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Buildings as Power Stations

Distributed Energy Analysis Division

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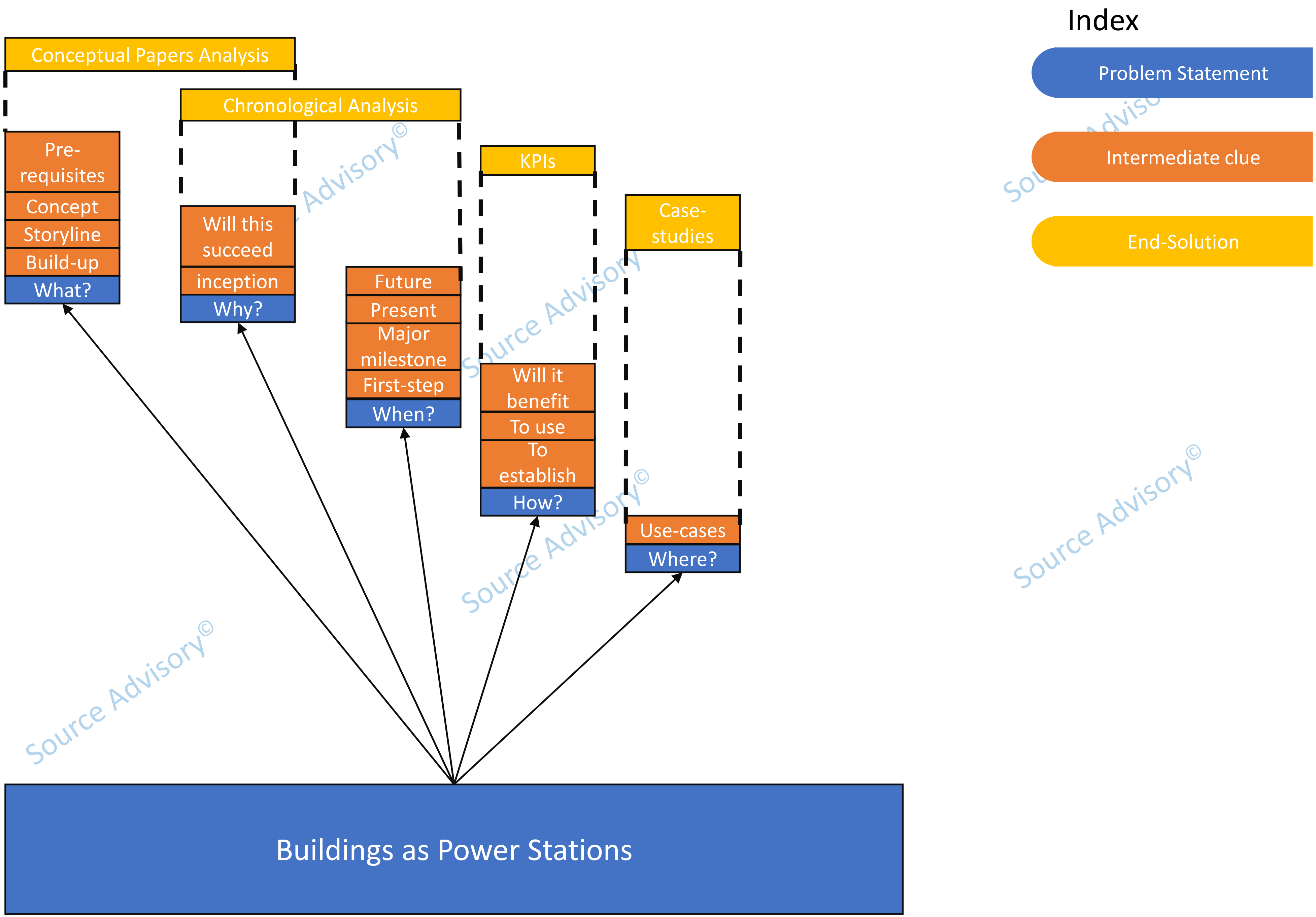
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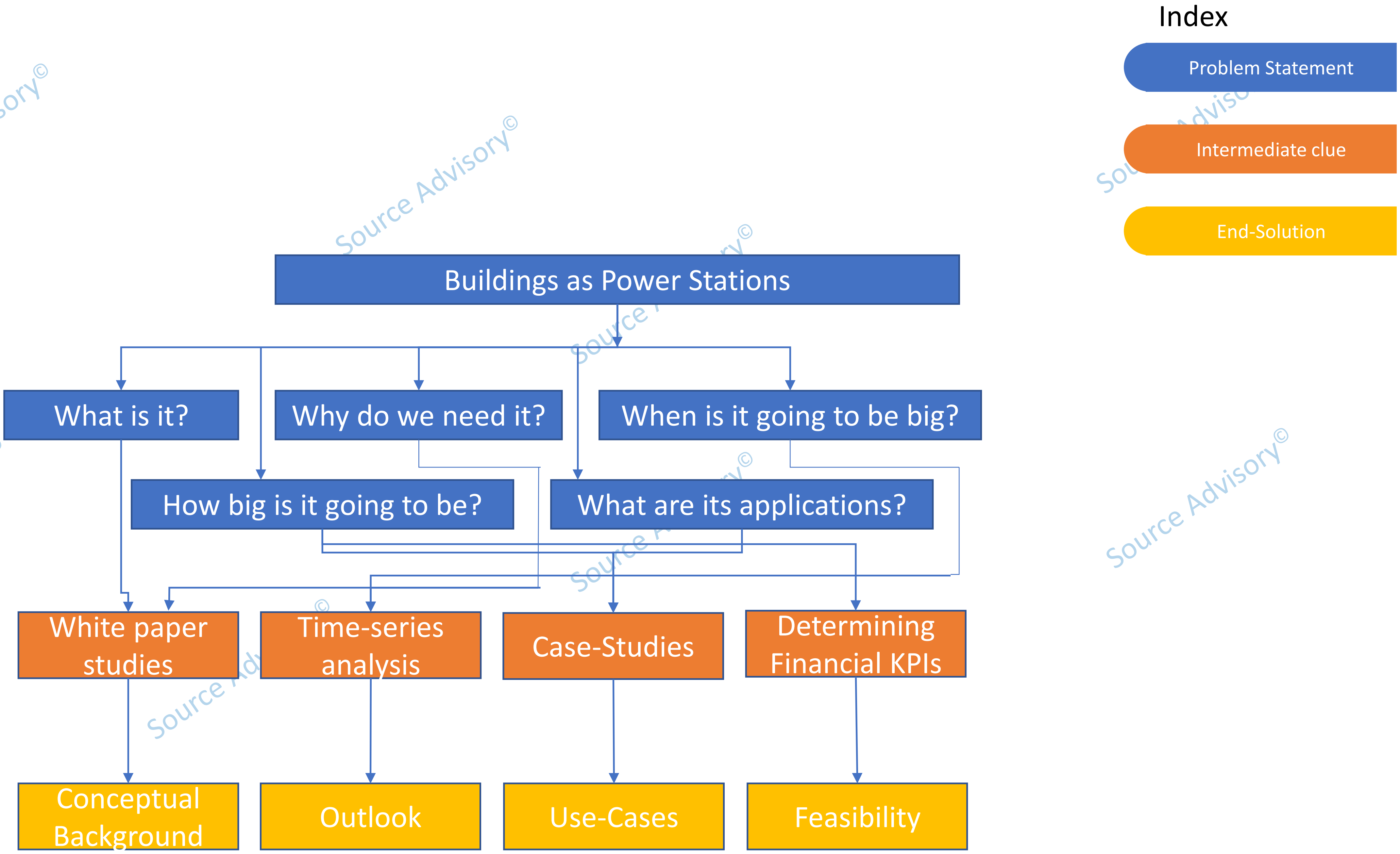

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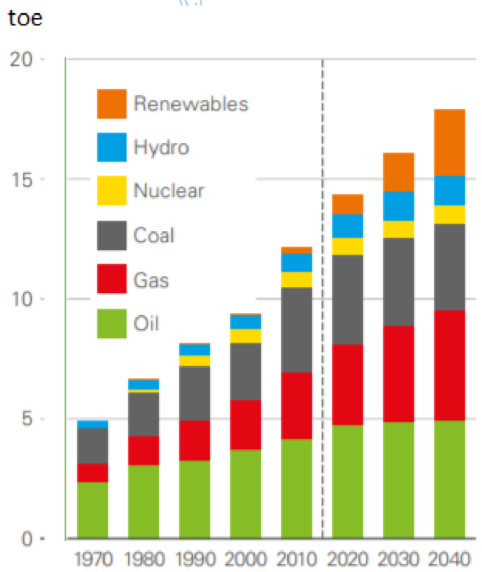
Chapter 1: Buildings as Power Stations – an Introduction

- **Power generation – when everything collapses into a singularity**

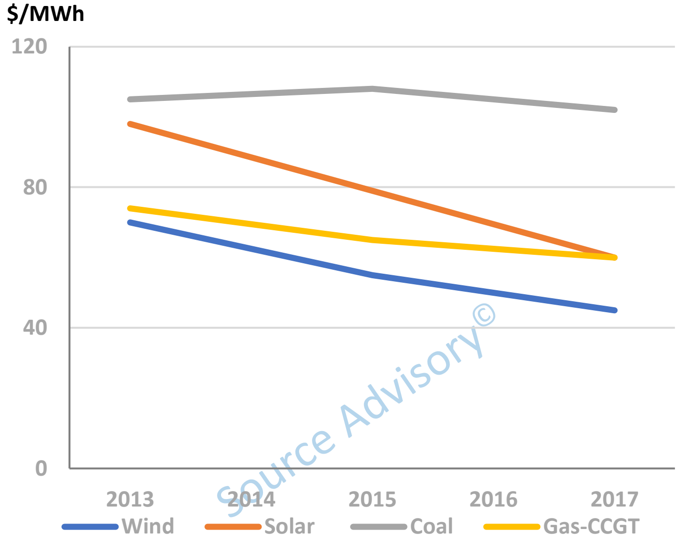
Power generation mix around the world is primarily dominated by fossil-fuels even in 2019. However, on the optimistic side of the story renewable energy sources in the generation mix are picking up. Renewables have almost reached at price-parity[2] with the fossil-fuels even when the volume of installed capacity of renewable power plants is not anywhere near to the volume of installed capacity of the conventional fossil-fuel driven power plants. One could only imagine the price of energy produced from renewable sources to follow a downward trend as the economies-of-scales catch-up.

Moreover, there is a major drift in generation technology with the upcoming saga of renewables. The power plants were earlier confined to the solitude of barren masses of lands due to the issues like "NYMBISM", pollution and hence, a difficult "Right of Way" (R.O.W.). However, with the advent of renewable energy, its nature of portability and ease of miniaturization, power generation has found its way in the laps of urban and rural social localities. With such power plants, power has reached to places where the conventional power lines were difficult to take. Not only these technologies have empowered and made the society self-driven but have transformed the power consumer into power producer and local storage units.

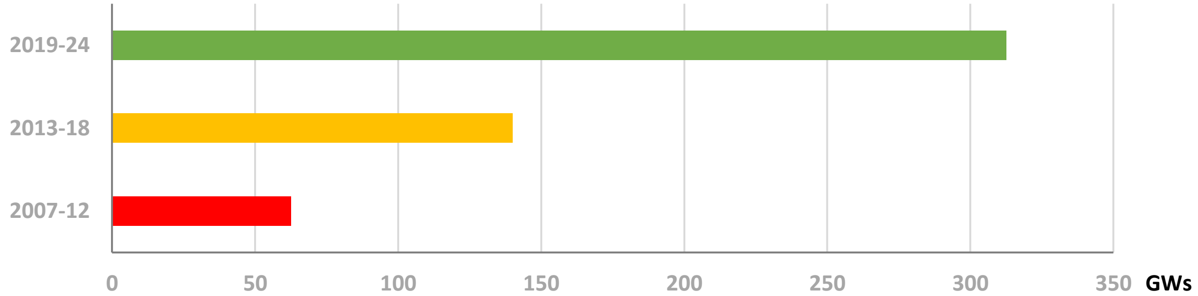
Buildings with such power plants and storage units installed within them have become the holy trinity – the producer, the consumer and the provider of power.



World energy fuel mix[1]



Downward trend in LCOE ($/MWh)[3]



Distributed generation (BAU scenario)[4]

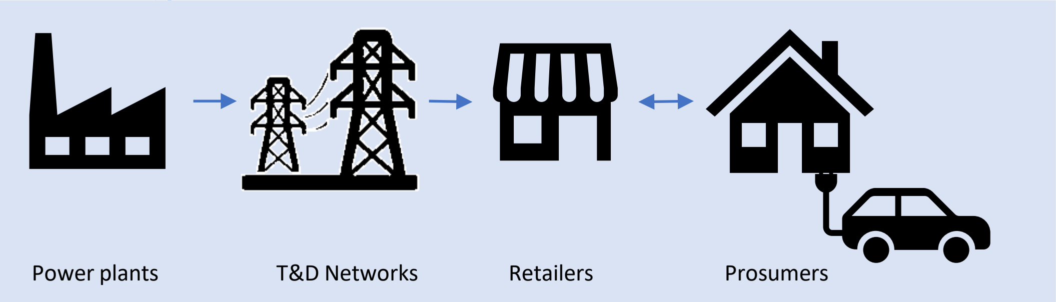
References:
(1) BP Energy Outlook 2019
(2) Institute of Energy Economics and Financial Analysis
(3) Energy Innovation Policy and Technology
(4) International Energy Agency - Renewables 2019 – Market Analysis and Forecast

- **The consumer has become a prosumer**

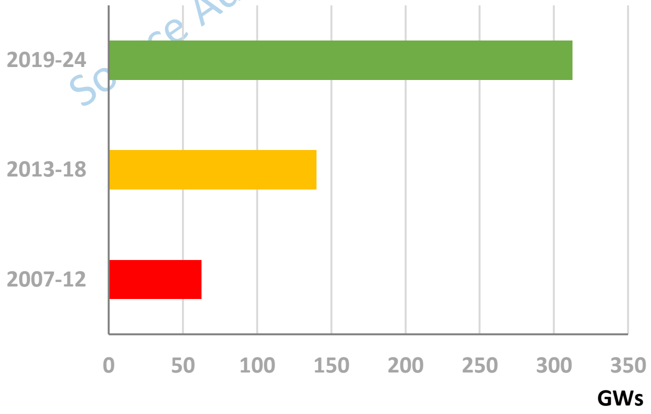
The power industry's market is going to flip in the next decade. This is evident from the fact that the number of energy consumers with distributed energy and storage at their facilities have not only grown but have started participating in selling the excess energy produced by their energy systems. The growth of such systems is encouraged by the government and the power retail companies due to increasing cost of power procured from the conventional utility scale power plants.

Governments around the world are incentivizing microgrids (MG) and virtual power plants(VPP), which manage distributed resources. The virtual power plant market which was valued at $726 million in 2016 is anticipated by global players to reach at ~$4.5 billion by 2023[6]. Whereas, the global microgrid markets that registered a value of $15 billion in 2017 is expected to reach $30 billion by 2022[7].

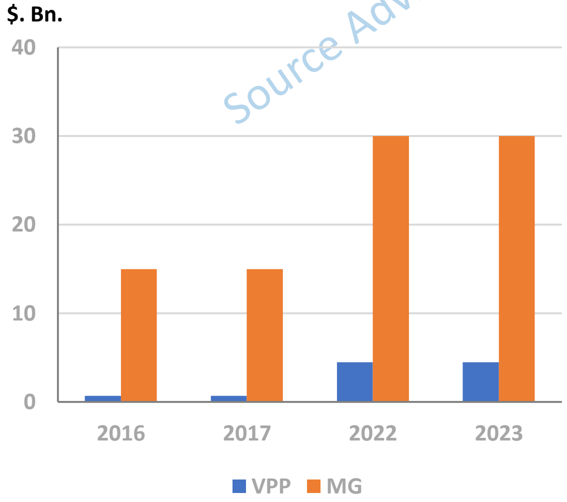
This change in the future could be phenomenal as discussed in later parts of the report.



Bi-directional Power flow



Distributed generation (BAU scenario)[4]



VPP and MG valuations

References:
(5) Global DER Deployment Database
(6) Allied Market Research Reports
(7) Power Technology research

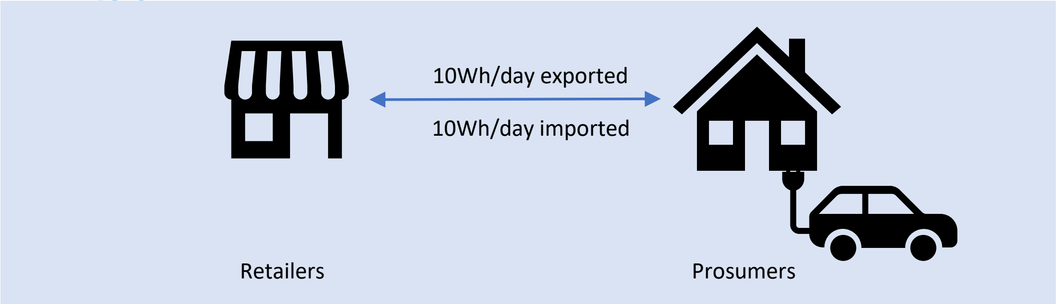
- **Power-positive buildings**

Imagine a building, which is self-sufficient in fulfilling its energy needs using the various systems installed within its premises, without using any power from the grid. Such buildings are called Ideal "Net Zero" Buildings. In a real scenario a "Net Zero" Building is a facility that exports the same amount of power to the grid as the amount of power it imports from the grid.

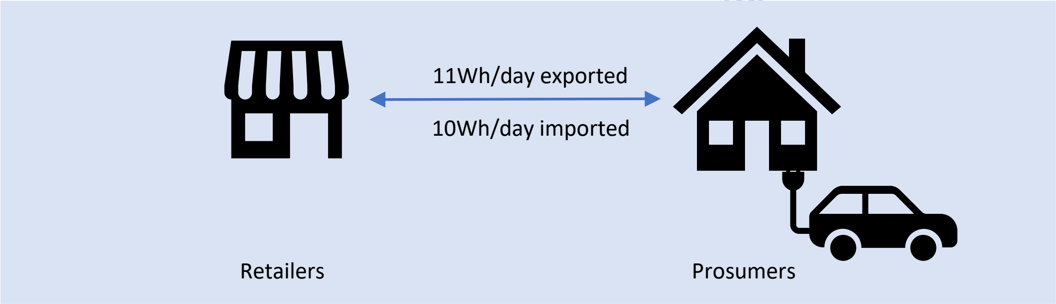
Now consider a case, when a "Net Zero" Building delivers additional units of electricity to the grid than what it consumed. Such a facility/ premise is assumed to be an energy positive/ energy surplus building.

Though the definition of a power-positive building is not that easy. The "Global Buildings Performance Network" defines it based on the following parameters[8]:

Boundary Conditions	System Boundary (premises of building)
Energy Balance	Items of balance (building loads)
	Balancing period (control period for the analysis-usually 1 Yr.)
	Energy efficiency (measures taken to reduce consumption)
	Energy Supply (items credited for the balance)
	Requirements of the balance (difference in produced and consumed energy)
Verification of Energy Use	Verification through operations data
	Verification through comparison with similar buildings



Example of a Net Zero Building

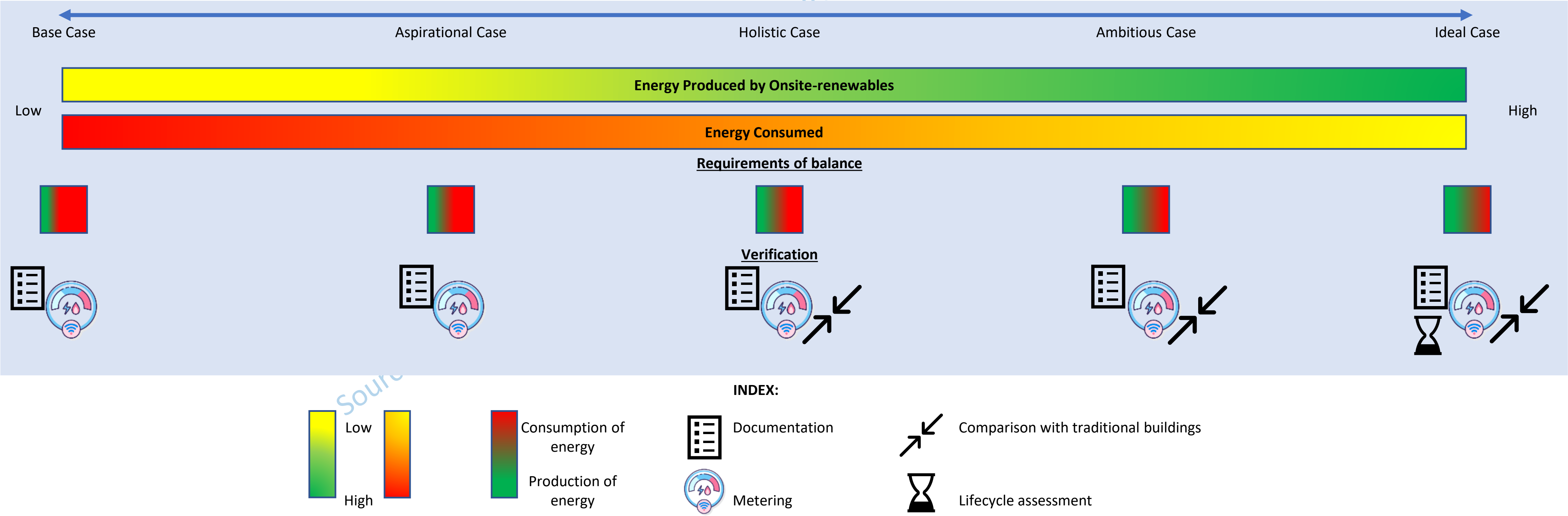


Example of a Power-positive Building

References:
(8) GBPN-Building Policies for a better world

- **What makes a building power positive? (1/2)**

The following infographic shows the detailed definition of a power positive building:



References:
(8) GBPN-Building Policies for a better world

Chapter 2: When did it all start?

- **What is stopping us?** [9]

Every industry finds itself in a tight spot sometimes, which is difficult to overcome. Such bottlenecks at various points in time pose a problem for industries both established and new. However, one could think of possible drivers to overcome such challenges.

"Power Positive Buildings" is a young industry and will take time to mature. At this stage like every other industry it will require a lot of support to overcome its challenges. Some of the major challenges could be classified under the following heads:

- Energy efficient design and architecture
- Advancement in energy efficient and renewable energy technology
- Public awareness
- Policy and regulatory support

The adjacent table presents primary issues under each head:

Time frame	Design and architecture	Technology	Public awareness	Policy and Support
Past	Architectural design and structure of old buildings is not energy efficient and renewable energy friendly	Unavailability of affordable energy efficient and distributed renewable technologies	Public was unaware of any such interventions available. Hence, adoption and demand was low	Policies and regulations for energy efficiency have existed for more than a decade. But these were not heavily promoted
Present	Building codes have been updated to adopt energy efficiency and renewable energy technologies in buildings. However adoption of both lack synergies with current designs.	Desired technology is available. However, retrofitting existing facilities is infeasible.	Public is aware of availability of possible intervention. However, the willingness to pursue an energy efficient future is not persistent	Policies and regulations on adoption of energy efficiency and distributed energy have become more significant and stringent. However, these do not seem to be electricity retail friendly
Near Future	Advanced courses in energy efficient and renewable friendly designs are anticipated to lack the efficacy to deliver buildings with tightly integrated energy efficient and renewable energy systems	Affordability and portability of technology is expected to improve with modularity in buildings. However, the learning curve might not be steep enough to achieve economies of scale	Demand of energy efficiency and renewable energy in buildings demand successful case studies. Such case studies are rare in nature to influence decision making	Policies and regulations are expected to be adopted actively with newer business models available for energy retailers. However, many retailers do not anticipate similar profits from new businesses.

The major bottlenecks

References:
(9) PV Tech

- **What can we do to help?** [10]

Adjacent table presents the primary actions required by various stakeholders of the society for the maturation of the industry.

Stakeholders	Policy and Regulations	Technology	Awareness
Government	- Promote supporting policies and regulations for energy efficient buildings - Lay out independent fiscal Budget for the pilot projects	- Importing energy efficient technologies for buildings - Promoting development of indigenous technologies	- Promote awareness campaigns and pilot projects - Incentivize developers interested in pilot project development - Launch educational programs in fields of energy efficient architecture
Regulators	- Building code enforcing distributed energy and energy efficiency architecture and design - Supportive net-metering and p2p energy trading regulations	- Easing trade for technology import - Easing direct investments in real estate	- Provide tax relaxation and fixed returns for pilot projects to improve feasibility
Builders/Developers	- Actively participate in formulation of policies and regulations - Follow best procedures as directed by the authorities for their projects	- Invest in modern technology and architectural designs - Use energy efficient architectural designs and green building material	- Hold marketing campaigns for awareness and promotion of energy efficient buildings. - Engage in developing pilot projects to develop successful case-studies
Public			- Participate in awareness campaigns to know for avenues of energy savings and overall sustainability in energy efficient buildings
Financiers		- Relax interest rates for investments in technology imports - Provide moratorium period for investment in pilot projects	
Energy Retailers		- Adopt smart metering infrastructure - Make two way power transmission efficient and effective	

Drivers for maturation of Power Positive Buildings [12]

References:
(10) Source Advisory Analysis

- **What the future could help?** [12]

The future is certain but still holds multiple possibilities. Energy efficient buildings with distributed energy systems are inevitable but, to what extent.

Imagine a city with an unvarying 100MWh/year of power requirement. There could be n possibilities, but for now, let's just consider three of them:

- One, where just ten percent buildings become power positive
- Second, where almost about fifty percent buildings become power positive
- Last one where all of the buildings become power positive

Lets consider some assumptions:

a) Geometric

- The city has a uniform geometry
- The distribution grid is uniformly divided
- The power positive buildings in all scenarios are uniformly distributed across the grid

b) Electrical

- The power positive part could be islanded in case of complete system shutdowns and can provide power to the same proportion of city in case of emergencies
- Energy consumption by buildings is uniform and same

- Total consumption: 100MWh/year - Proportion of Power positive buildings: 10% or 10MWh/ year - Actual remaining energy requirement with the city: 90MWh/ year (because the 10% buildings are self sufficient) - 10% of all buildings during a complete shutdown of the grid could power the entire city (**assuming all buildings limit emergency consumption to 10%**) - Distribution utilities would procure 10% power locally from prosumers around the year. This would cost less due to reduction in number of nodes as compared to number of nodes when power is procured from generating stations (assuming there is no peer to peer trading) - Reduction in 10% GHG generation - Buildings would pay for themselves in a span of 5-10 years
- Total consumption: 100MWh/year - Proportion of Power positive buildings: 50% or 50MWh/ year - Actual remaining energy requirement with the city: 50MWh/ year (because the 50% buildings are self sufficient) - 50% of all buildings during a complete shutdown of the grid could power the entire city (**assuming all buildings limit emergency consumption to 50%**) - Distribution utilities would procure 50% power locally from prosumers around the year. This would cost less due to reduction in number of nodes as compared to number of nodes when power is procured from generating stations (assuming there is no peer to peer trading) - Reduction in 50% GHG generation - Buildings would pay for themselves in a span of 5-6 years
- Total consumption: 100MWh/year - Proportion of Power positive buildings: 100% or 100MWh/ year - Actual remaining energy requirement with the city: 0MWh/ year (because the 100% buildings are self sufficient) - 100% of all buildings during a complete shutdown of the grid could power the entire city - Distribution utilities would procure 100% power locally from prosumers around the year. This would cost less due to reduction in number of nodes as compared to number of nodes when power is procured from generating stations (assuming there is no peer to peer trading) - Reduction in 100% GHG generation - Buildings would pay for themselves in a span of 4-5 years

Hypothetical scenarios for power positive buildings [12]

References:
(10) Source Advisory Analysis

Chapter 3: The number game

- **KPIs – retrofitting old buildings**

Here comes the analysis. Something we can actually depend on. In this section we will be assuming :

- One case, where we will analyze the Costs v/s benefits of converting an old building to a power positive building

Tables on the right show the costs and benefits involved.

Table below represents important KPIs for such retrofitting of buildings.

KPIs	
NPV @ 3% in $	15400.53
IRR	11%
Payback Period (Years)	5.00

Cost Items	kWh/ sq. ft. (for general building)	Improvement with energy efficiency	Area (sq. ft.)	Total kWh	Costs ($/ sq. ft.)	Total Cost ($)	% of Total Cost
Building works							
architectural design			22		100	2200	4%
energy efficient materials			22		1000	22000	36%
building re-works			22		10	220	0%
Power generation systems							
solar generation integrated units	0.24		220	52.8	150	33000	55%
Energy efficient systems							
lighting	7.00	90%	22	15.4	10	220	0%
refrigeration	8.00	50%	22	88	15	330	1%
air conditioning	3.00	60%	22	26.4	25	550	1%
heating	2.00	20%	22	35.2	40	880	1%
ventilation	2.00	90%	22	4.4	10	220	0%
hot water	0.50	50%	22	5.5	30	660	1%
Total	**22.26**			**174.9**	**1390**	**60280**	**100%**

Benefits	kWh/ sq.ft. (for general building)	Improvement with energy efficiency	Area (sq. ft.)	Total kWh	Reduction ($/ kWh/ year)	Total Reduction ($/ year)	% of Total Reduction
Energy Savings							
lighting	7	0.9	22	138.6	87.6	12141.36	43%
refrigeration	8	0.5	22	88	87.6	7708.8	27%
air conditioning	3	0.6	22	39.6	87.6	3468.96	12%
heating	2	0.2	22	8.8	87.6	770.88	3%
ventilation	2	0.9	22	39.6	87.6	3468.96	12%
hot water	0.5	0.5	22	5.5	87.6	481.8	2%
Energy Sales (10% of total production)							
solar generation integrated units	0.24		220	52.8	0.48	25.344	0%
Carbon Reduction							
CO_2 (30% below set base line)						10	0%
Total	**22.26**					**28076.104**	**100%**

References:
(10) DOE, USA and Source Advisory Analysis

Chapter 4: Success Stories

- **Case Studies** [11]

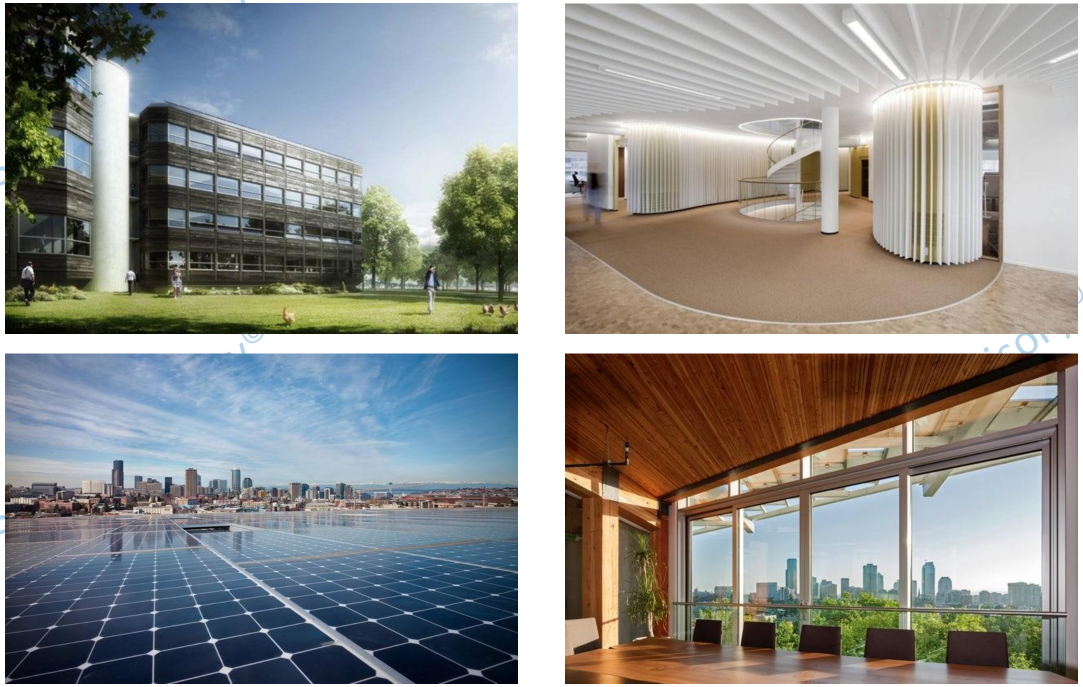
Project Powerhouse was started as a joint venture by:

- Entra which is a Real Estate company
- ZERO which is an environmental organization
- Snøhetta architects
- Asplan Viak, a consulting company
- Skanska, a construction company

The first project realized by Powerhouse was revival of an old office building built in 1980s. The project was called Powerhouse Kjørbo. The revival project combined and optimized the existing technologies to reduce consumption in the building by 90%. The structure also promises a 6x reduction in GHG emissions as compared to any traditional structure. The building is expected to produce more renewable energy and export to the grid as compared to the energy that it will consume over its entire lifetime.

Project Powerhouse has accomplished many other projects including:

- Powerhouse Brattørkaia
- Powerhouse Telemark
- Powerhouse Drøbak - Montessori school



Powerhouse Kjørbo[12]

References:
(11) Architizer
(12) Project Powerhouse

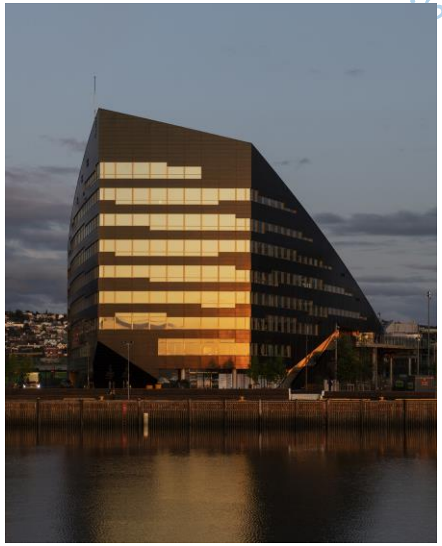
Project Name:	Powerhouse Kjørbo	Powerhouse Telemark	Powerhouse Drøbak Montessori school	Powerhouse Brattørkaia
Location:	Sandvika	Porsgrunn	Drøbak	Trondheim, Norway
Building type:	Renovated office building	Office building	School	Office building
Area:	5,200 m^2 GFA (block 4 and 5), and for construction stage 2: 9,800 m^2 GFA (block 1, 2 and 3)	8,313 m^2 GEA	886 m^2 GIA	18,200 m^2 GIA (13,500 m^2 above ground) 8 floors + mezzanine and underground parking
The building's own energy generation:	Approx. 230,000 kWh per year, and for construction stage 2: 325,000 kWh per year	Approx. 240,000 kWh per year	Approx. 30,500 kWh per year	Approx. 485,000 kWh per year
Supplied energy, including equipment:	Construction stage 1: -9.3 kWh/m^2 heated GIA. Construction stage 2: – 4.4 kWh/m^2 heated GIA	-2.7 kWh/m^2 heated GIA	Appr. 28,000 kWh per year	-4.9 kWh/m^2 heated GIA
Environmental classification:	BREEAM NOR "Outstanding as built", and "Excellent" for construction stage 2	BREEAM NOR Excellent	N/A	BREEAM Outstanding
Building owner:	Entra ASA	R8 Property	Drøbak Montessori foundation	Entra ASA
Architects:	Snøhetta	Snøhetta	Snøhetta	Snøhetta
Entrepreneur:	Skanska	Skanska Norge	Skanska	Skanska
Consulting engineers:	Asplan Viak	Asplan Viak	N/A	N/A

Project Powerhouse Statistics [10]

References:
(12) Project Powerhouse

Powerhouse Kjørbo

Powerhouse Telemark



Powerhouse Brattorkaia

References:
(12) Project Powerhouse

References

(1) BP Energy Outlook 2019

(2) Institute of Energy Economics and Financial Analysis

(3) Energy Innovation Policy and Technology

(4) International Energy Agency - Renewables 2019 – Market Analysis and Forecast

(5) Global DER Deployment Database

(6) Allied Market Research Reports

(7) Power Technology research

(8) GBPN-Building Policies for a better world

(9) PV Tech

(10) DOE, USA and Source Advisory Analysis

(11) Architizer

(12) Project Powerhouse

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