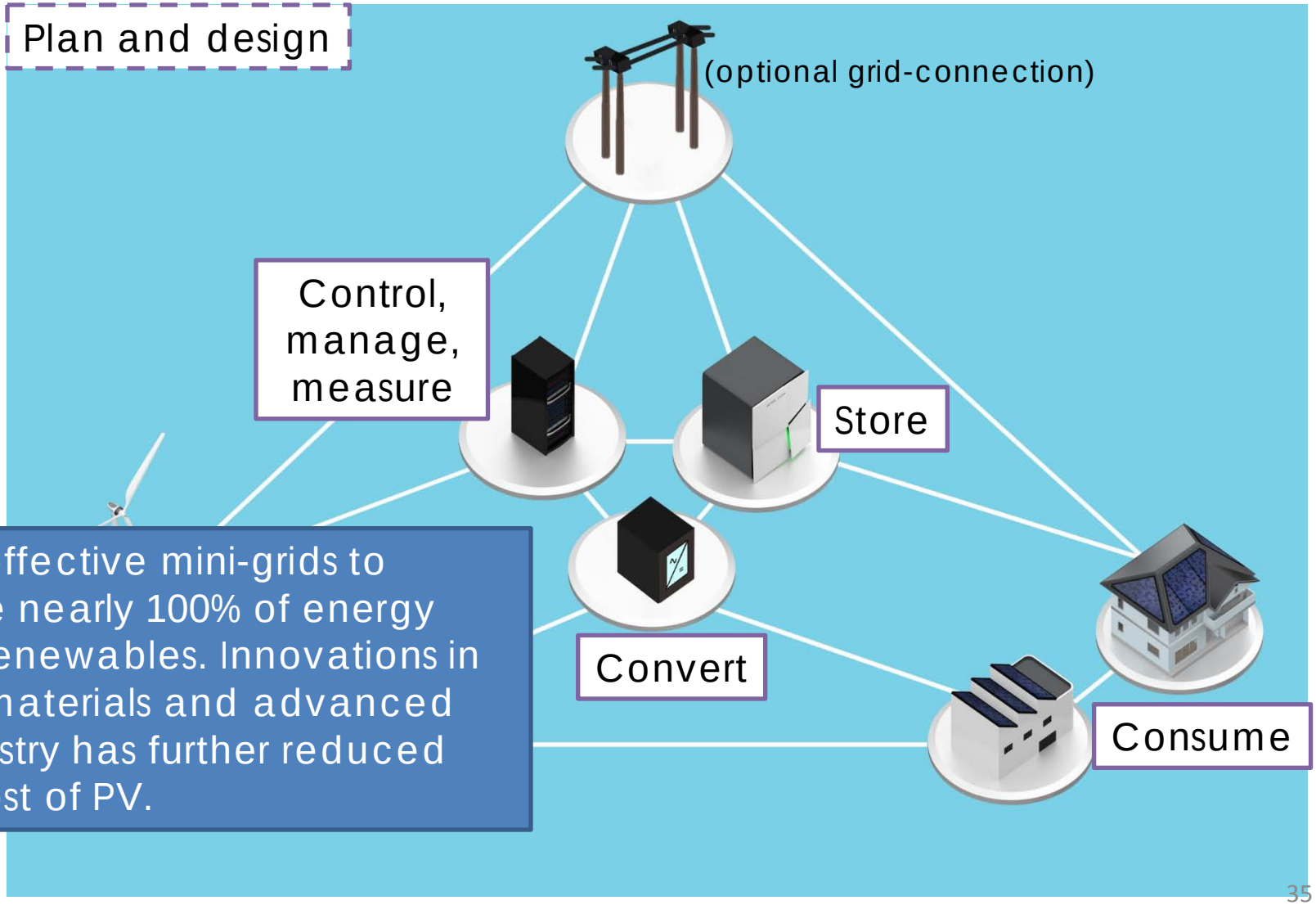

Plan and design
(optional grid-connection)
New battery chemistries become cost-competitive with LIBs and ALABs. Long-term storage and improved high-power outputs are affordable, reducing the use of gensets.
Control, manage, measure
Generate
Convert
Consume

# Generate – 2025

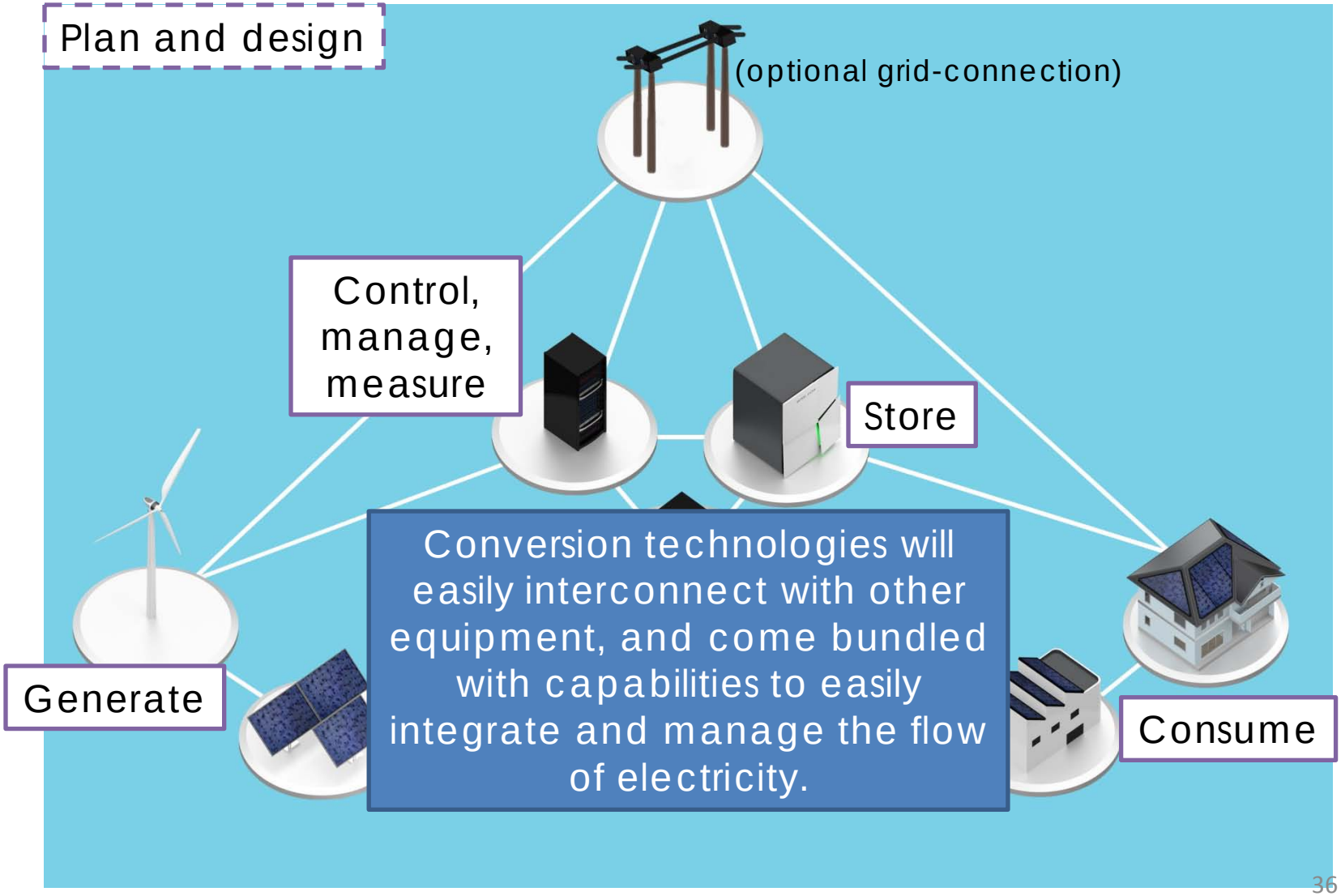



Renewable generation technologies have already seen impressive cost declines. These trends are expected to continue. Generation technologies will achieve better resource capture, be more robust, and have lower maintenance needs.

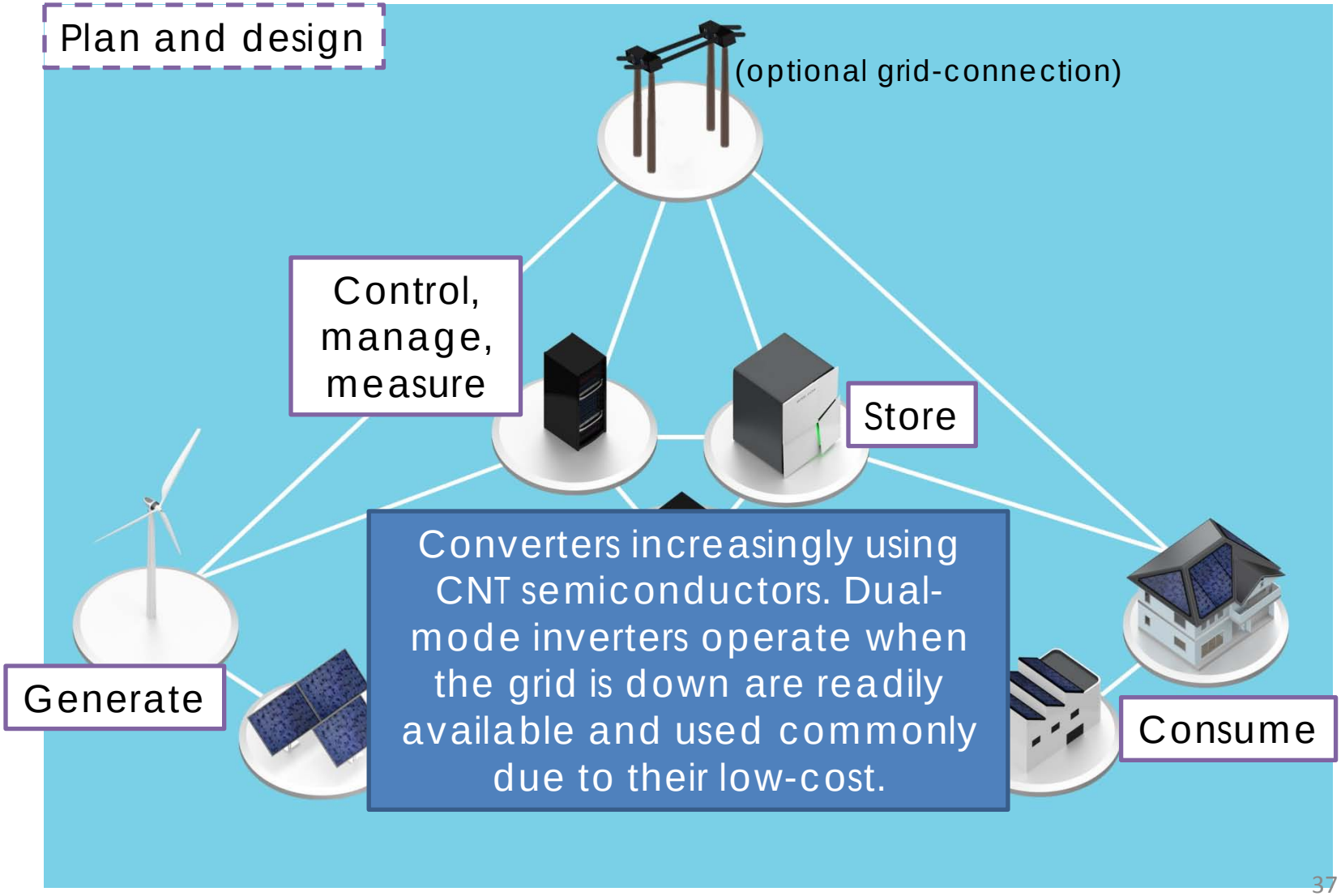
# Generate – 2035



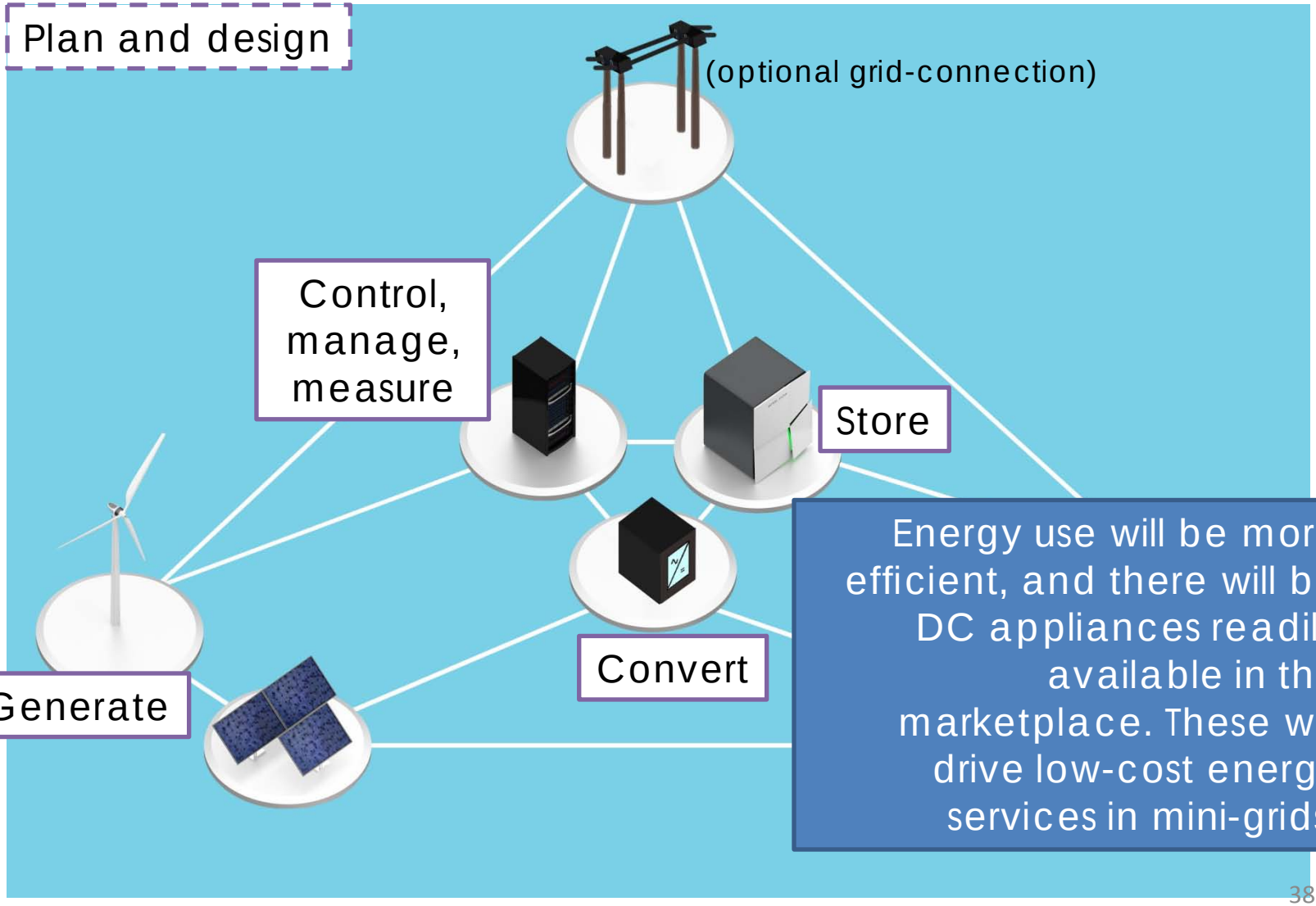
# Convert – 2025



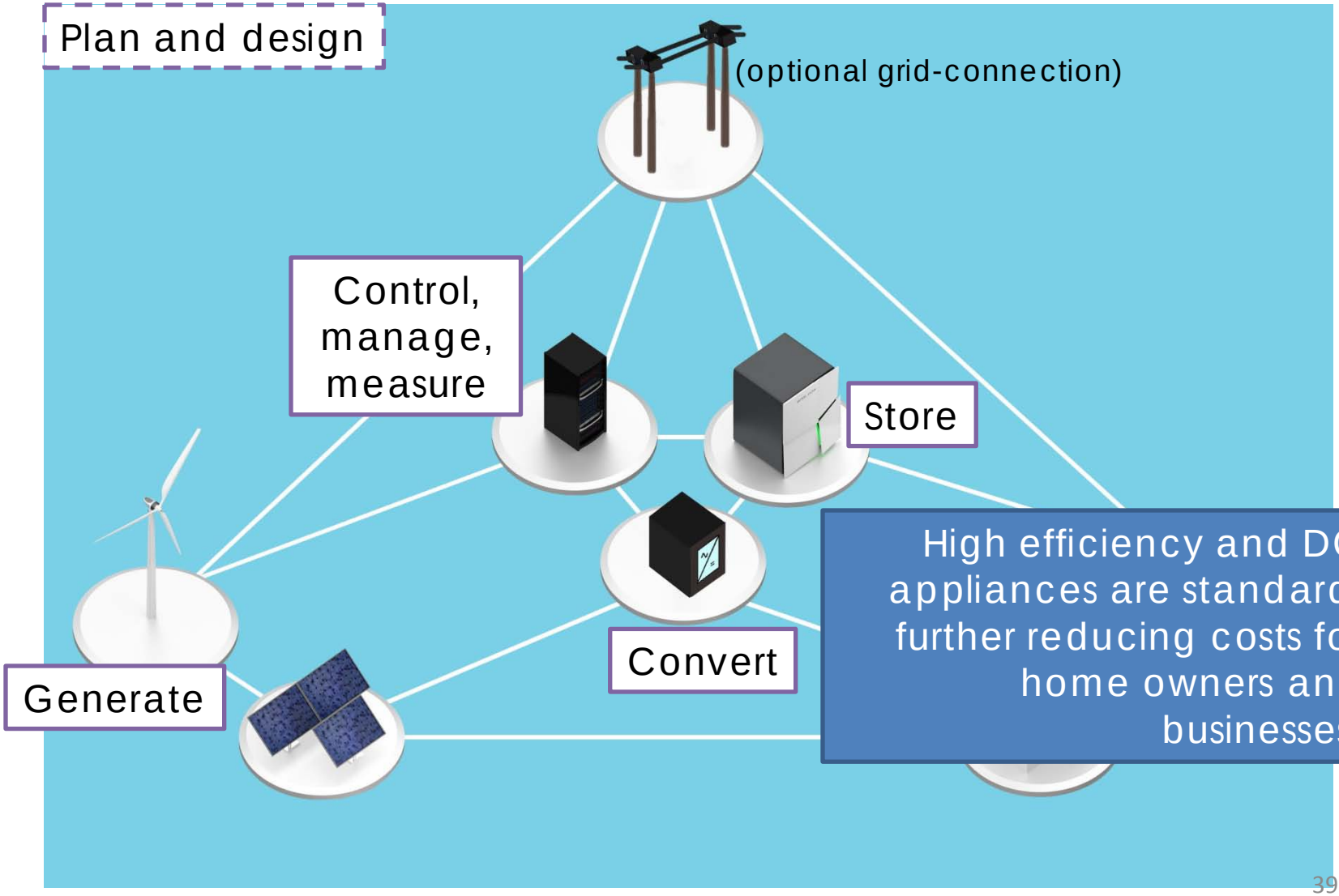
# Convert – 2035



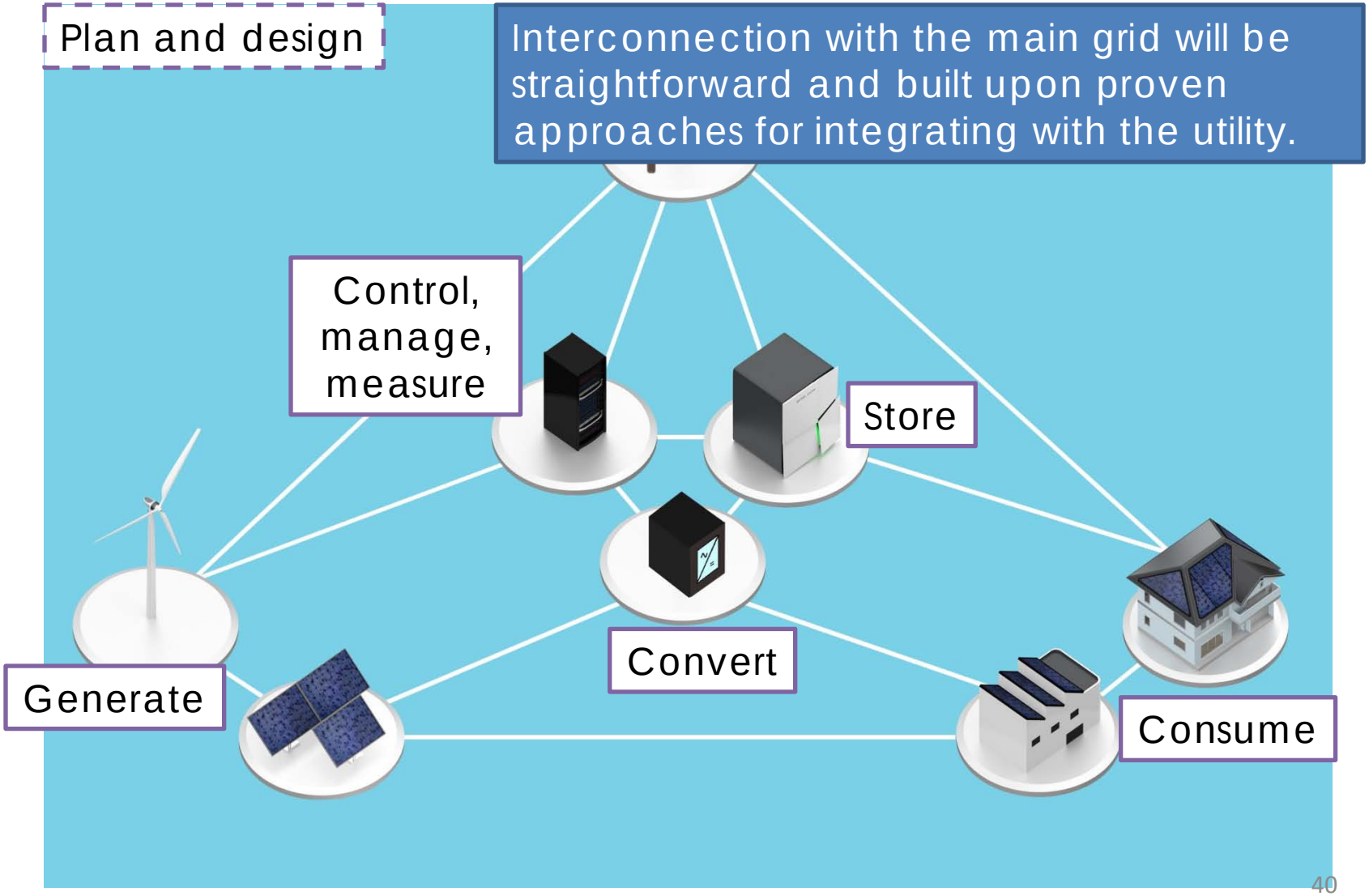
# Consume – 2025



# Consume – 2035



# Interoperability




# Thank you very much for your attention!

You can download the report from the link below:

https://goo.gl/Xf9LQg