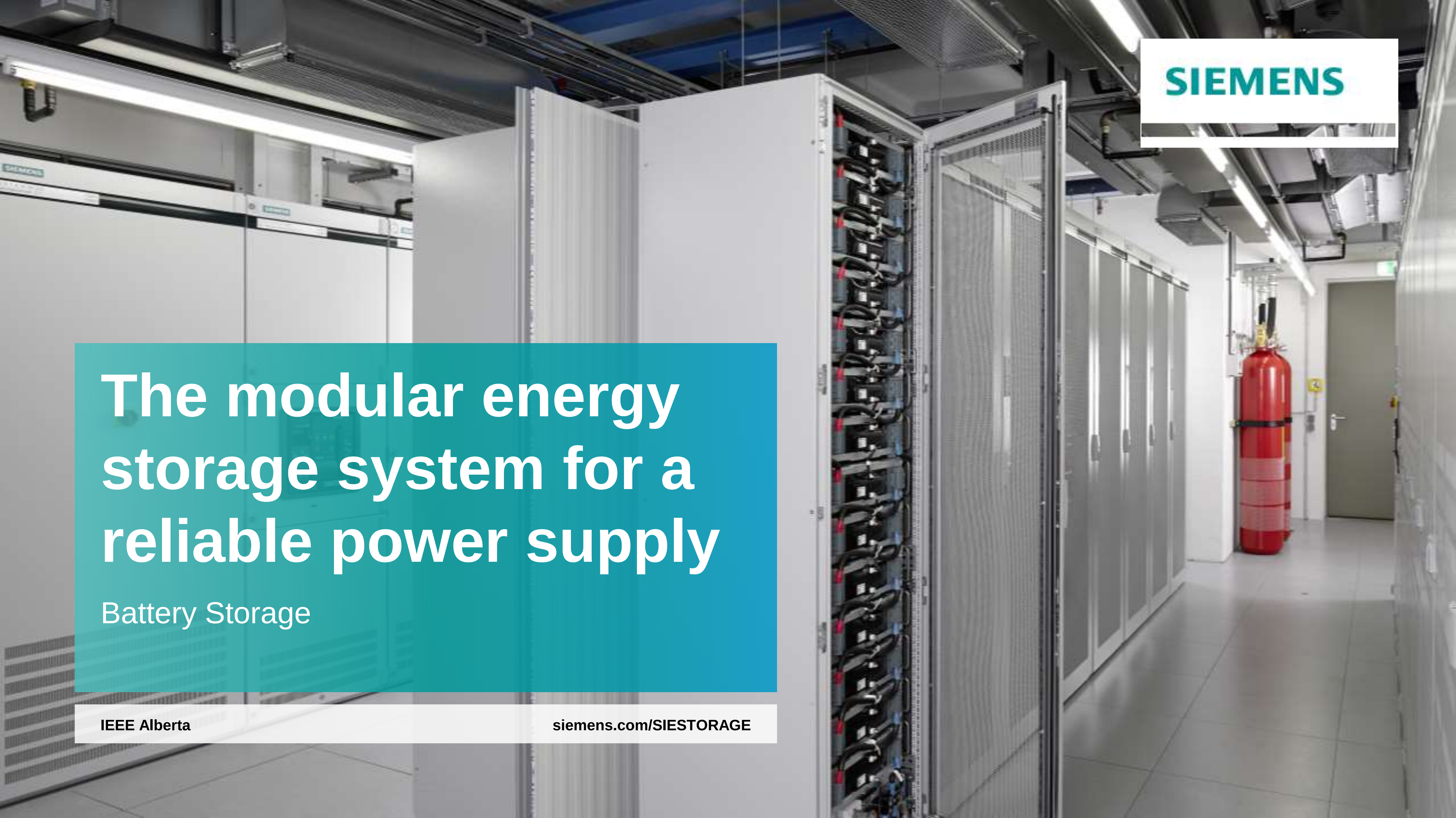


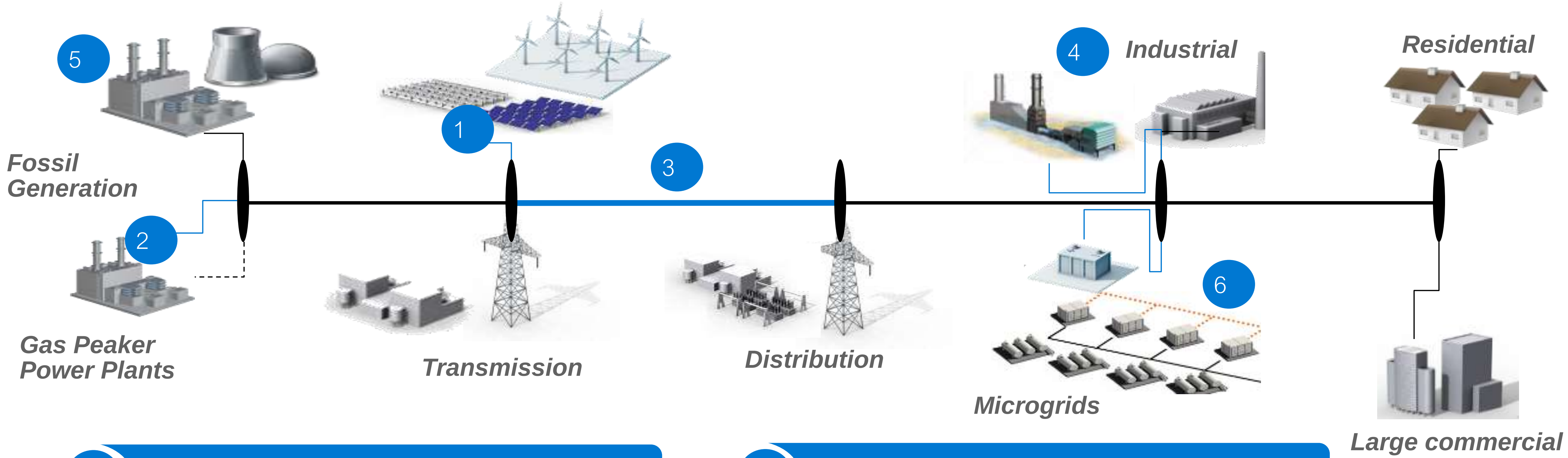
The modular energy storage system for a reliable power supply

Battery Storage

IEEE Alberta

siemens.com/SIESTORAGE

Evolving Grid Creates New Operation Challenges
Major Drivers Fostering Adoption of Energy Storage Systems



1. Penetration of Renewables
2. Change of Energy Mix
3. Saturation of Infrastructure
4. Increase of Grid complexity
5. Fuel Price Fluctuations
6. Deployment of Microgrids

Drivers:
Striving for Efficiency

Utilities

- **Limitation of the grid**
- **Multiplication of decentralized generation**
- **Fluctuation of energy costs**
- **Renewable energy, storage**
- **Deregulation**

Increasing in efficiency:
rising electrification
of the society

Industry

- **Oil price fluctuations**
- **Assurance of energy quality**
- **Optimization of losses**
- **Reducing consumption**
- **Secure power**

Increasing
Power supply reliability
& quality

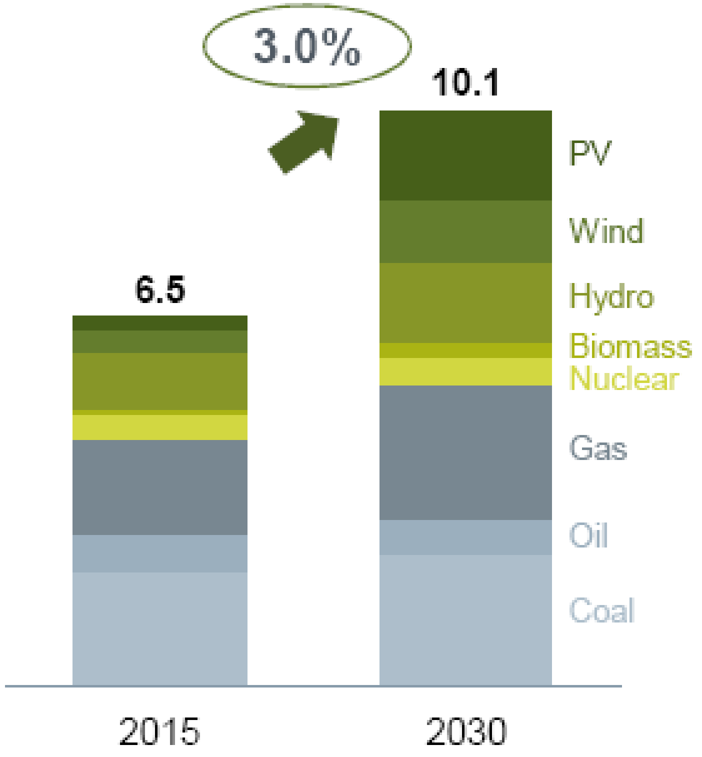
Cities & Infrastructure

- **Increase of human population**
  7,5 Mrd. by 2020 (+1,1 Mrd.)
- **Megacities** (>10 Mio. pop.)
  27 Megacities by 2025
- **Climate targets**: long-term reduction
  of CO2-emissions

Increasing availabity &
demand for
„clean“ power

Increasing electrification in all sectors – Heading towards an all-electric world

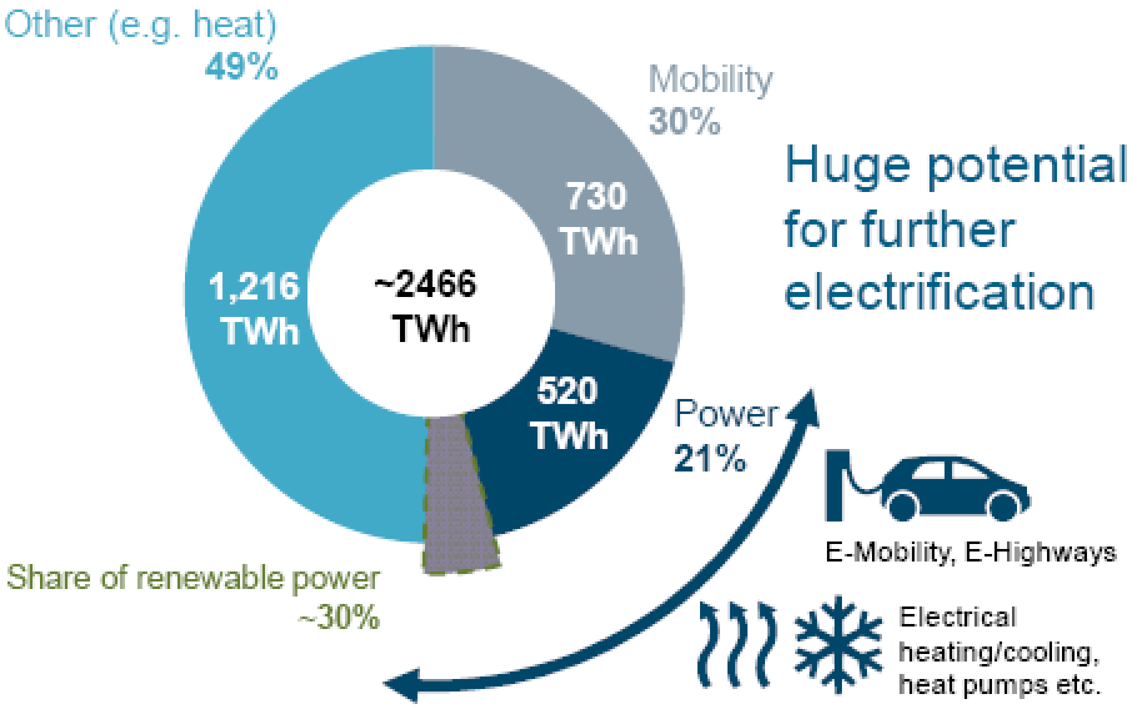
Global power generation capacity in TW



Renewables and distributed power generation grow above average

Source: Siemens Energy 2020 Project 2014 – Base Case Scenario

Example: Final energy consumption in Germany 2015



Huge potential for further electrification

Source: umweltbundesamt.de/Arbeitsgemeinschaft Energiebilanzen, status 7/16; IHS

Challenge through change
Future prospects for the energy architecture

The task: Using renewable energies

Today's challenges ...

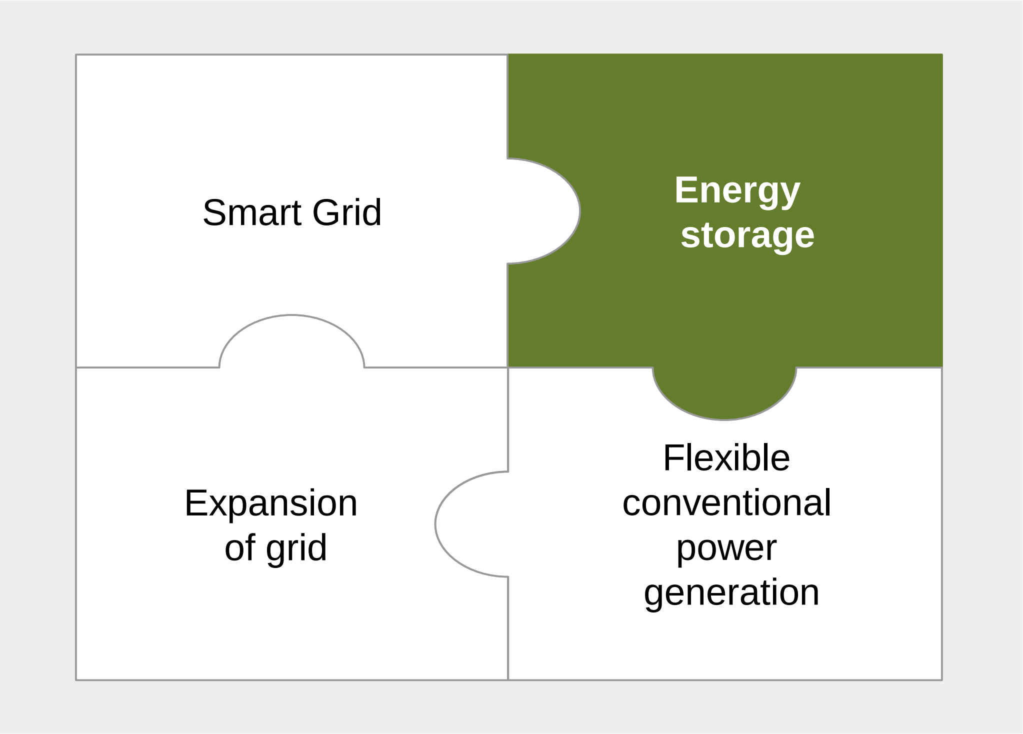
- Germany 2011: Up to 150 GWh of potential wind energy production is capped due to overloading
- United States, TX 2009: 17% of potential wind energy production is capped due to overloading

... will be even greater tomorrow:

- Germany 2030: approx. 24,000 GWh of excess energy expected1
- EU 2050: 80 % of energy production is to come from renewable energies according to proposed legislation

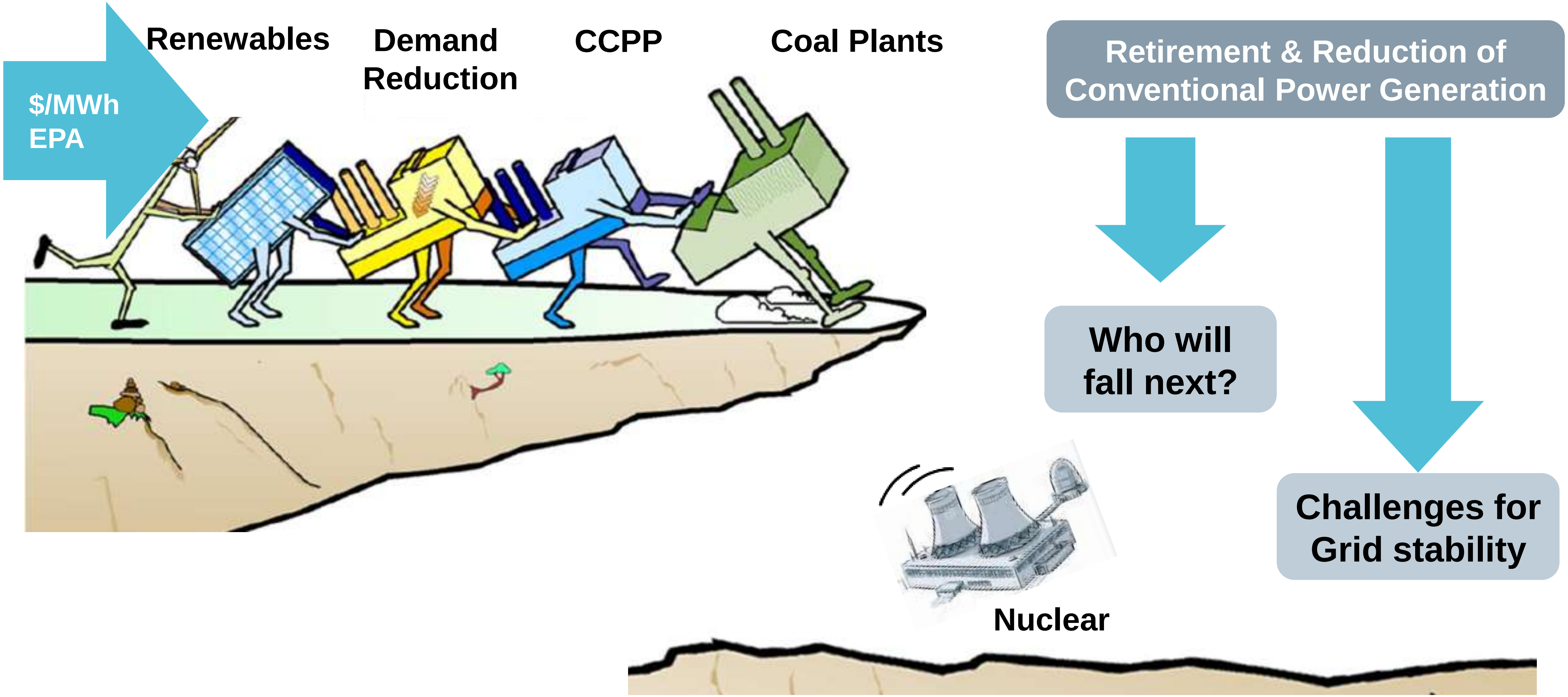
Source: Bundesverband WindEnergie, EEG, Team Thermal Storage, Source E ST MC / SR 2011 / Basic case 1 – 9 % of production (26 % of the installed base) from volatile renewable energy sources
2 – 31 % of production (54 % of the installed base) from volatile renewable sources, assuming maximum grid expansion "Copper sheet" modell)

A solution approach: Energy storage



The Market

Energy Transition…
What does it mean?



Retirement & Reduction of Conventional Power Generation

Who will fall next?

Challenges for Grid stability

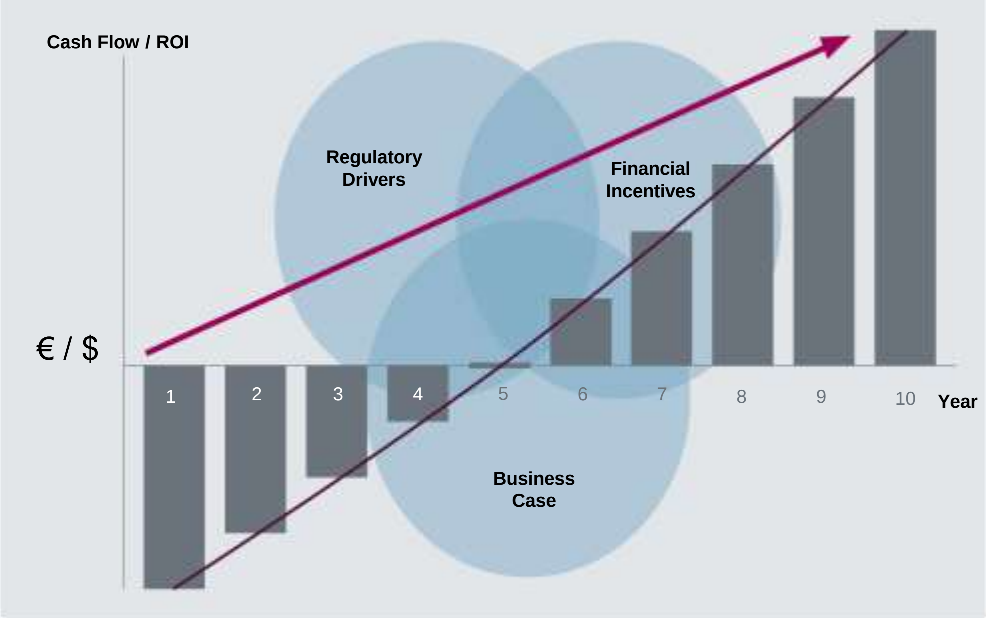
Market Needs Drive Value Propositions

1. There Is A Clear Demand For E-Storage and Hybrid solutions
2. Multiple Drivers Boost Adoption (NOT JUST ONE)
3. “One-Size-Fits-All” Concept Is Unlikely To Succeed
4. Value Is Perceived in the Solution NOT Product
5. Long term O&M important to success of project

Revenue and cost savings through asset optimization

* Dependent upon application and requires assessment as a first step

Storage
CAPEX
$



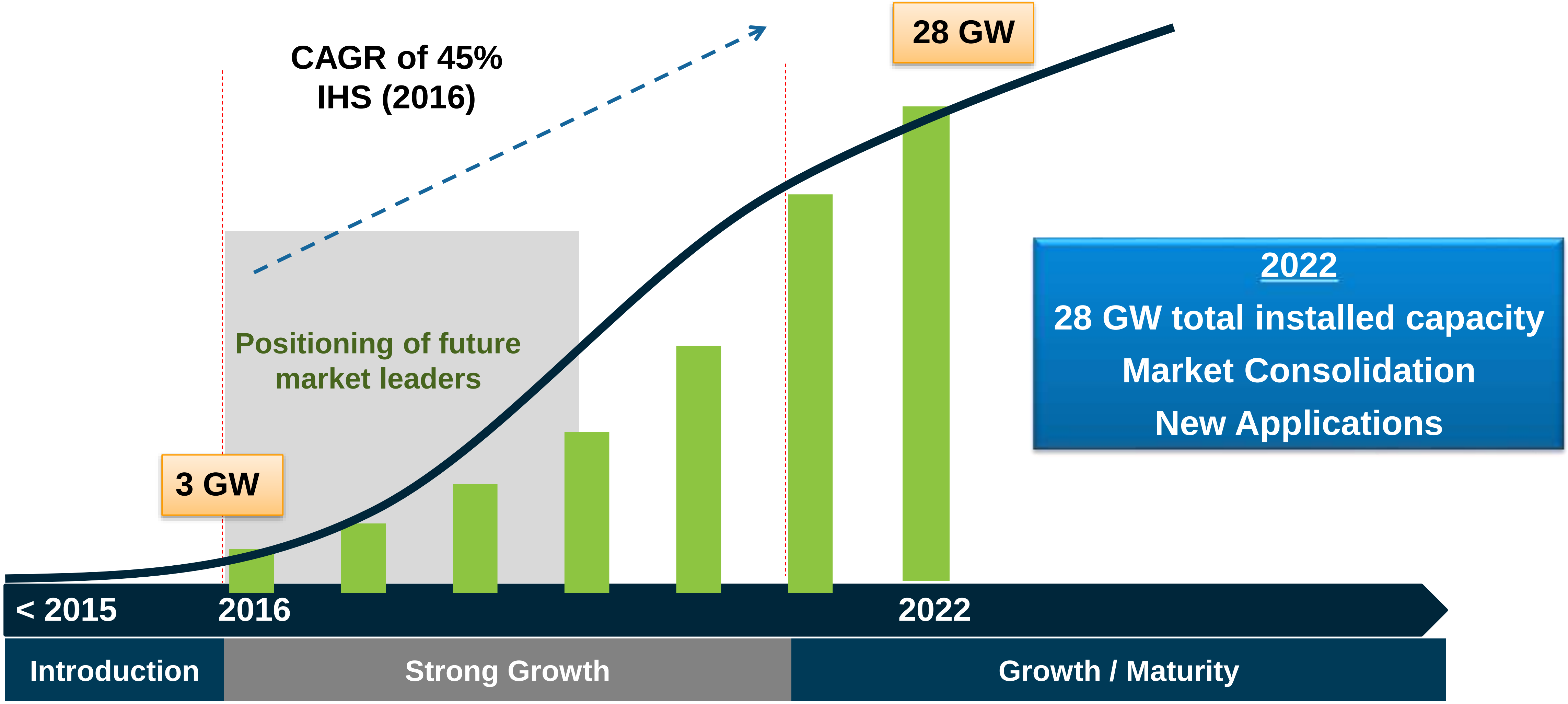
Conventional
Investment
$

The potential is dependent upon three drivers:

- Regulatory drivers (mandated by policies and regulations)
- Financial incentives
- Business cases (additional revenue stream and/or reduced costs, due to efficiency gains such as optimization and investment deferral)

The greatest opportunity for the implementation of STORAGE will occur if all three drivers co-exist.

The Energy Storage Market has entered a new growth phase



2022

28 GW total installed capacity

Market Consolidation

New Applications

Source: IHS (2016)

Subject to customary regulatory approvals

The Market

Storage Technologies

What is the difference between Power (KW, MW) and Capacity / Energy (kWh, MWh)?


15 min System

30 min System

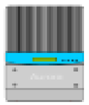
1 hour System

2 hour System

4 hour System

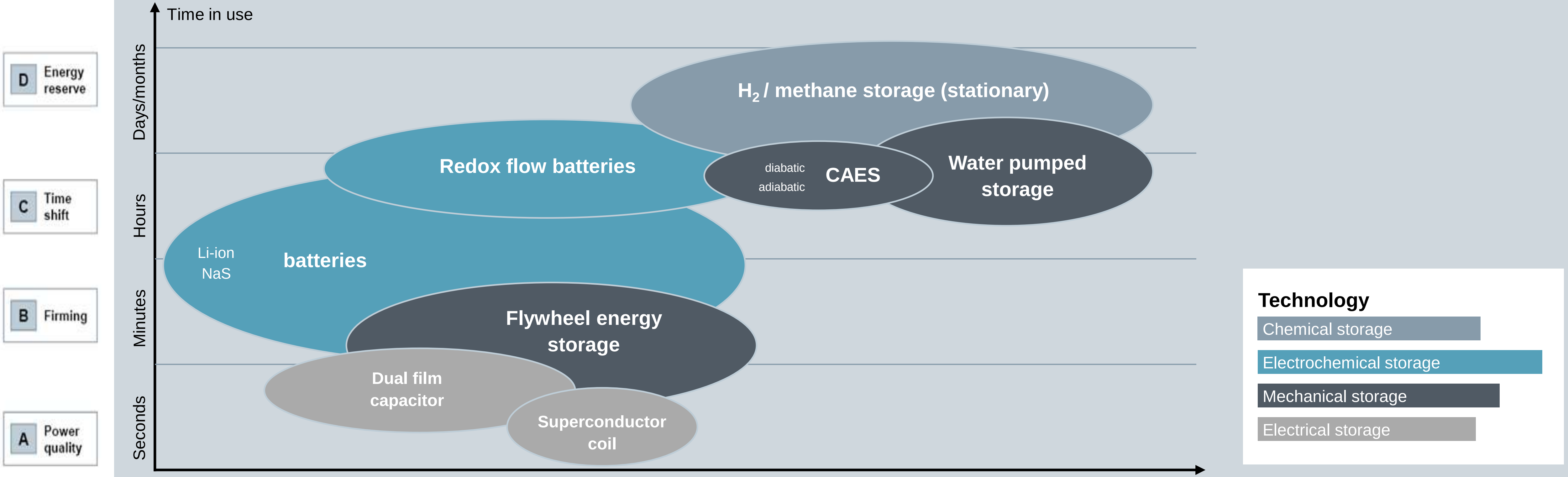
← Power Market

Capacity / Energy Market →

Water Bottle (Gallon)		Energy Element: Responsible for the Capacity	→		Battery (MWh)
Faucet (Gallon/min)		Power Element: Responsible for the delivery	→		Inverter (MW)

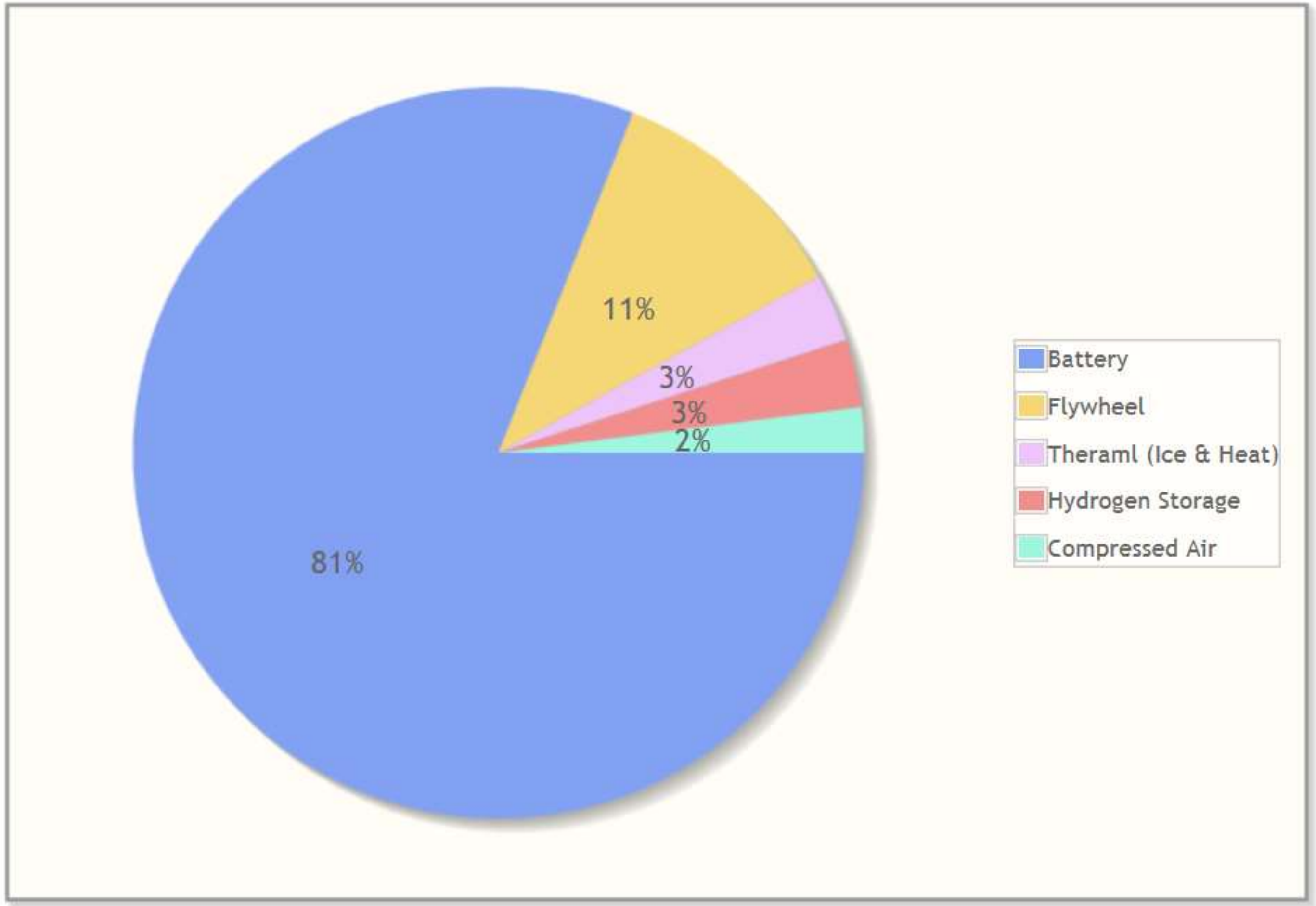
Storage Technologies

Technologies and application areas



Source: Study by DNK/WEC „Energie für Deutschland 2011“, Bloomberg – Energy Storage technologies Q2 2011
CAES – Compressed Air Energy Storage

NEB’s Market Market Snapshot:
Batteries Dominate Early Stage Testing for Energy Storage in Canada



Proposed and Operational Energy Storage in Canada

Several storage systems are being tested in Canada: flywheels, compressed air, hydrogen, batteries, thermal heat, and ice.

Batteries are expected to be the dominant storage technology in the near future.

By 2018, over 50 megawatts (MW) of battery capacity is expected to be operational in Canada, accounting for 81 per cent of the total electricity storage market

Source: https://www.neb-one.gc.ca/nrg/ntgrtd/mrkt/snpsht/2016/07-03bttrsdmnttstng-eng.html

Applications and Business Cases


Microgrids
T & D deferral
Critical power
Integration of renewables
Frequency regulation
Peak load management
Power quality

Customer Challenges

Generators:

- Thermal Generators required to provide Spinning Reserve.
- Renewable Energy Developers wishing to profit from more dispatch-able power.
- Seeking alternative resources to optimise portfolio and participate in energy markets.

Transmission Utilities:

- Facing challenges with integrating more renewable energy.
- Facing challenges to balance supply and demand and manage congestion.
- Seeking better performing providers of ancillary services (frequency regulation, voltage regulation, black start)

Distribution Utilities:

- Facing challenges with integrating more renewable energy.
- Facing challenges to balance supply and demand and manage congestion.
- Seeking better ways to manage Peak Load.

Industrial End Users:

- Experiencing load shedding.
- Facing challenges to manage additional capacity charges/ costs associated with peak load.
- Having to work with irregular voltage
- Having to manage harmonics.
- Supporting black start. (GT start up when no grid power is available)

Customer Challenges

Campuses:

- Wanting to integrate more renewable energy.
- Wanting to be more self sufficient and have less reliance on the grid.
- Wanting to implement micro-grids

Special Economic Zones:

- Industrial, Commercial, Technology, Research parks.
- Wanting to integrate more renewable energy.
- Wanting to be more self sufficient and have less reliance on the grid.
- Wanting to implement micro-grids

Rural Electrification

- Facing challenges with grid expansion.
- Able to integrate and use more renewable energy.
- Wanting to implement off-grid or micro-grid solutions.

Critical Infrastructure:

- Hospitals, Airports, Military sites.
- Requiring a more secure power supply.
- Wanting to integrate more renewable energy.
- Wanting to be more self sufficient and have less reliance on the grid.
- Wanting to implement micro-grids

Applications and Business Cases

Ancillary Services

Applications and Business Cases - Ancillary Services (GenCo‘s and IPP‘s)

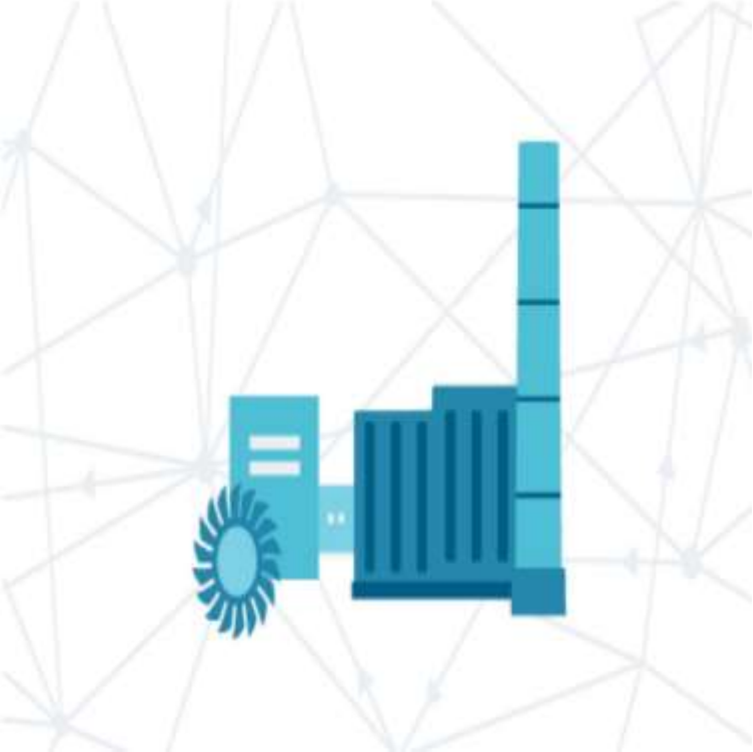
- Ancillary services are necessary services that must be provided in the generation and delivery of electricity.

- More variable renewable energy means greater needs for balancing tools e.g. ancillary services (Frequency regulation, voltage regulation, black start).

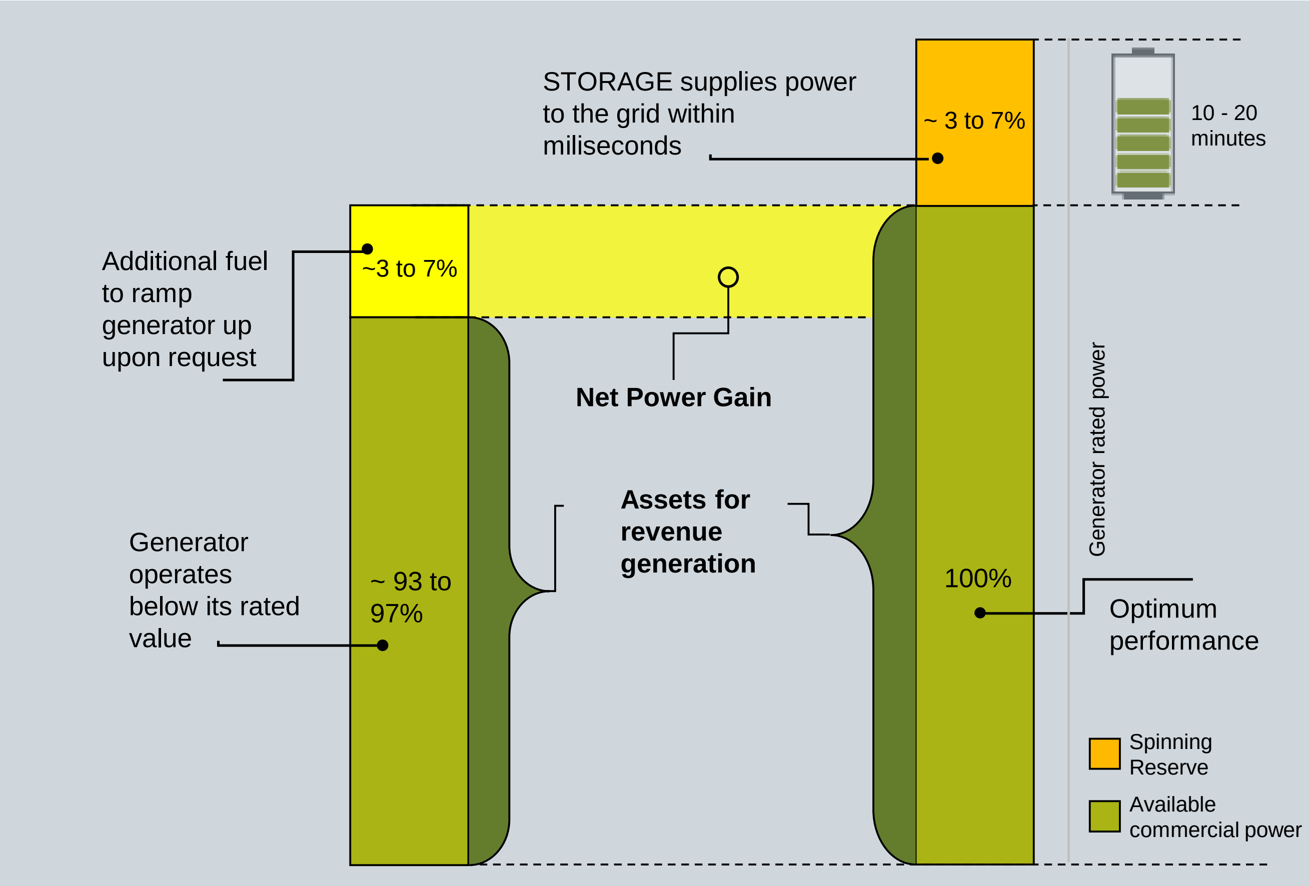
- Some countries and regions oblige generator to maintain reserve capacity to provide grid support services shouldthey be needed. (Spinning or synchronised reserves)

- Grid operators seek more resources such as energy storage as it is faster to respond and therefore reduced balancing costs (40%)

- Power plant operators seek to release reserve capacity for traditional supply contracts this optimising plant efficiency and guaranteeing revenue streams.



Applications and Business Cases
Ancillary Services
Reserve capacity



STORAGE supplies power to the grid within miliseconds

~ 3 to 7%

10 - 20 minutes

Additional fuel to ramp generator up upon request

~3 to 7%

Net Power Gain

Assets for revenue generation

Generator rated power

Generator operates below its rated value

~ 93 to 97%

100%

Optimum performance

🟧 Spinning Reserve

🟩 Available commercial power

Spinning reserve : Grid-connected generator capacity that is withheld to respond to grid emergencies. Response time varies by region.

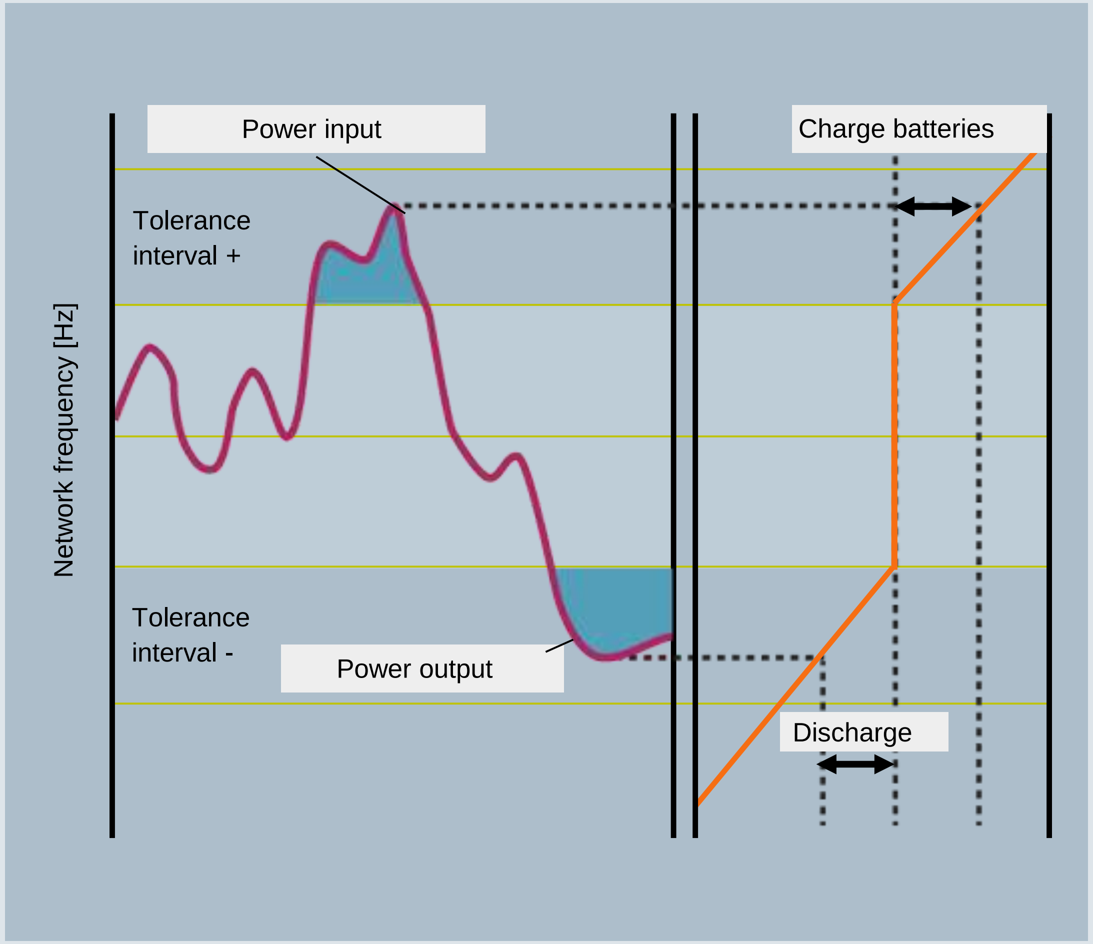
Challenges

- Conventional power plants have to withhold a mandated reserve capacity to respond to grid emergencies (3-7 %).
- Power plants lose efficiency by not running at design capacity (higher losses, emissions, etc.).
- Power plant revenue models are based on maximum output over a fixed period. Reserve revenues are not always guaranteed (e.g. stand by capacity /energy payments, etc).

Solution with STORAGE

- STORAGE can be co-located with conventional generators to release reserve capacity, leaving the power plant to operate at 100% or full capacity
- Improved system stability as a result of faster to respond
- More flexible resources
- Attractive financial alternative business cases in regions where reserve capacities are mandated
- Improved power plant efficiency, less emissions, etc.

Applications and Business Cases
Ancillary Services
Primary Reserve Frequency Regulation



Quelle: Chartouni, Bühler, Linhofer

Challenges

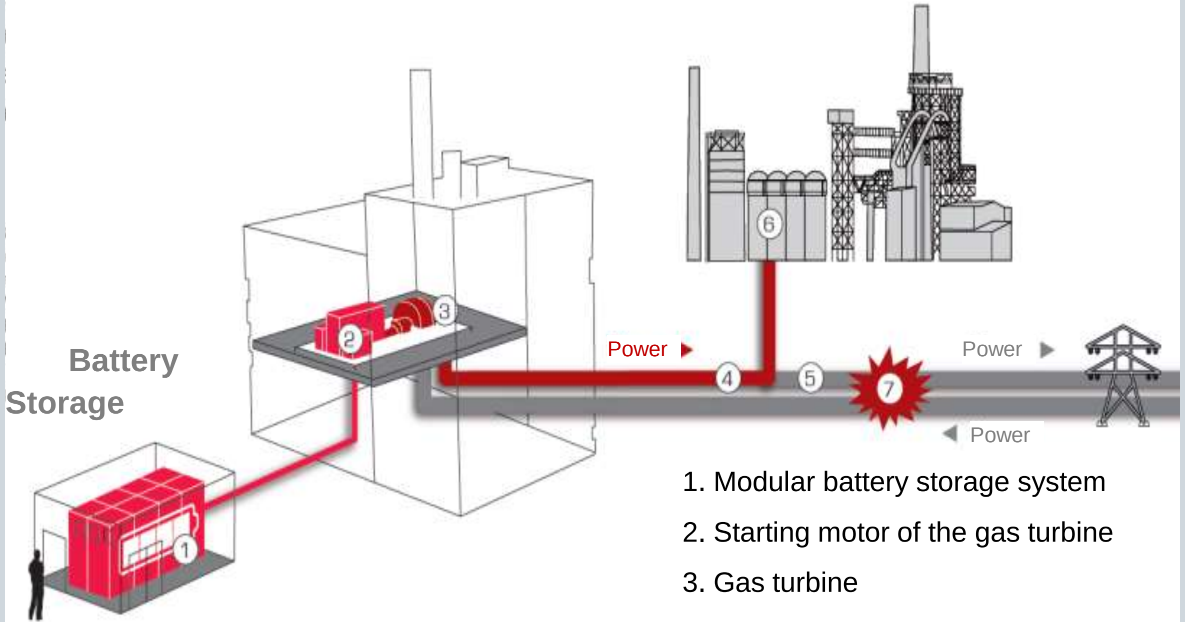
- Quick response (seconds to minutes) to frequency fluctuations is required to maintain grid stability
- Continuous ramping of generators reduces efficiency and asset lifetime
- Requirements for frequency regulation are increasing with the integration of renewables due to their unpredictable nature and large fluctuations
- End users with increasingly higher levels of technology demand better power quality

Solution with Battery Storage

- Faster and more precise response time than any other primary control systems (<10 s)
- Higher payments for ancillary services (pay for performance) due to the faster response time and increased accuracy (compared to a conventional generator)
- Higher cost efficiency in grid management due to improved response accuracy
- Greater flexibility in regulation services portfolio
- More competition in regulation markets

Applications and Business Cases
Ancillary Services
Black Start

Example in an industrial application: Where a gas-fired power plant is used to provide back-up power, Battery Storage provides ignition to the starting motor of the gas turbine in the place of diesel generation, ensuring rapid start up.



1. Modular battery storage system
2. Starting motor of the gas turbine
3. Gas turbine
4. Off-grid / factory grid
5. Public grid
6. Integrated iron and steel works
7. Blackout on local grid

Challenges

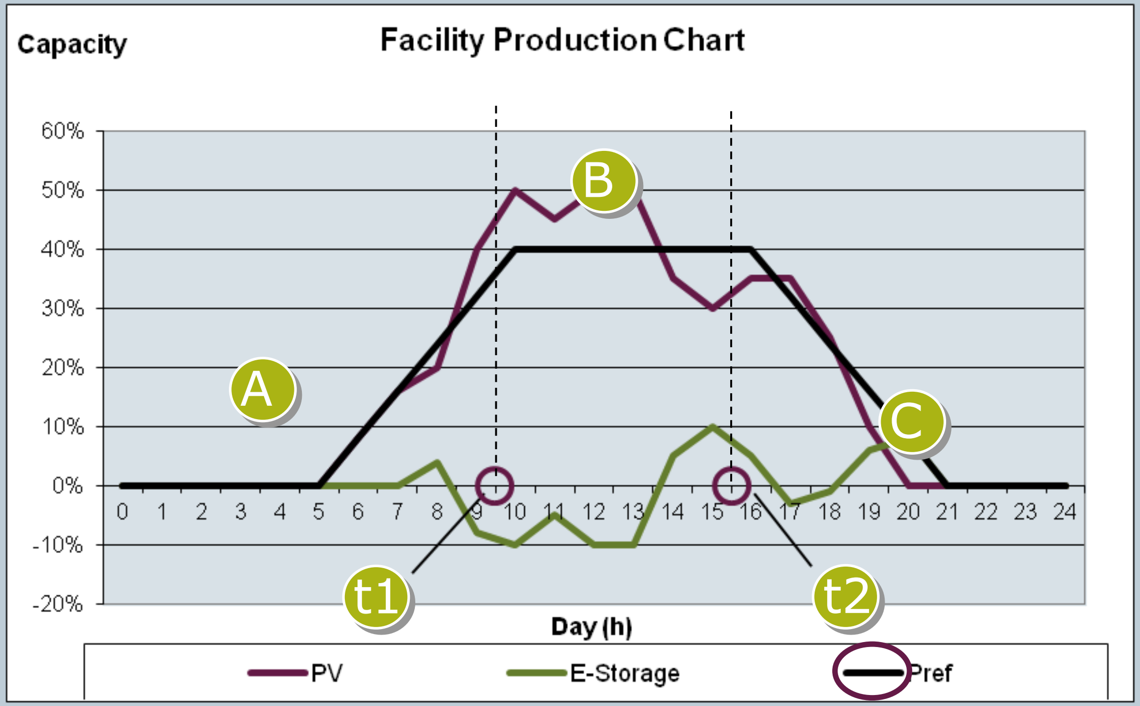
- Grids can experience partial or total system failure known as brownouts or blackouts
- Conventional generators require an external auxiliary power supply to start or re-start and have to be synchronized before re-connecting to the grid
- Black start capability is often mandated for fast response generators or can be provided as an ancillary service

Solution with Battery Storage

- Faster response time than conventional generator to provide black start, allowing grids to be re-energized faster and reducing production downtimes
- Reducing losses related to production downtimes
- Providing the power quality parameters required by the generator to be synchronized and reconnected to the grid

Applications and Business Cases
Renewable Energy Integration
Grid Compliance

EMS predicts one day ahead the production curve (t1, t2, Pref) based on weather forecast.



A - Ramping-up phase

B - Stationary phase

C - Ramping-down phase

t1 - End of ramping-up phase

t2 - Beginning of ramping down phase

Challenges

- Providing clean sustainable energy that is variable and intermittent
- Greater challenge for grid operators to balance supply and demand due to variability of renewable energy
- Grid codes for connection to the grid, e.g. ramp rate, reactive power and power factor requirements
- Penalties for scheduling deviations

Solution with Battery Storage

- Compensating the variability and intermittency of renewables by quickly charging and discharging to smooth output
- Limiting ramp rates to comply with grid codes and connection agreements
- Frequency and voltage regulation to improve power quality
- Better forecasting, scheduling and dispatch accuracy through controlled output
- Improved supply and demand matching due to time shifting
- Faster cost recovery through energy arbitrage

Applications and Business Cases

Asset Optimisation

Applications and Business Cases
Asset Optimisation
Peak Load and Congestion Management

Charging
Off-peak hour

Discharging
Peak hour

Challenges

- Maximum demand and time-of-use (ToU) charges applied by some utilities
- Higher rates at peak times and lower pricing at off-peak times for commercial and industrial customers (to reduce energy consumption)
- Grids are oversized only to address growing peak demand, resulting in lower efficiency
- Peak load and congestion are localized; however grid has to be oversized to point of injection in order to compensate
- Times of low load also create challenges where long-term power purchase contracts are in place

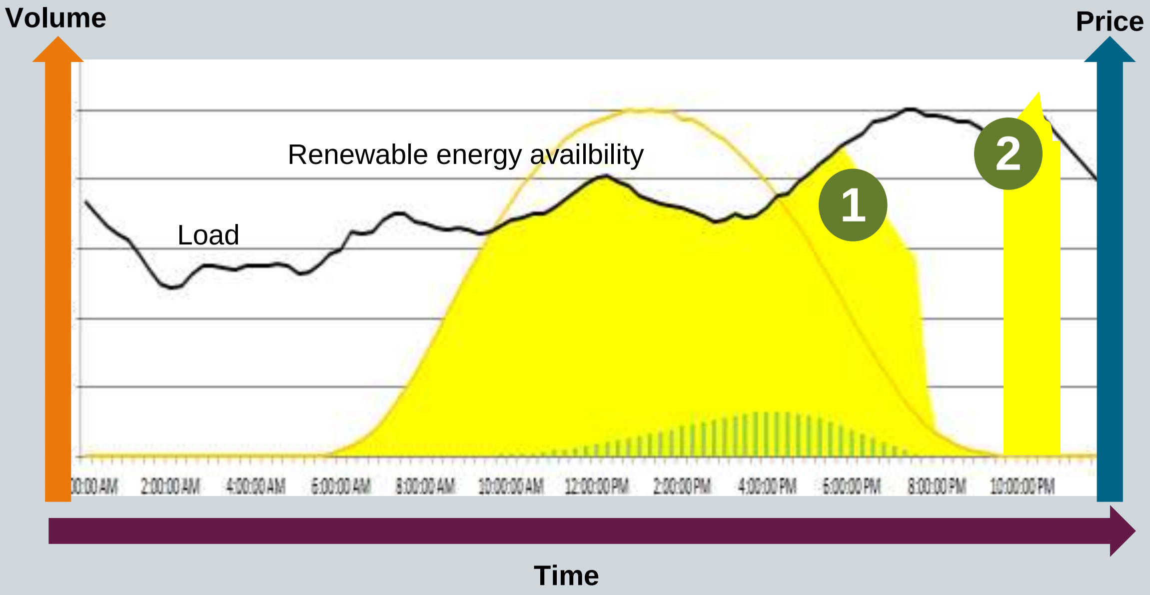
Solution with Battery Storage

- Avoiding higher rates by reducing the amount of energy consumed during peak times
- Consuming power during low load times and supporting the load during peak times
- Localized storage helps to avoid or defer network upgrades (T&D asset deferral)
- Co-location with renewable energy helps to better utilize generation capacity by matching supply to demand

Applications and Business Cases
Renewable Energy Integration
Energy Arbitrage / Time Shifting

① Time shifting: to make excess renewable energy available to match load requirements

② Energy arbitrage: to sell excess when market prices are higher



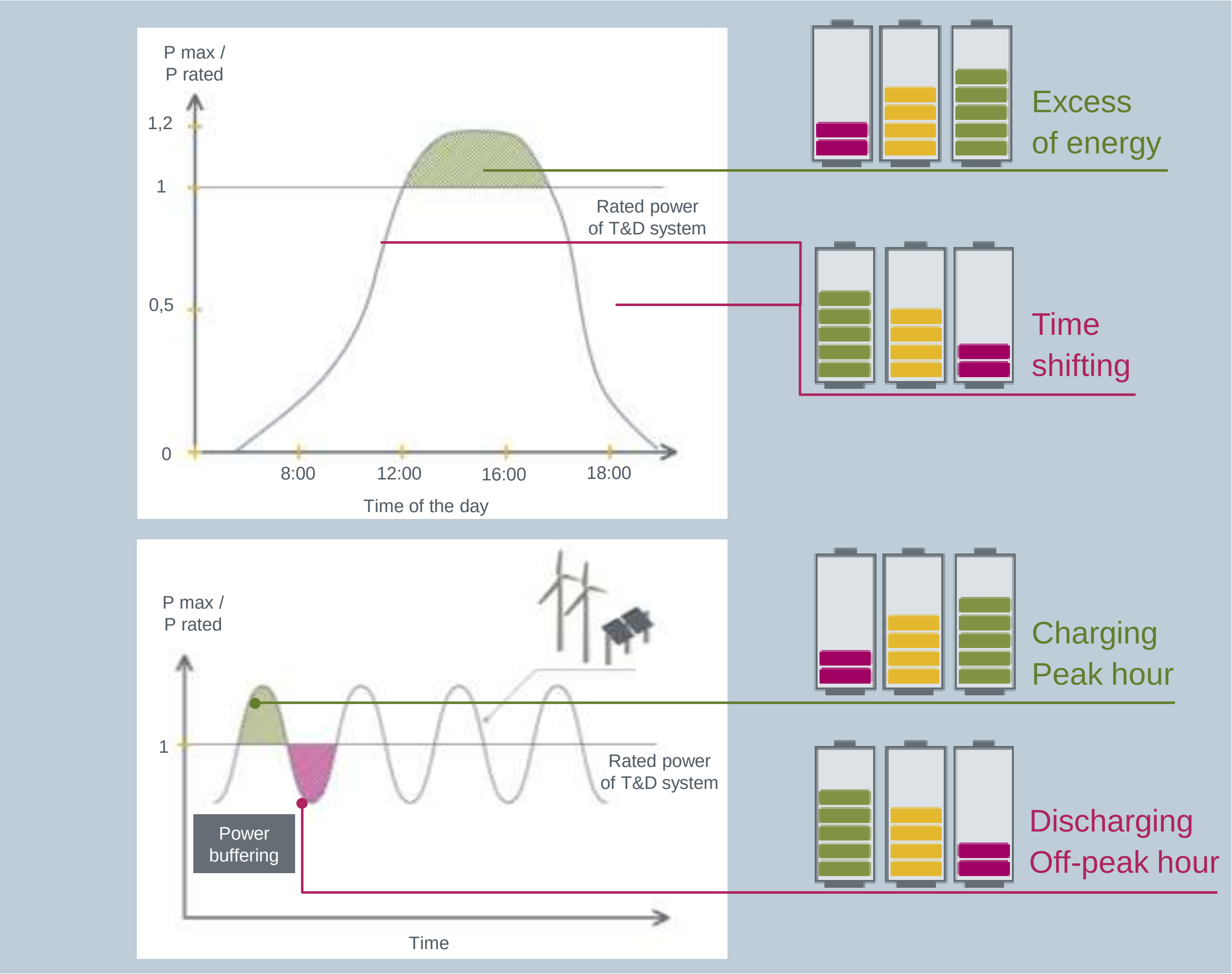
Challenges

- Wind power is most intense during the night and solar power at midday. Demand normally peaks during the morning or evening, creating a mismatch
- In some instances renewable plants are required to curtail production as local demand cannot absorb capacity
- Market prices reflect demand requirements and can become negative for oversupply and high when demand peaks

Solution with Battery Storage

- Providing a means to better utilize renewable energy capacity by storing it and making it available when the load requires
- Cost can be recovered faster or revenue increased by storing renewable energy and selling it into the market when prices are higher/demand is higher

Applications and Business Cases
Asset Optimisation
T&D Upgrade Deferral



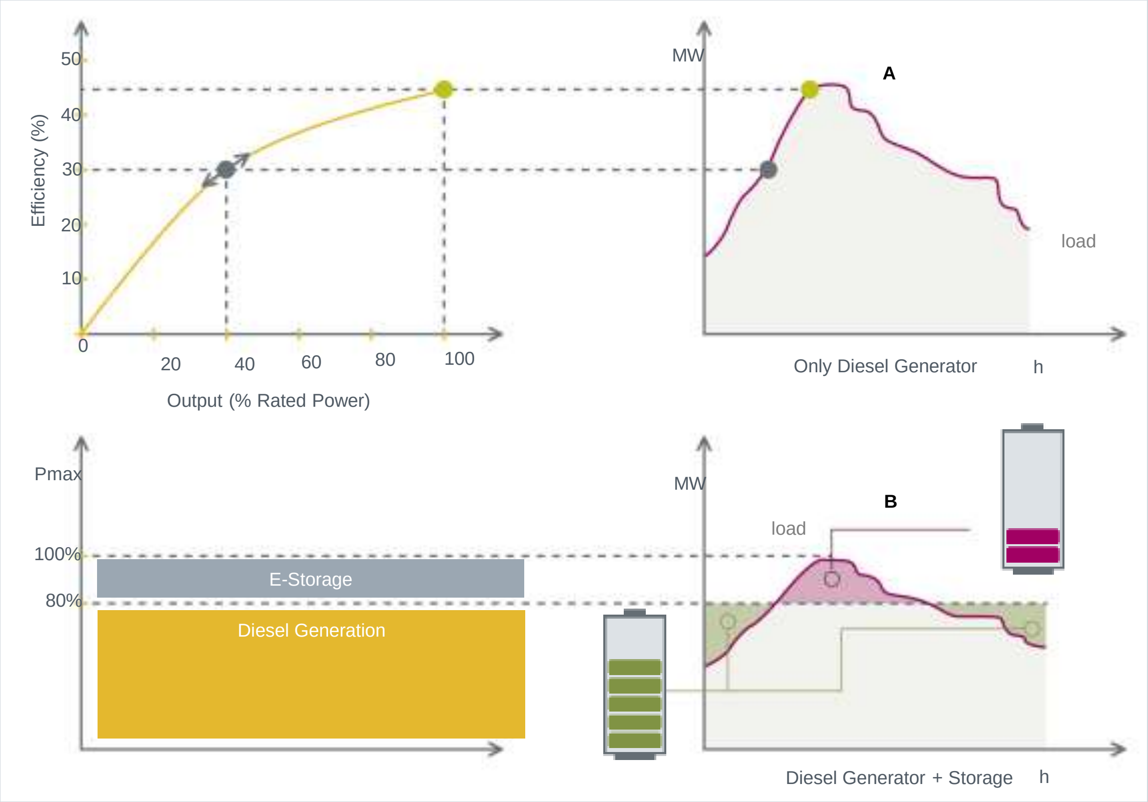
Challenges

- Increased peak demands and integration of renewable plants
- Congestion of transmission lines as a large amount of renewables are injected in the grid at off-peak times
- Large losses due to the misalignment between generation and loads so that power transport occurs across large distances
- Very expensive upgrades and extension of power grid assets

Solution with Battery Storage

- Increasing capacity by installation at a substation in the T&D grid Battery Storage can be sized to meet the rising pressure on the asset
- Storage of power during off-peak times to be consumed during peak times when grid assets are under pressure
- Deferral of grid upgrades until new T&D assets investments are financially justified

Applications and Business Cases
Asset Optimisation
Diesel offset / Replacement



Challenges

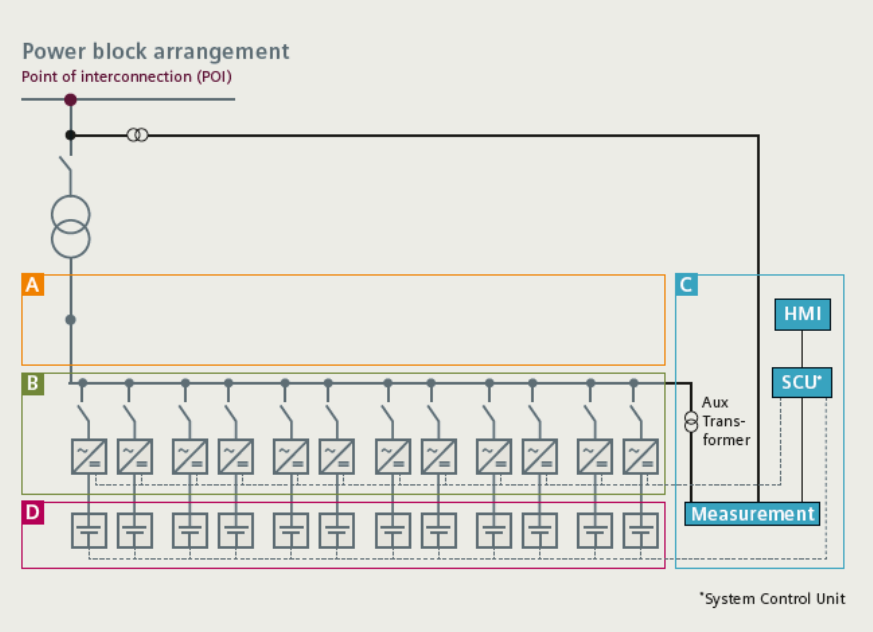
- Diesel generators are the only solution to provide power in remote locations without connection to the main grid
- Large diesel generators pollute the local environment (high fuel consumption and millions of tons of emissions per year) and provide significant hazards related to transport and storage
- Ramping of diesel generators is inefficient and requires more fuel
- Diesel fuel is increasing in price (year on year) while the cost of renewable energy is falling

Solution with Battery Storage

- Co-installation with diesel generators to reduce fuel consumption by allowing the generator to operate at a fixed output and avoid ramping up and down
- Co-installation with renewable plants and diesel generators to optimize renewable integration and micro-grid operation
- Opportunity for off-grid and grid applications for CO_2 abatement and climate protection

Technology Overview

Battery STORAGE modular concept
Four components into an innovative solution



A

Grid connection cabinet*

- Cable tap for grid connection
- Busbar system

* optional

B

Inverter cabinet

- inverter modules and related control equipment

Each module:

- V nominal: 400 V
- I nominal: 170 A
- S nominal: 118 kVA

C

Control cabinet

- HMI (Human Machine Interface)
- System Control unit (SCU)
- Ethernet switch
- 24V DC power distribution
- Aux. Power transformer

D

Battery cabinet

Content example:

- 14 modules
- 1 BMS (Battery Management System)
- Power: 90 kW
- Energy: 45 kWh

Courtesy of Siemens

Basic System Configuration

The basic version of the Battery STORAGE system, the 1PS (1 Power Stack or Converter Unit) consists of one Inverter Panel, one Battery Cabinets and one Control Cabinet as shown on diagram below (Fig.1A).

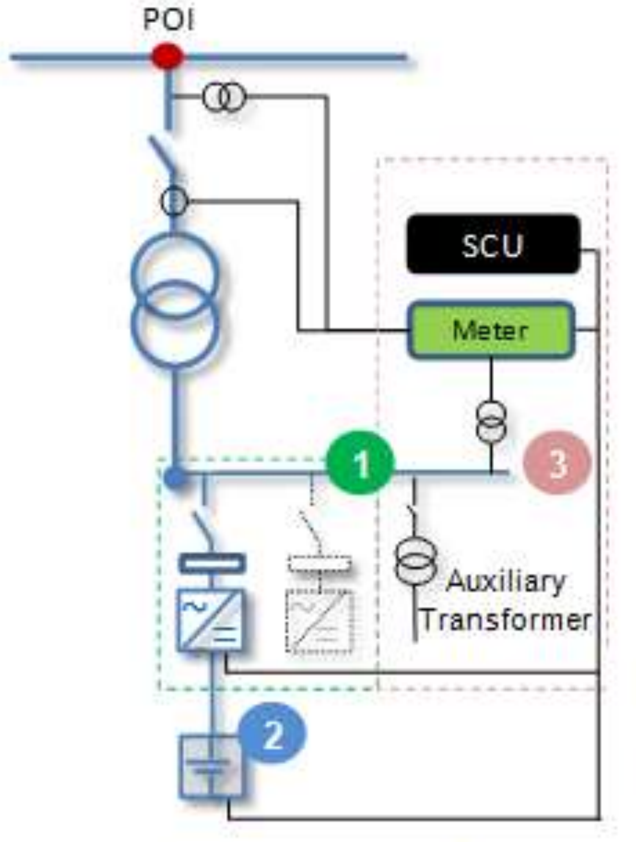


Fig. 1A; Standard 1PS: 1 Battery Rack / Inverter

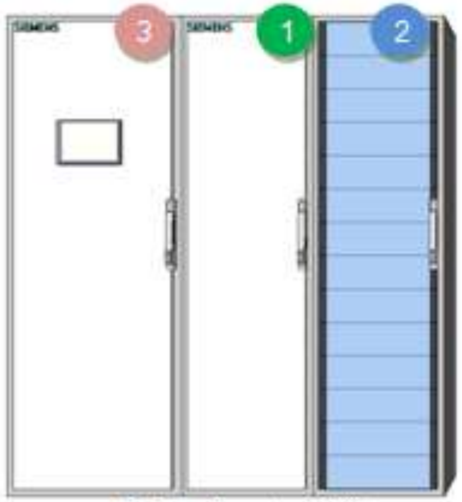


Fig. 2A; Standard 1PS

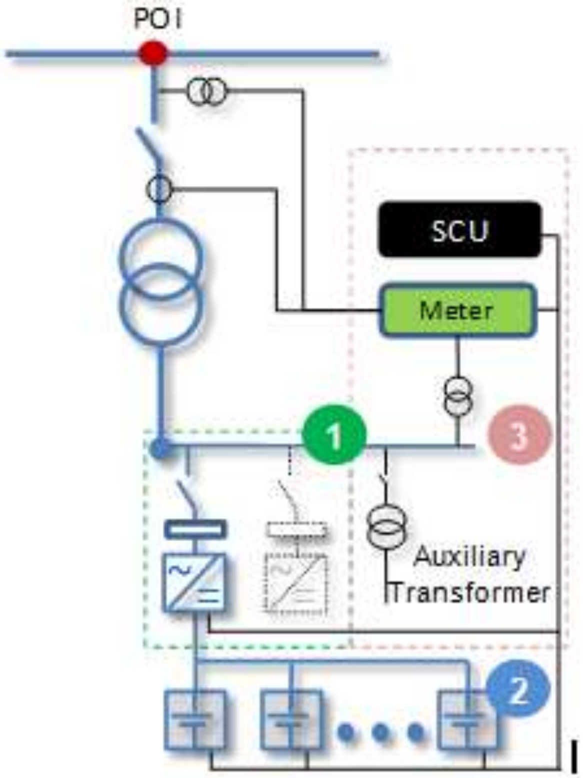
Typically, the 1PS block handles one battery rack (Fig.1A).

One battery rack contains up to 14 battery modules. For simple maintenance and safe operation, the battery modules have a maximum voltage of 60 V DC, and can be pulled out, inserted and moved individually.

- To increase system power and energy at the same time as avoiding inconvenience of balancing DC loads, each battery cabinet is individually connected to a single inverter; then all the inverters are interconnected on the AC side.

Basic System Configuration

For high energy density applications, a single inverter can be connected to multiple battery racks (Fig.1B).



Legend:
1 – Inverter Panel
2 – Battery Rack
3 – Control Rack

Fig. 1B; 1PS Application Multiple Battery Racks / Inverter

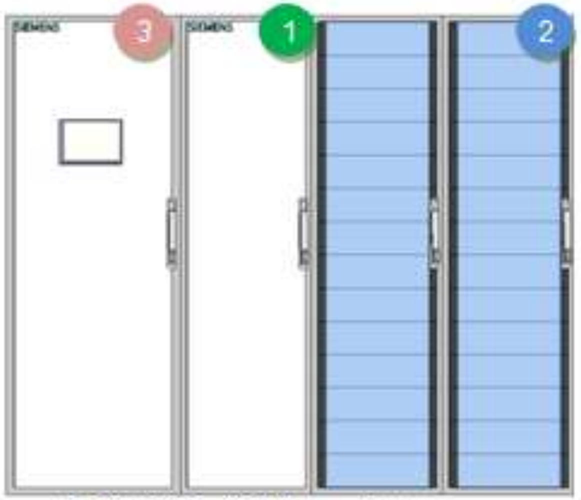


Fig. 2B; 1PS with 2 Battery Racks

Legend:
1 – Inverter Panel
2 – Battery Rack
3 – Control Rack

12PS System Configuration

Up to 12 power inverters and BMS modules are connected to one SCU. Local operation of a POWER BLOCK is possible through the human machine interface (HMI) mounted on the control panel. Information on the operating state of the batteries, auxiliary subsystems (HVAC, fire suppression/detection, etc), medium-voltage switchgear, and alarms can be quickly accessed by this interface.

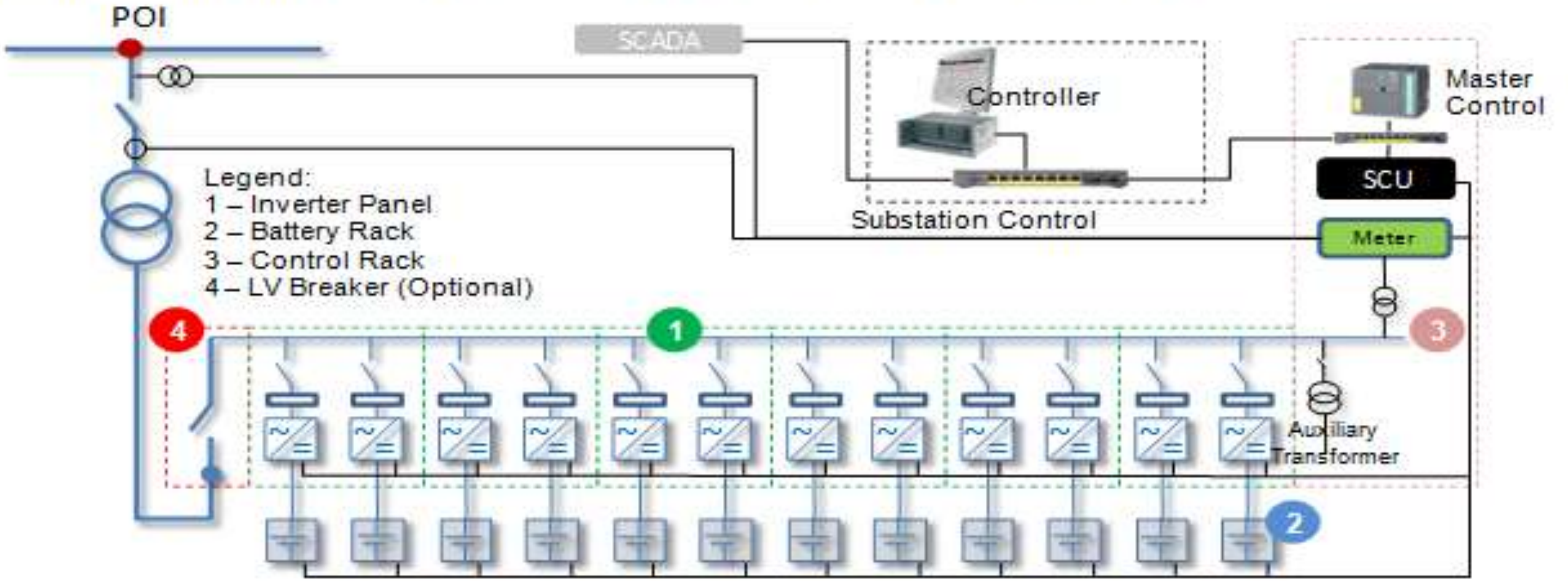
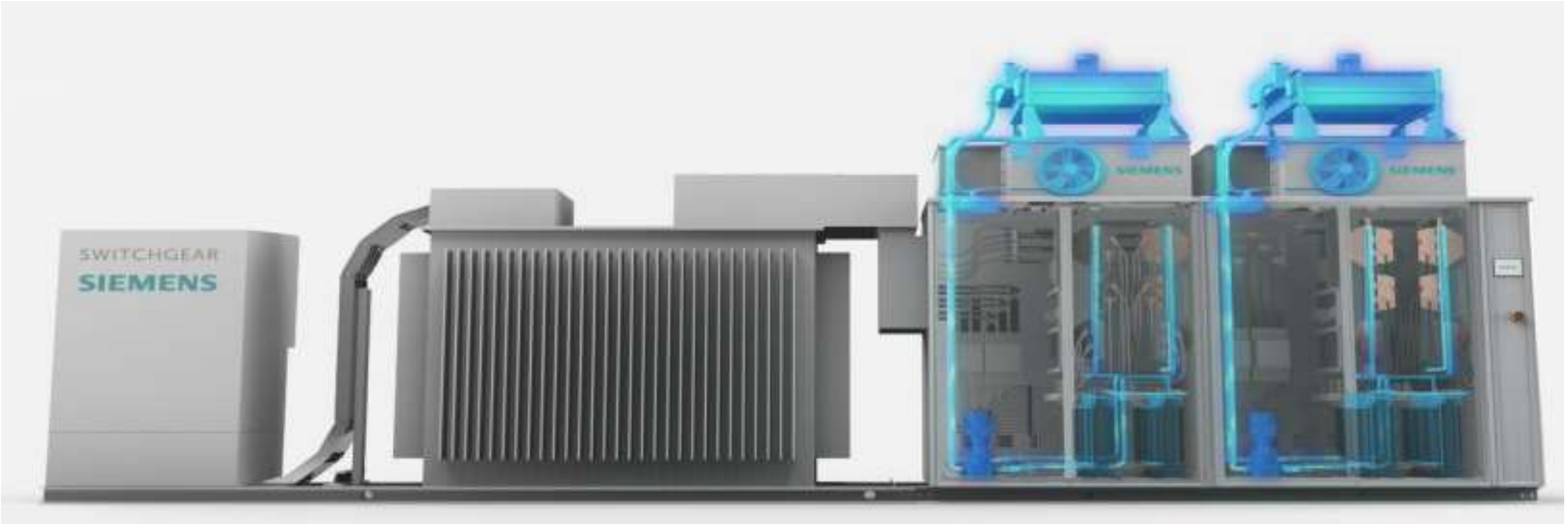


Fig. 3, Standard 12PS Solution: 1 Battery Rack / Inverter

MV Inverters

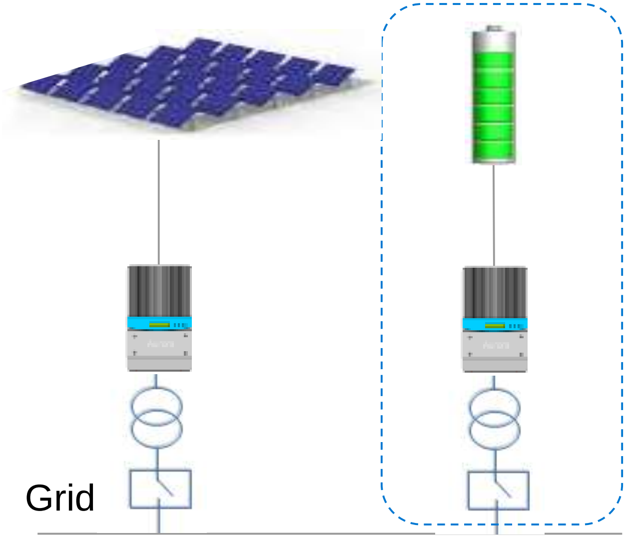
Courtesy of WSTech



Courtesy of Siemens

AC & DC Coupled Systems for New and Existing PV Plants

AC Coupled System

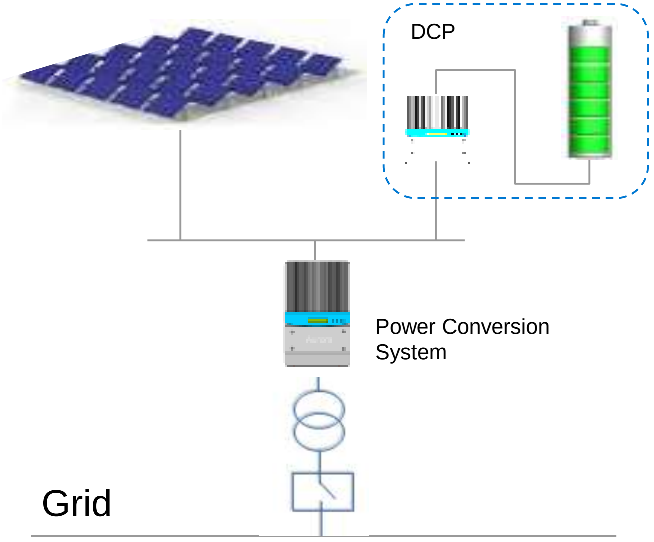


New PV Plant ★

Existing PV Plant ★★

Traditional Deployment of Hybrid Plants
Highest BOP CAPEX & System Losses

DC Coupled System (1)

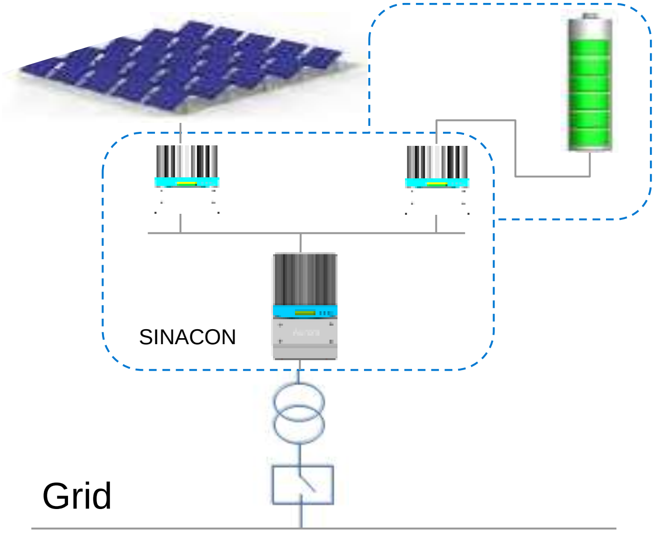


New PV Plant ★★

Existing PV Plant ★★★

Best Solution for Existing Plants due to
Low losses and initial CAPEX

DC Coupled System (2)



New PV Plant ★★★

Existing PV Plant ☆

Maximum Renewable Penetration
Optimization of battery usage and
Power Flow Control

Courtesy of Siemens

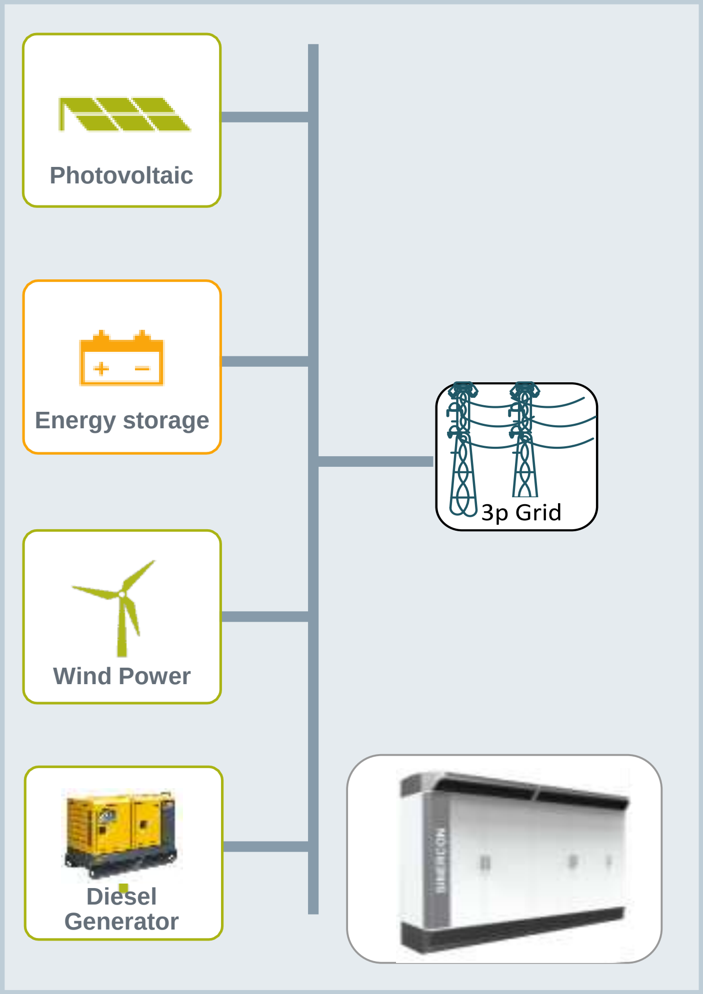
Hybrid Plants (Renewables + Storage + X)
New Technology for Reliable Renewable Penetration

Fuel Dependency ↓

Grid Stability ↑

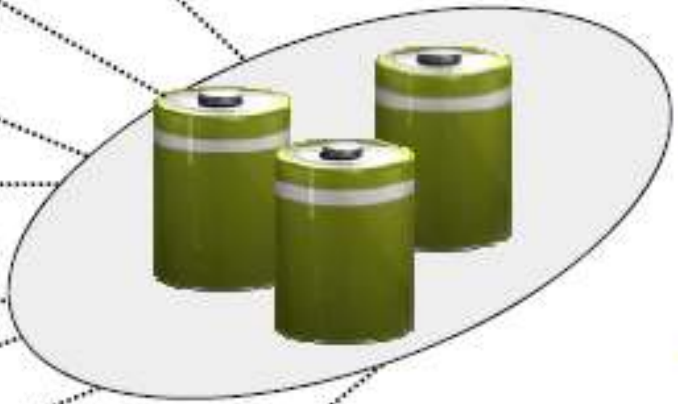
Greenhouse Gas Emission ↑

Energy Usage Optimization ↑



Courtesy of Siemens

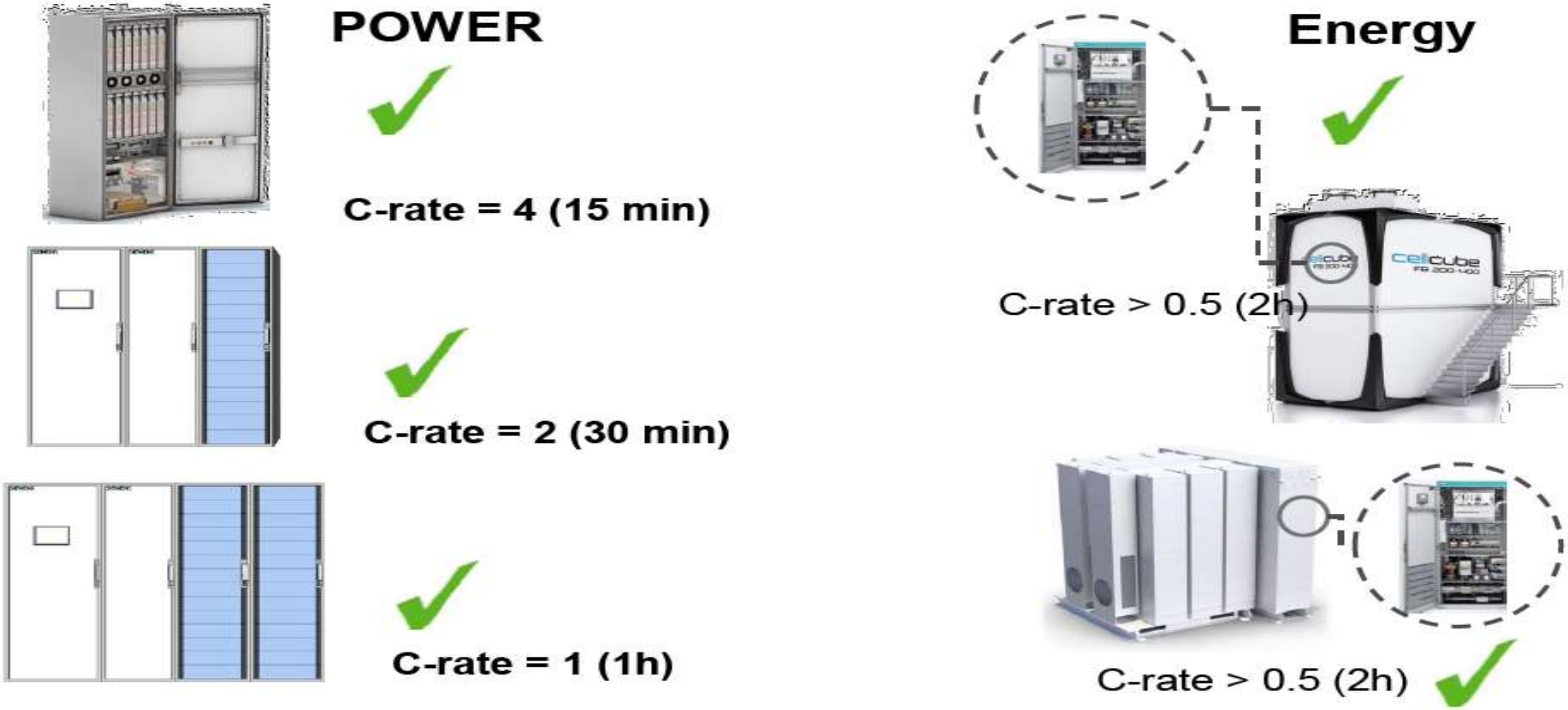
Storage technologies
High-performance Li-ion batteries



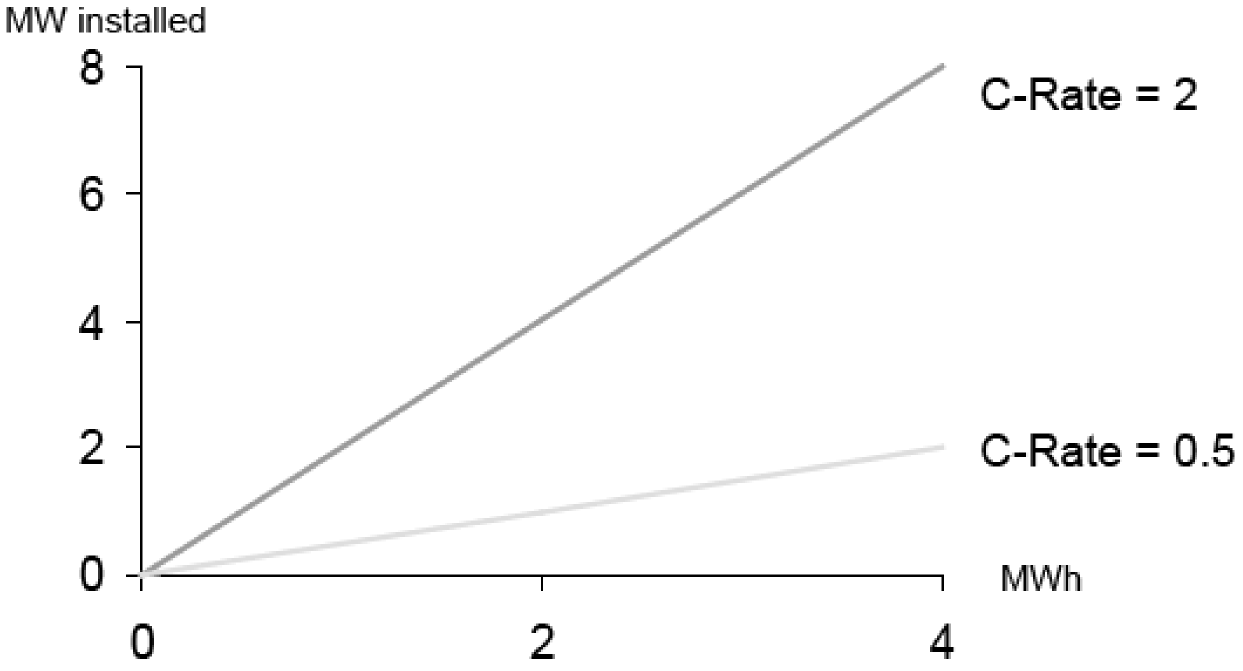
- Constant availability to charge/discharge
- High C-rate* (2-4 compared to other batteries)
- High round-trip efficiency
- Low self-discharge
- Low battery weight due to high energy density
- Operation temperature 0 °C to 40 °C
- Power in/out within milliseconds
- High manufacturing volume due to applications in other markets

* C-rates specify charge and discharge currents. At 1C, the battery charges and discharges at a current that is par with the marked Ah rating; at 0.5C the current is half, and at 0.1C it is one tenth. On charge, 1C charges a good battery in about one hour; 0.5C takes 2 hours and 0.1C 10 to 14 hours.

C-Rate Defined by Power and Energy



System Needs Defined by Application



Installing ESS depends on desired project layout where C-Rate defines the use

Battery Performance

The calendar life curve (example) is the graph that estimates the capacity degradation rate during 10 years. The reference point is based on the measured results with varying State of Charge (SOC) at room temperature. Among the test condition under different SOC level, it shows that 60% of SOC is the best. If the SOC is higher than 60%, capacity deterioration is increased when compared with a SOC of 60%.

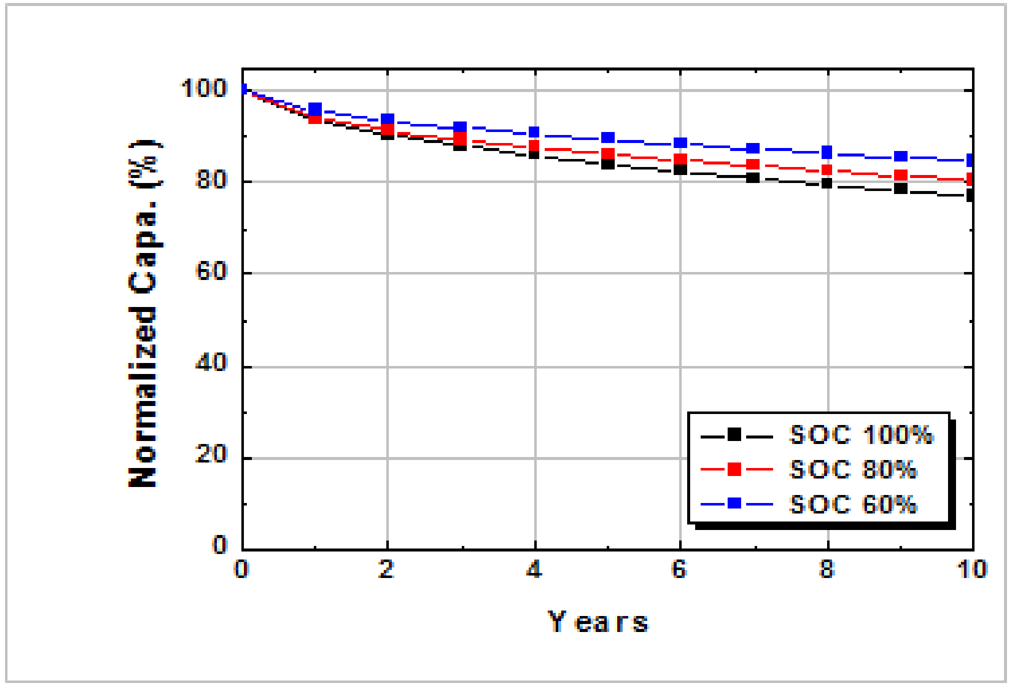


Fig. 1; General Aging effect on Battery Capacity considering different SOCs

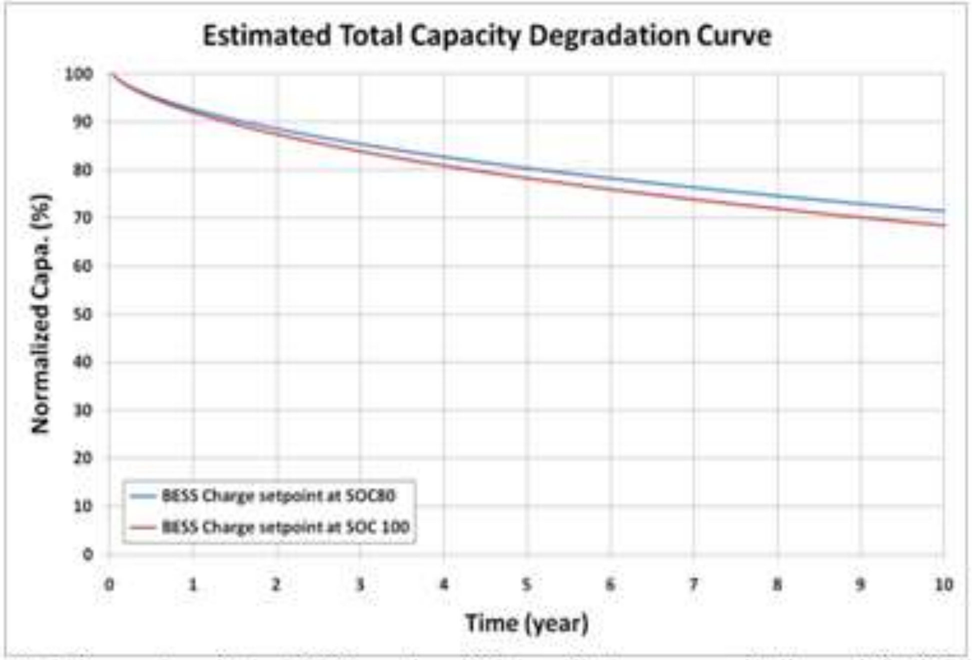
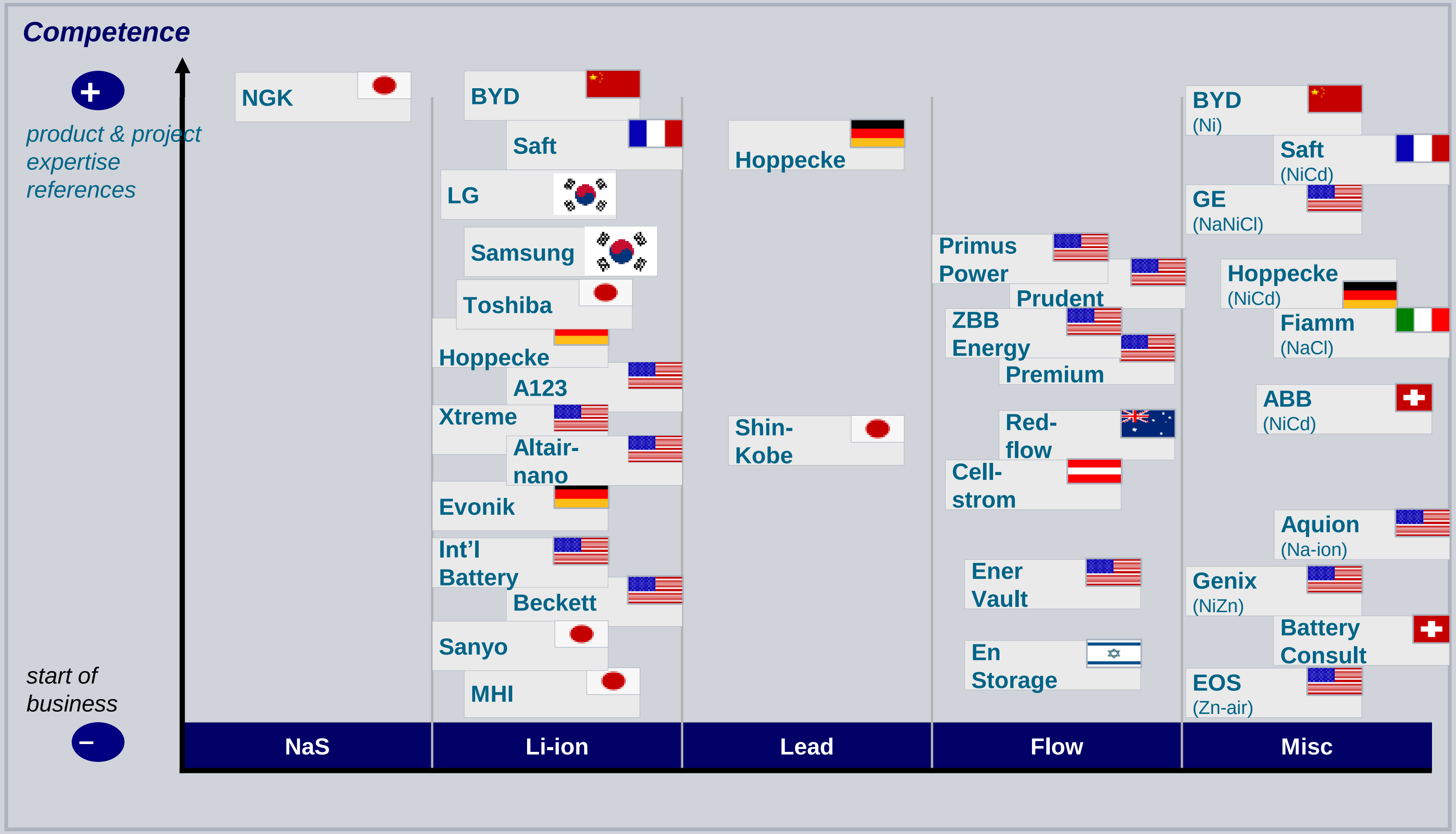


Fig. 2; Aging and projected 3000 cycles effect on Battery capacity through its life time

Storage Technologies:
Battery market with different technologies and suppliers

Battery OEM manufacturers

assessment for commercial stationary battery OEM only



Competence

\+ *product & project expertise references*

\– *start of business*

NaS
- NGK

Li-ion
- BYD
- Saft
- LG
- Samsung
- Toshiba
- Hoppecke
- A123
- Xtreme
- Altair-nano
- Evonik
- Int'l Battery
- Beckett
- Sanyo
- MHI

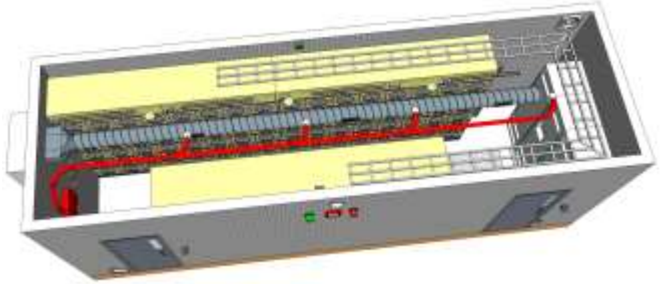
Lead
- Hoppecke
- Shin-Kobe

Flow
- Primus Power
- Prudent
- ZBB Energy
- Premium
- Red-flow
- Cell-strom
- Ener Vault
- En Storage

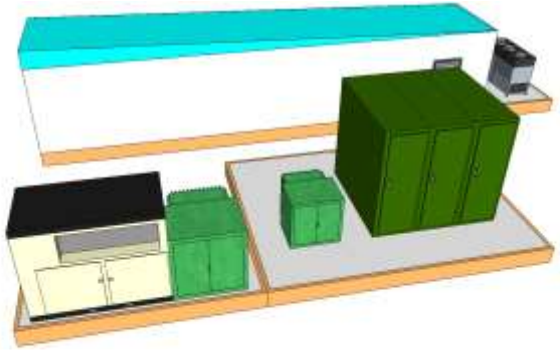
Misc
- BYD (Ni)
- Saft (NiCd)
- GE (NaNiCl)
- Hoppecke (NiCd)
- Fiamm (NaCl)
- ABB (NiCd)
- Aquion (Na-ion)
- Genix (NiZn)
- Battery Consult
- EOS (Zn-air)

- **Sole serious manufacturer of NaS batteries is NGK**
- **Many manufacturers of Li-Ion batteries indicate high potential for cost reduction**
- **Flow batteries emerging technology with focus on longer discharge times**

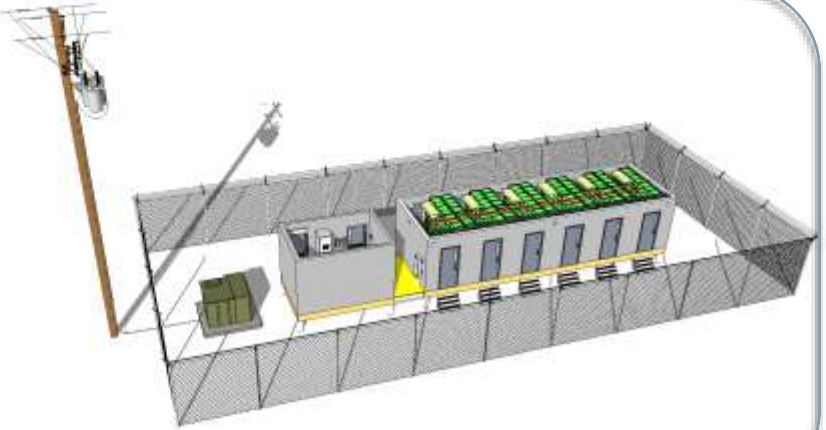
Solutions
Approach to the Multiple Energy Storage Applications



Container Design

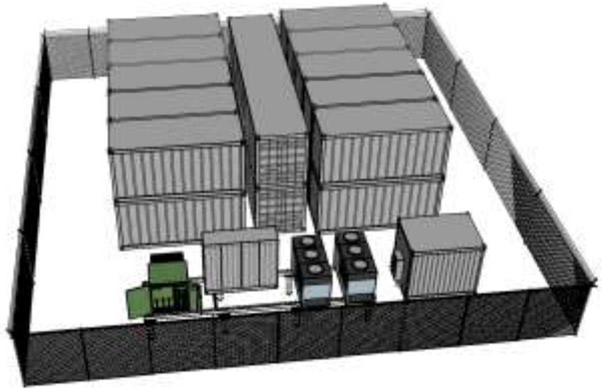


Block Design

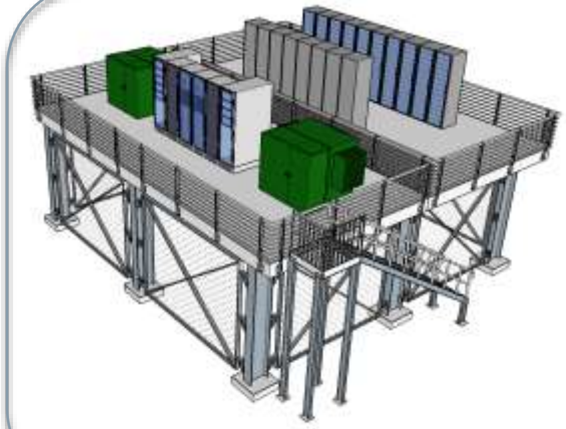


System Design

Plant Design



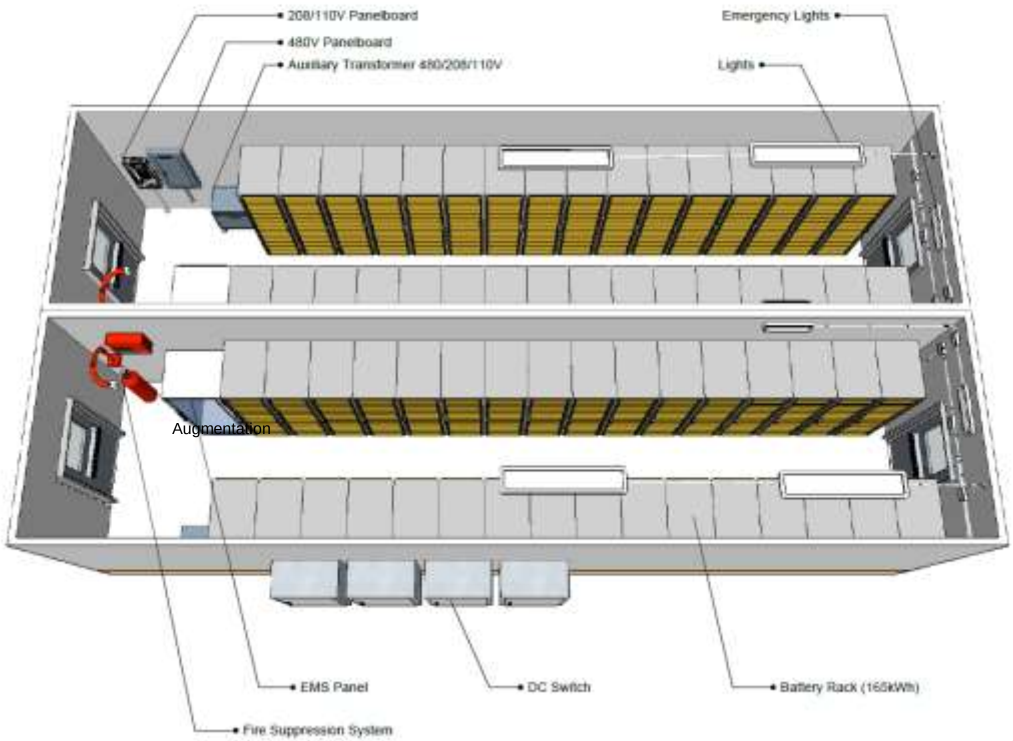
Application Driven Design

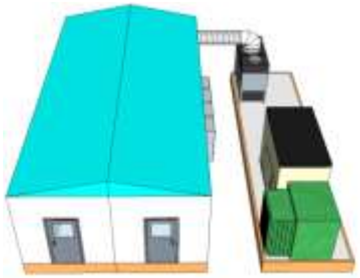


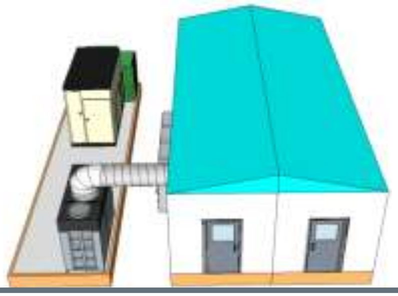
Customized Design

Grid Attached Storage
Overview of System Design – 2MW/2MWh Block

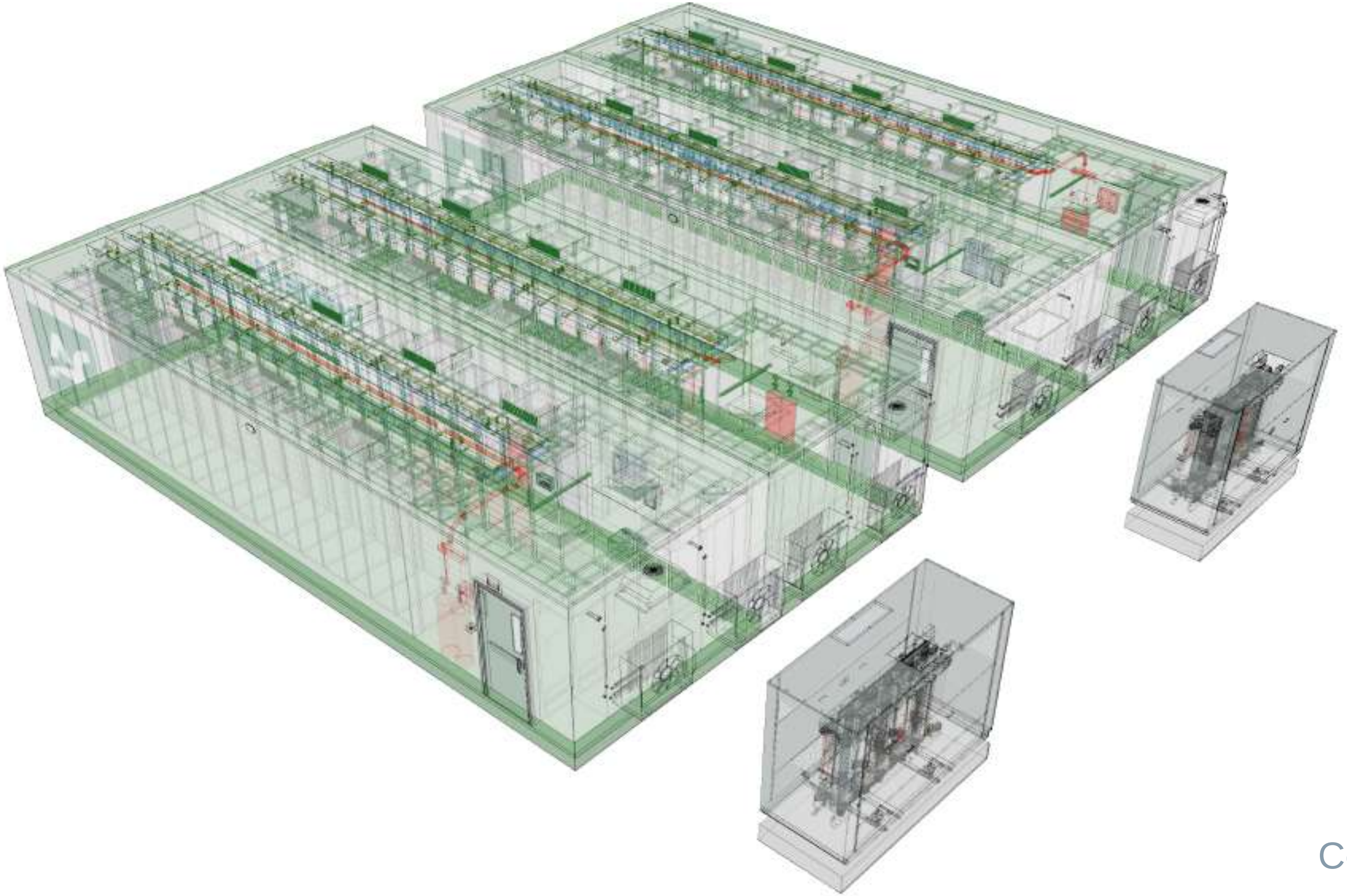
Courtesy of Siemens





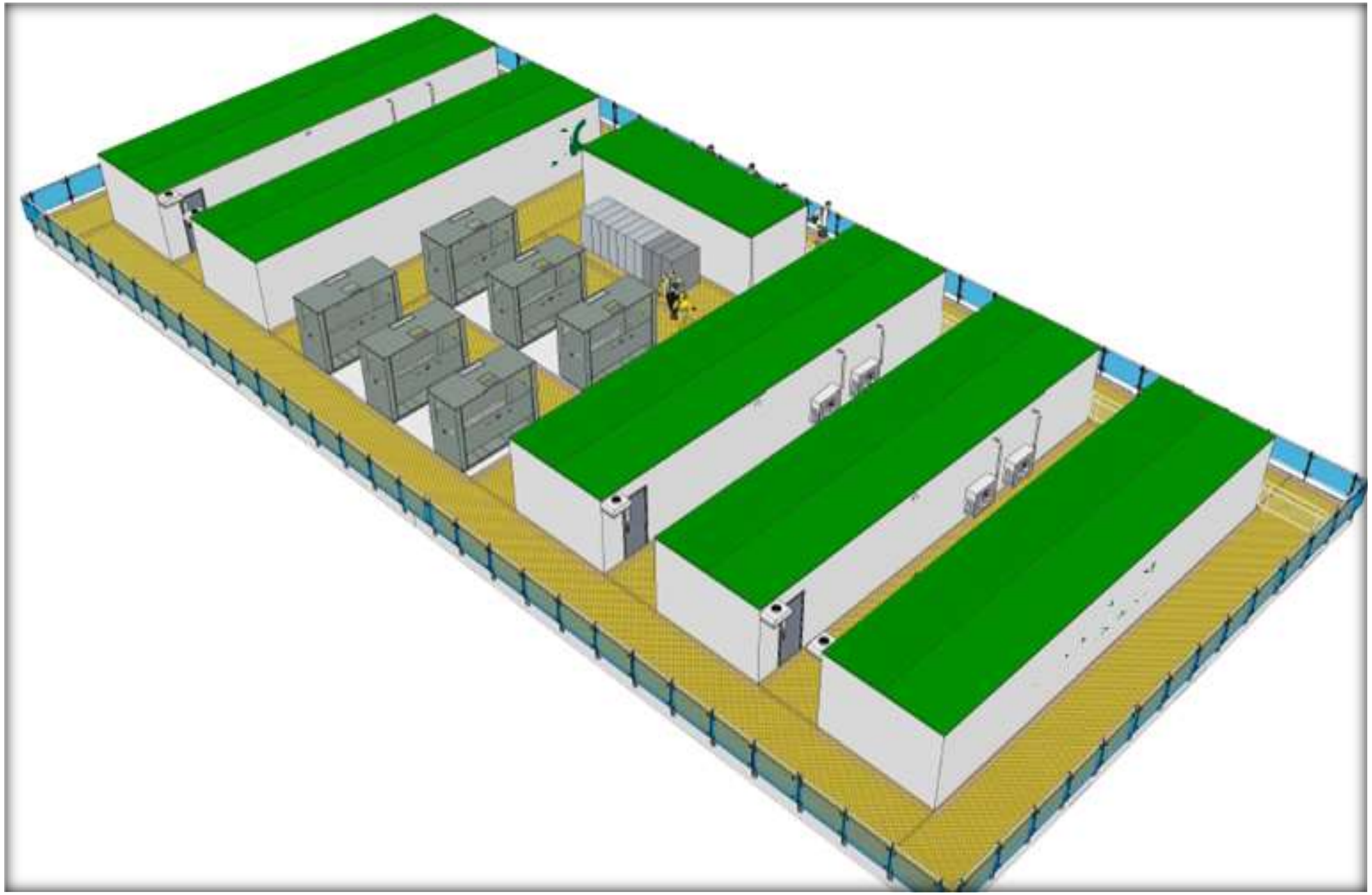


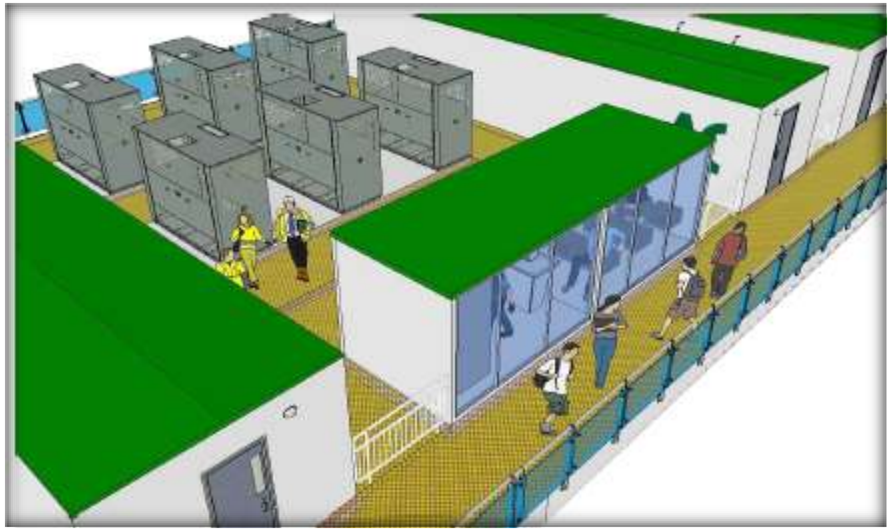
Example of Container designs

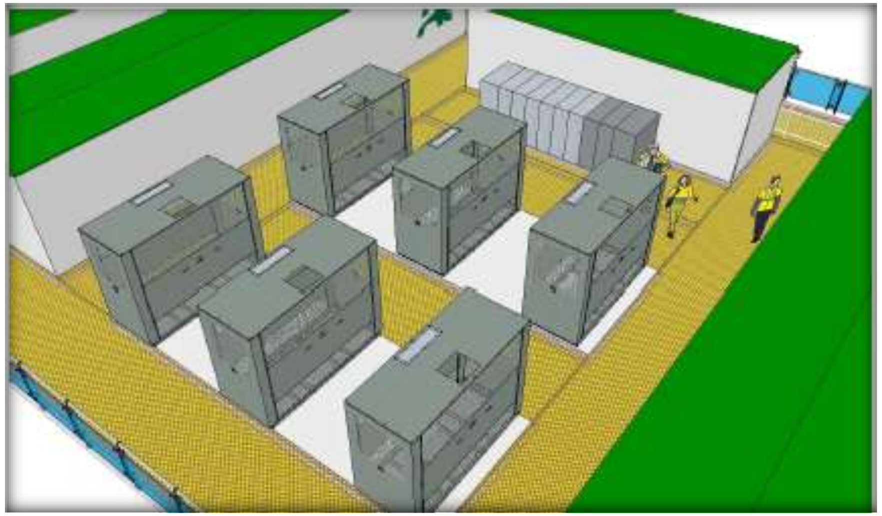


Courtesy of Siemens

Example of Container designs

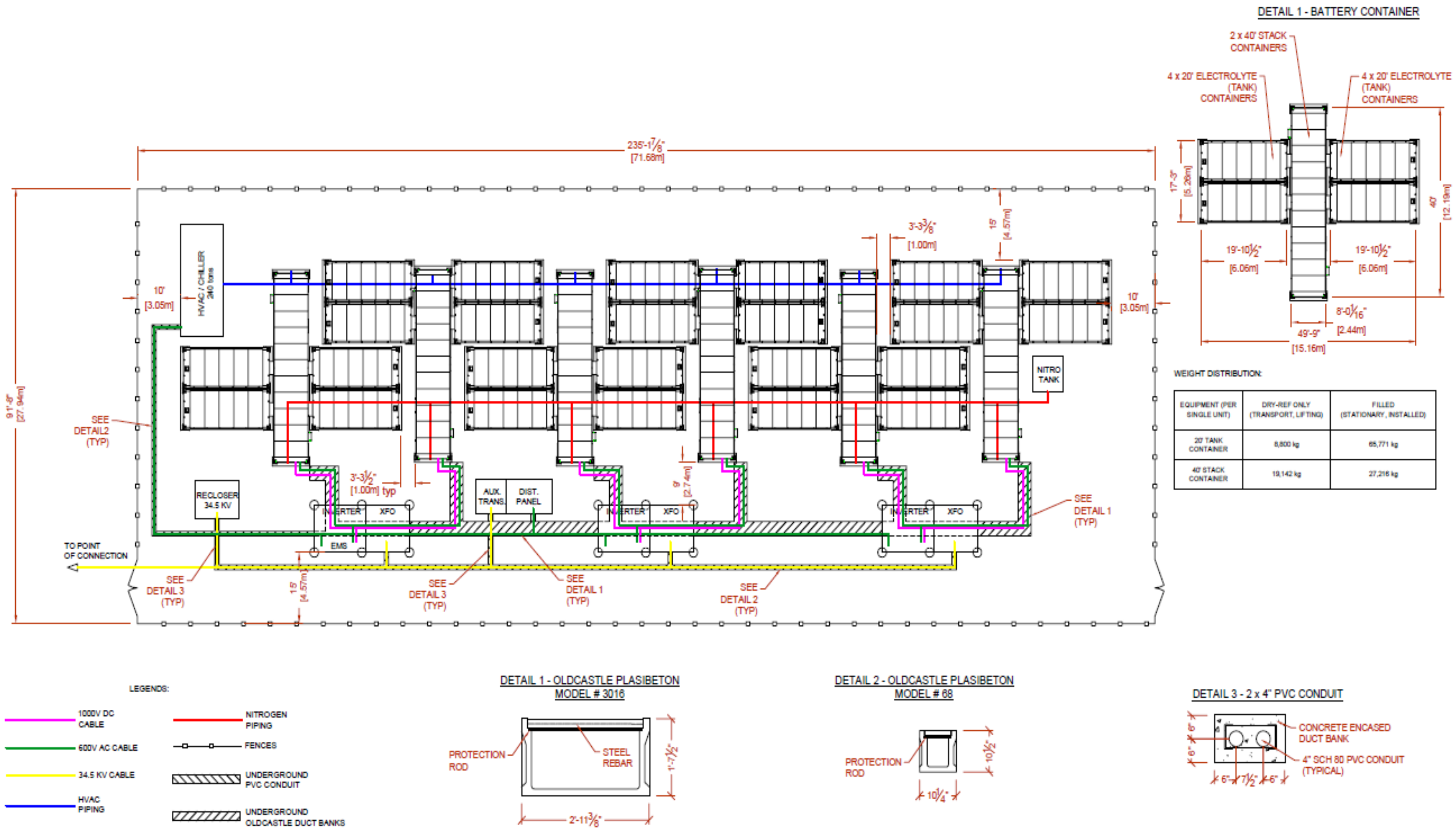






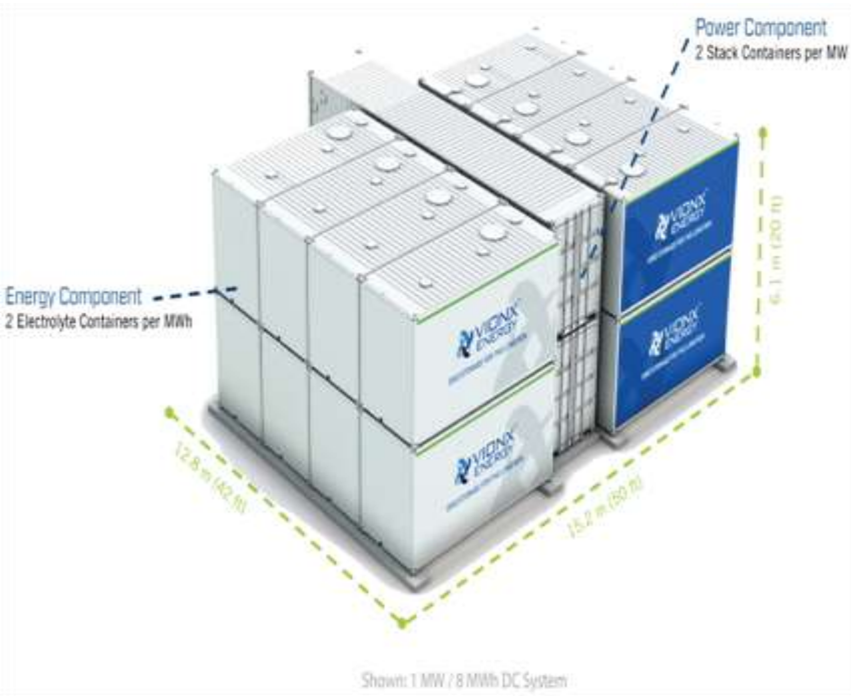
Courtesy of Siemens

Example Flow Battery System – 6MW / 24MWh



WEIGHT DISTRIBUTION:

EQUIPMENT (PER SINGLE UNIT)	DRY-REF ONLY (TRANSPORT, LIFTING)	FILLED (STATIONARY, INSTALLED)
20' TANK CONTAINER	8,800 kg	65,771 kg
40' STACK CONTAINER	19,142 kg	27,216 kg



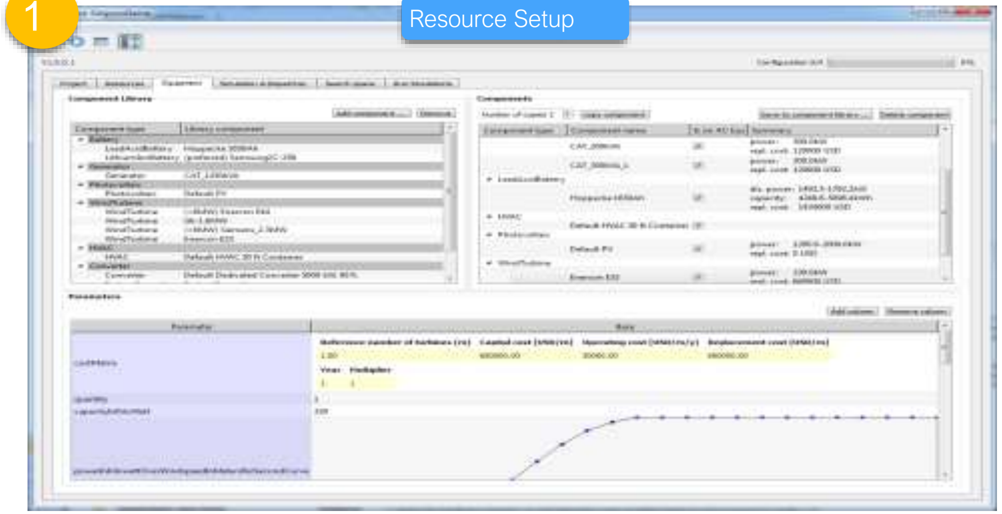
Shown: 1 MW / 8 MWh DC System

Courtesy of Siemens

Grid Attached Storage & Hybrid Plant Design Tool

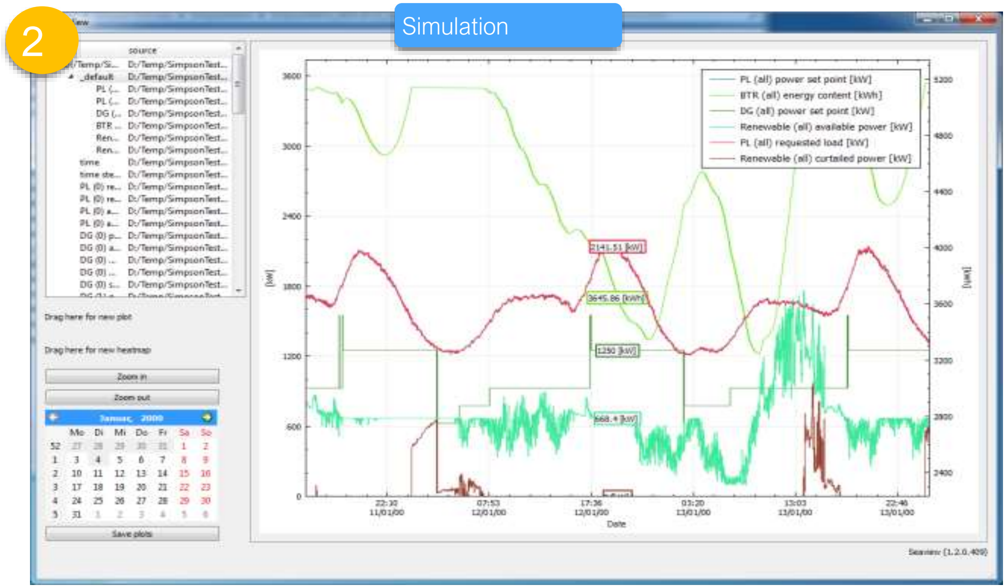
1

Resource Setup



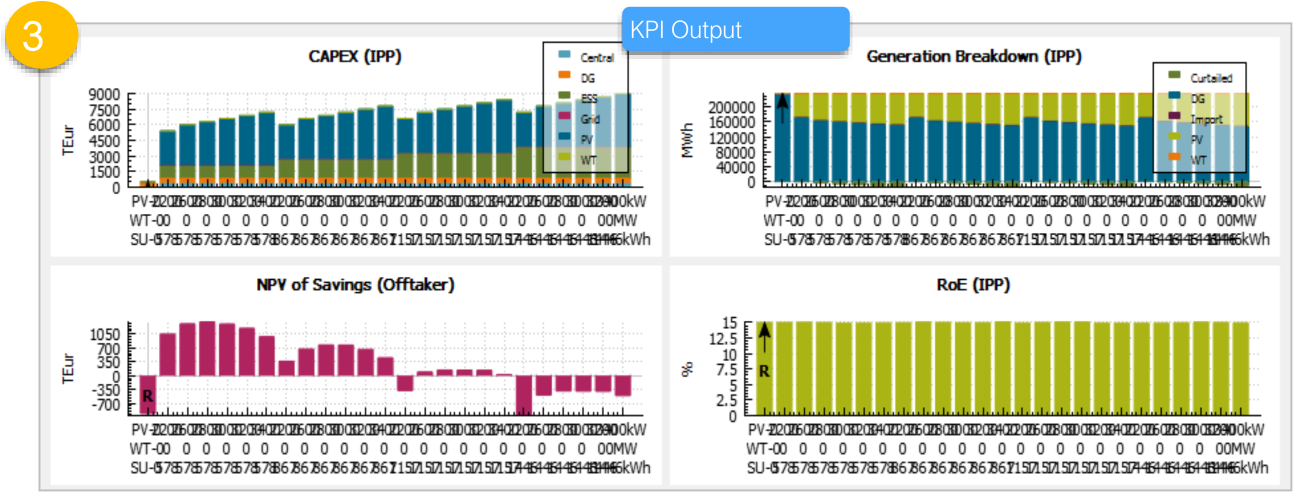
2

Simulation



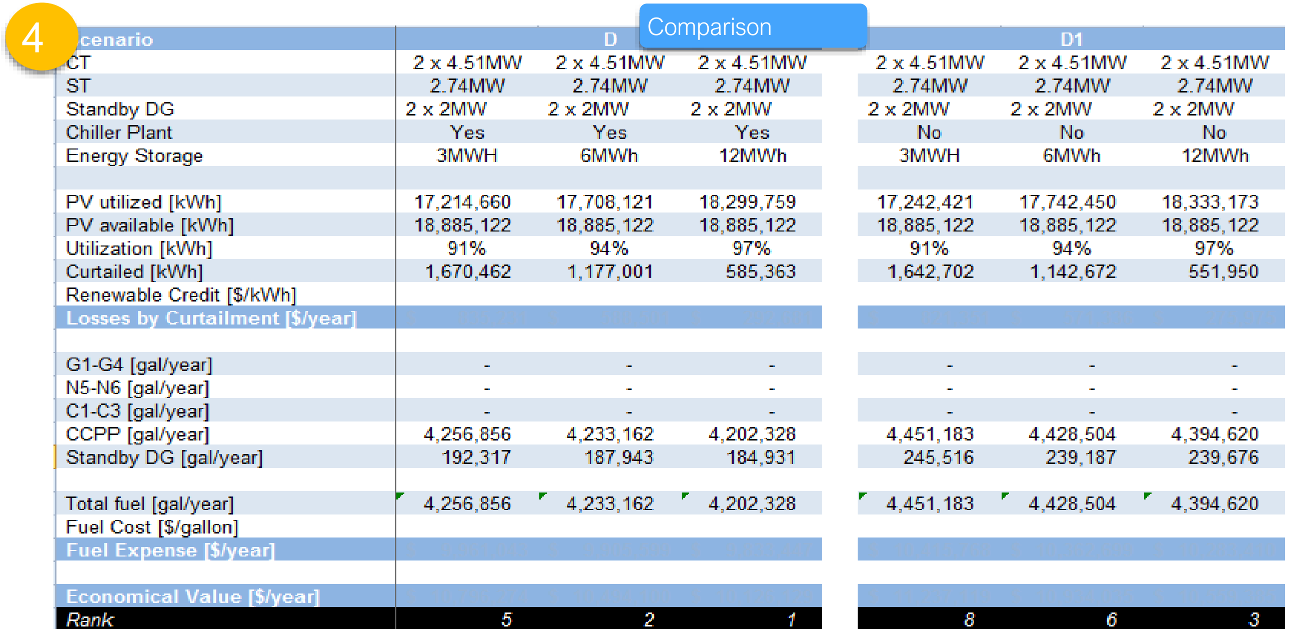
3

KPI Output



4

Comparison



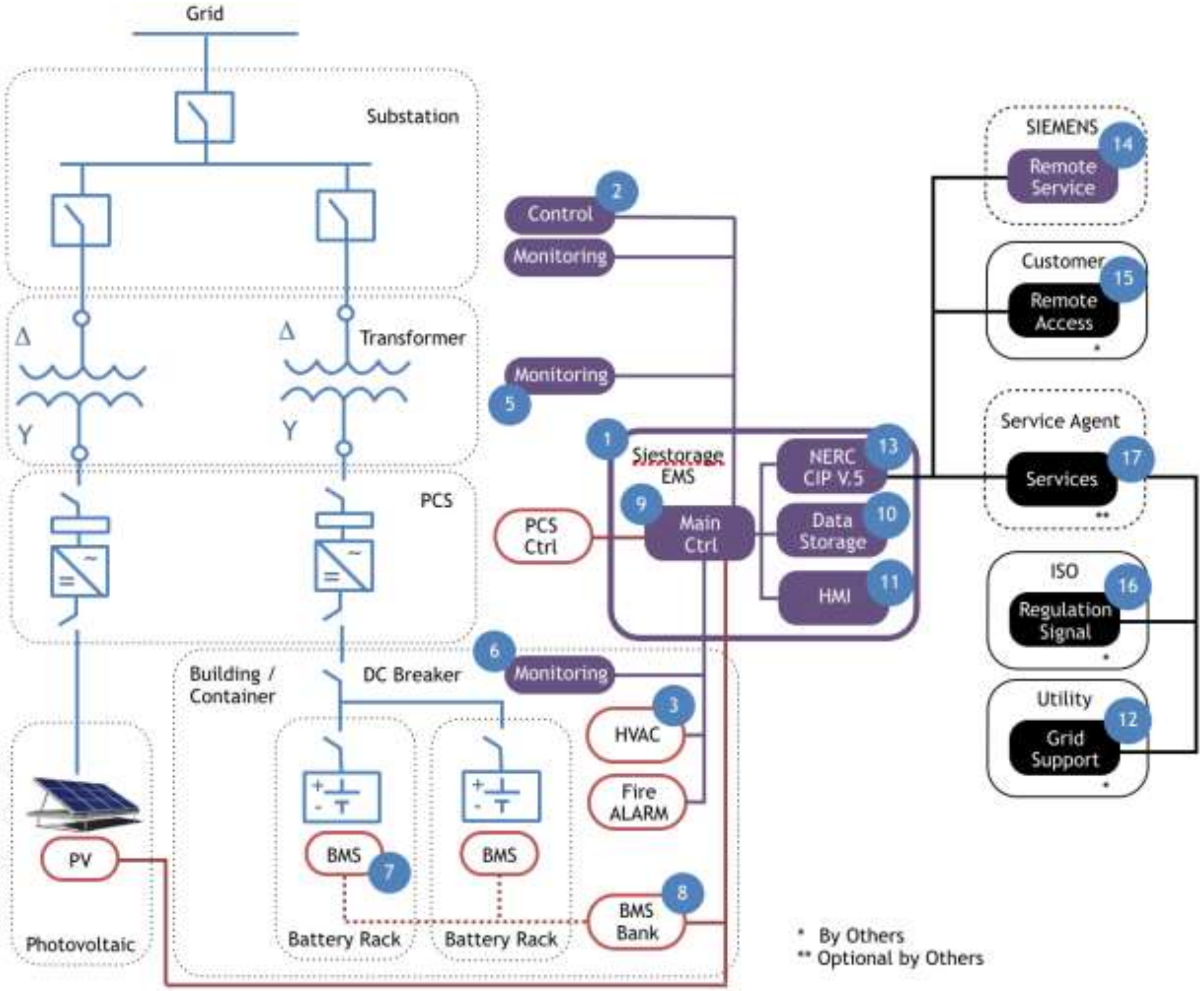
cenario	D			D1		
CT	2 x 4.51MW	2 x 4.51MW	2 x 4.51MW	2 x 4.51MW	2 x 4.51MW	2 x 4.51MW
ST	2.74MW	2.74MW	2.74MW	2.74MW	2.74MW	2.74MW
Standby DG	2 x 2MW	2 x 2MW	2 x 2MW	2 x 2MW	2 x 2MW	2 x 2MW
Chiller Plant	Yes	Yes	Yes	No	No	No
Energy Storage	3MWH	6MWh	12MWh	3MWH	6MWh	12MWh
PV utilized [kWh]	17,214,660	17,708,121	18,299,759	17,242,421	17,742,450	18,333,173
PV available [kWh]	18,885,122	18,885,122	18,885,122	18,885,122	18,885,122	18,885,122
Utilization [kWh]	91%	94%	97%	91%	94%	97%
Curtailed [kWh]	1,670,462	1,177,001	585,363	1,642,702	1,142,672	551,950
Renewable Credit [$/kWh]						
Losses by Curtailment [$/year]						
G1-G4 [gal/year]	-	-	-	-	-	-
N5-N6 [gal/year]	-	-	-	-	-	-
C1-C3 [gal/year]	-	-	-	-	-	-
CCPP [gal/year]	4,256,856	4,233,162	4,202,328	4,451,183	4,428,504	4,394,620
Standby DG [gal/year]	192,317	187,943	184,931	245,516	239,187	239,676
Total fuel [gal/year]	4,256,856	4,233,162	4,202,328	4,451,183	4,428,504	4,394,620
Fuel Cost [$/gallon]						
Fuel Expense [$/year]						
Economical Value [$/year]						
Rank	*5*	*2*	*1*	*8*	*6*	*3*

Battery Storage Energy Management System (EMS)
Overview of applications and functionalities

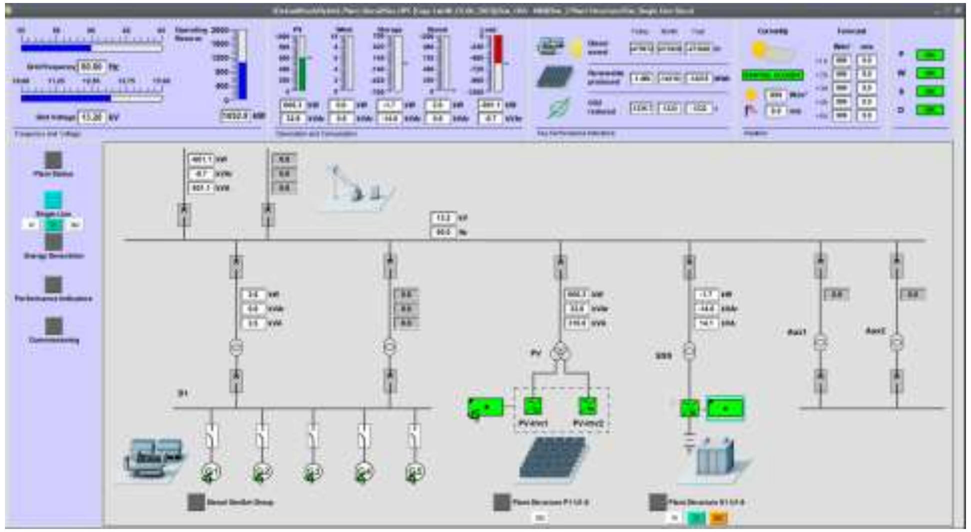
- *Ramp Rate Control*
- *Frequency Regulation / Support*
- *Voltage Regulation (V,Q Set-points)*
- *Power Factor Control*
- *Load Following*
- *Microgrid Operation*
  - *Island Operation*
  - *Grid Paralleling*
  - *Black Start*

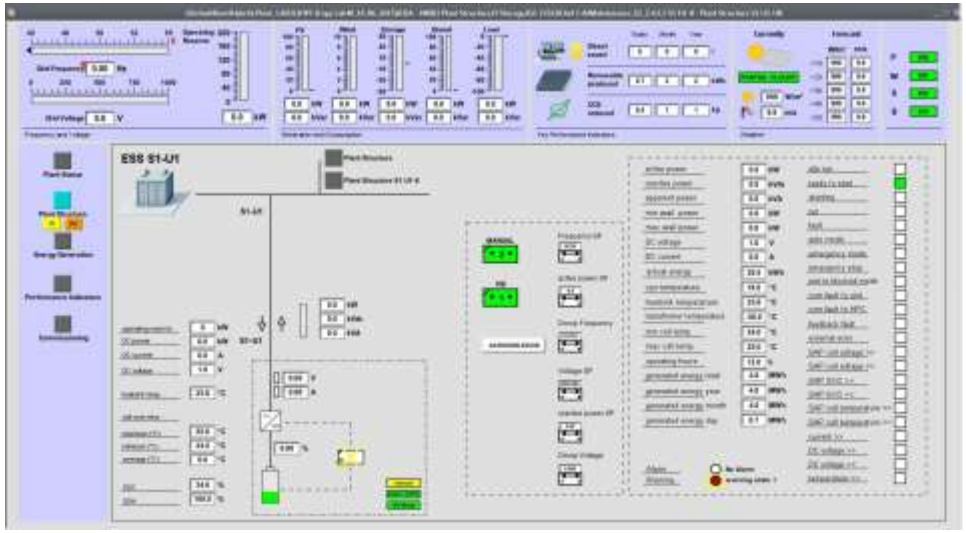
- *Renewable Smoothing*
- *Renewable Capacity Firming*
- *Time Shifting*
- *Arbitrage – Energy Trading*
- *Peak Shaving*
- *Time of Use (TOU)*

Battery Storage Energy Management System
Hybrid Plant & Hybrid Systems



* By Others
** Optional by Others





Elon Musk’s 100 day challenge

Elon Musk
@elonmusk

Replying to @mcannonbrookes

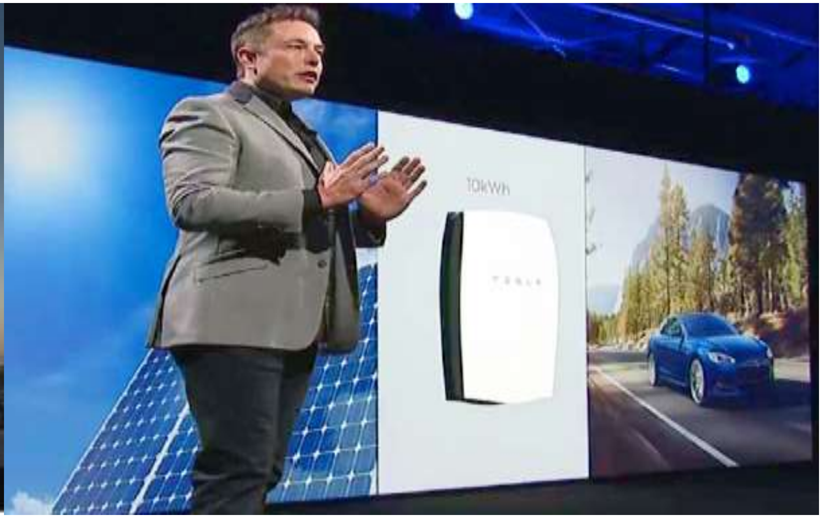
Tesla will get the system installed and working 100 days from contract signature or it is free. That serious enough for you?

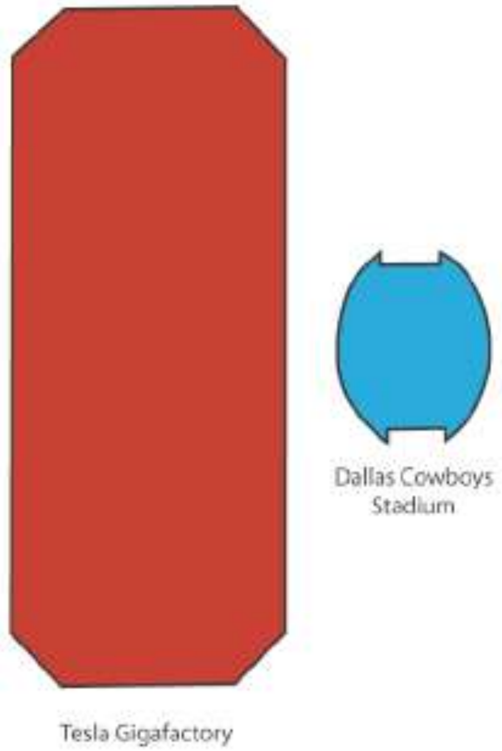
9:50 PM - Mar 9, 2017

608 6,925 15,563

100 days to win a bet. Tesla's Australian Powerpack project on Sept. 29, 2017

IMAGE: TIMOTHY ARTMAN/TESLA





Source: https://gcep.stanford.edu/pdfs/symposium2015/Presentations/Mooney_GCEPSymposium2015_EnergyStorage101.pdf

Energy Management – Low & Medium Voltage & Systems

Medium Voltage Contacts:

Energy Management - Medium Voltage and Systems
Siemens Canada Limited

MARK CHILDERHOSE
Medium Voltage and Storage

siemens.com/answers