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Realizing the Asia Super Grid
- Japan's situation and challenges

Renewable Energy Institute, Tokyo.

Per Christer Lund

September 2016

The Japanese electricity system

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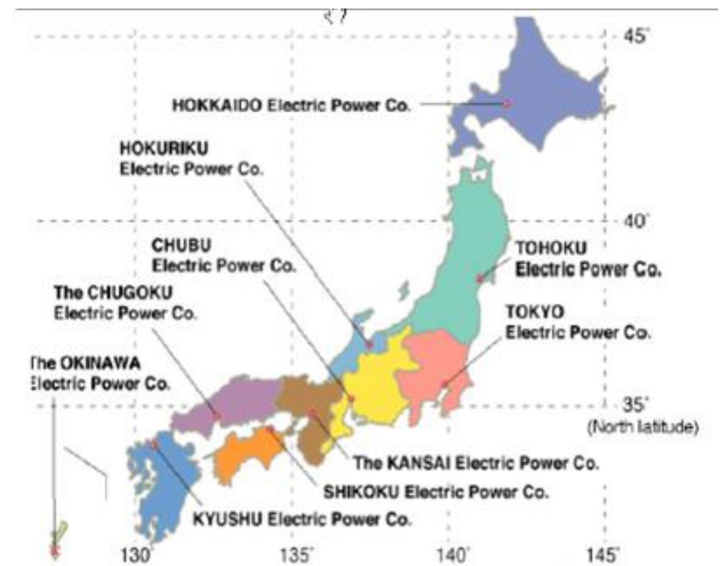
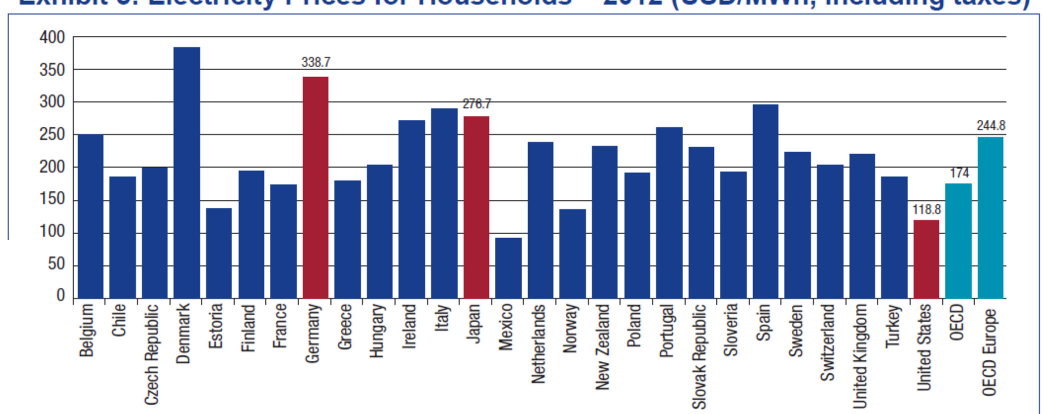
- One of the largest power markets in the world: 1,000 TWh/annum; 280 GW installed capacity.
- Technically a open wholesale and partially liberated (>50kW) market.
- However, dominated by 10 vertically integrated EPCOs – 96.4% of the power transacted.
- Bilateral, Day-ahead and forward markets since 2005 but small liquidity: JEPX – <2% of wholesale market
- High wholesale prices, but "average" retail prices (few add-ons and taxes)
- 2015: creation of new institutions:
  - OCCTO – coordinating the TSOs
  - Energy Market Surveillance Commission
  - April 2016: full retail liberalization



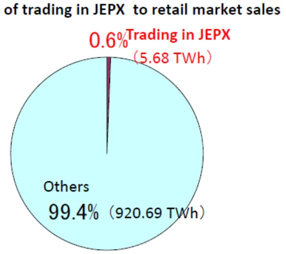
Source: Hiroshi Okamoto, TEPCO, 2013

Exhibit 5: Electricity Prices for Households – 2012 (USD/MWh, including taxes)

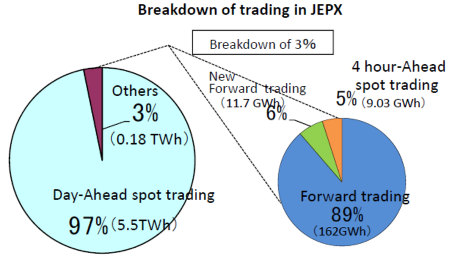


e: "Energy Prices and Taxes," OECD, http://www.oecd-ilibrary.org/sites/9789264185715-en/02/02/index.html?contentType=&itemId=/nt/chapter/9789264185715-19-en&containerItemId=/content/book/9789264185715-en&accessItemIds=/content/book/9789264185715-nimeType=text/html.

Share of trading in JEPX to retail market sales

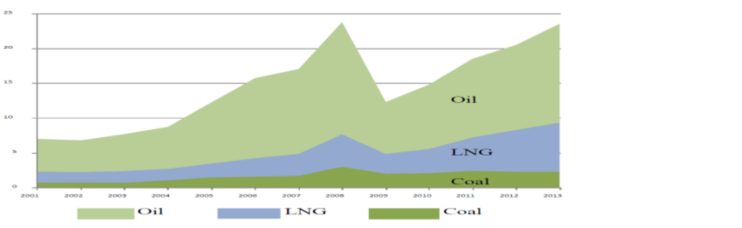


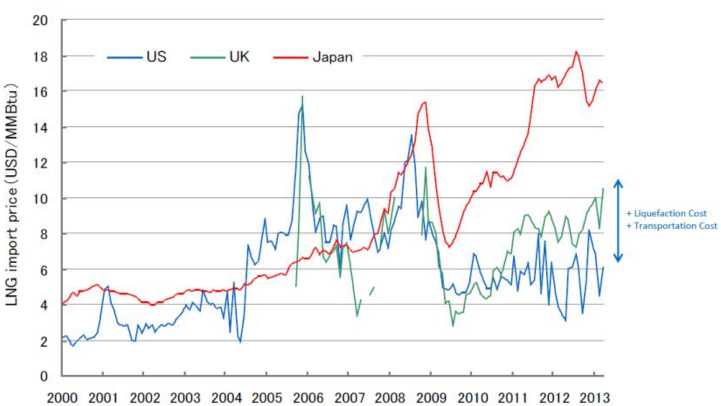
Breakdown of trading in JEPX

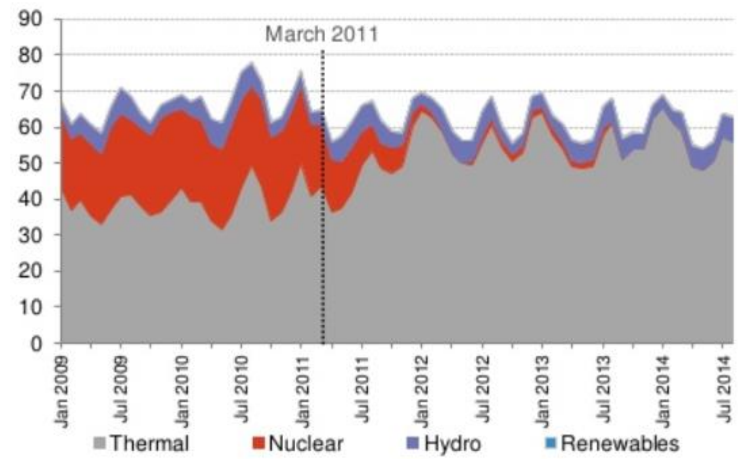


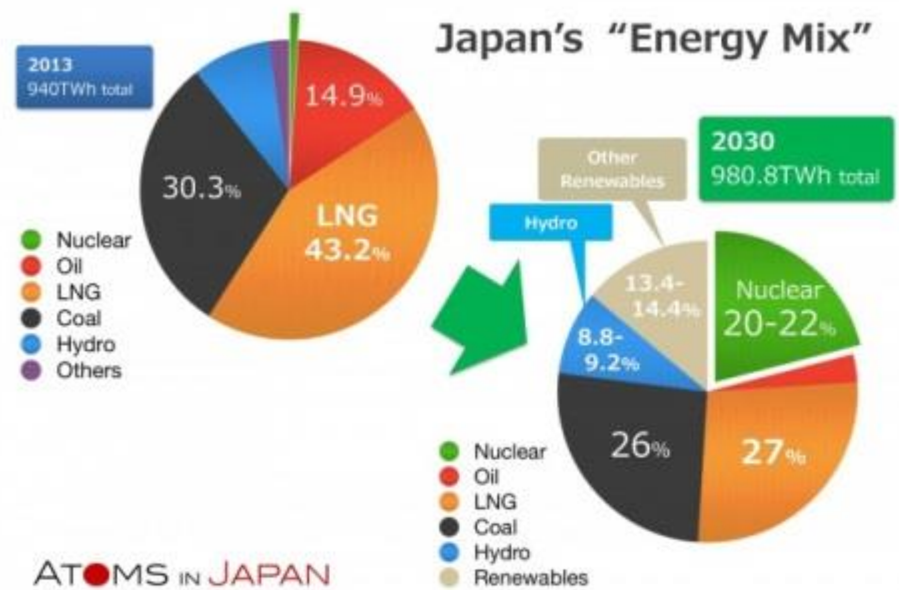
After “March-11” policy: nuclear phased out – replaced short term by LNG; on long term by renewable energy

- LNG import has sharply increased since 3/11 Earthquake.
- The cost of power generation has increased $ 36 billion.
- Negative impact to Japanese economy.
- Trade balance fell into the red, $180 billion budget deficits (2015).









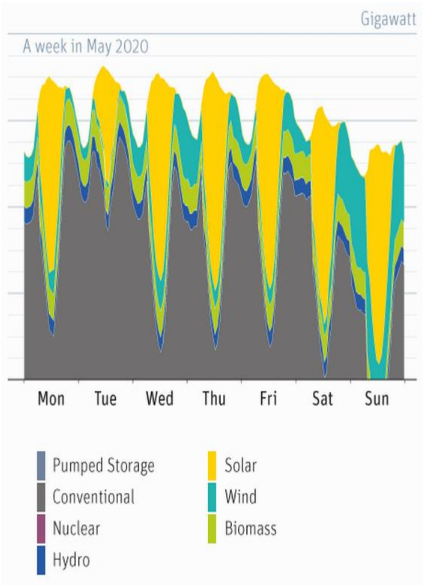
Renewables integration - challenges

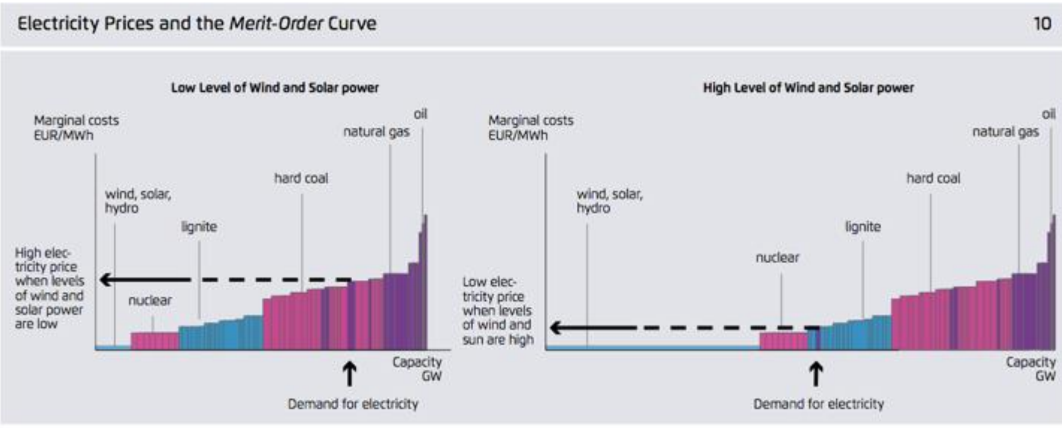
Example from Germany:

- ✓ Problem with system balancing when renewable sources not available
- ✓ Need to have substantial "backup" in forms of conventional thermal energy (coal, gas)
- ✓ Negative prices: not allowed to cut of renewable when total generation exceeds total demand.
- ✓ "Missing money": the back-up generators will not receive sufficient revenue from the market to cover their capital/fixed expenses.
- ✓ Wholesale market prices decreased due to "free" renewable energy
- ✓ Renewable incentive program has led to 40% increase in retail prices for residential consumers since 2005 -> however this leads to energy efficiency and self-generation.

Solutions:

- ✓ Flexible generation
- ✓ Increased interconnection
- ✓ Demand Side Response (DSR)
- ✓ Electricity storage





Importance of strong inter-regional/national grids

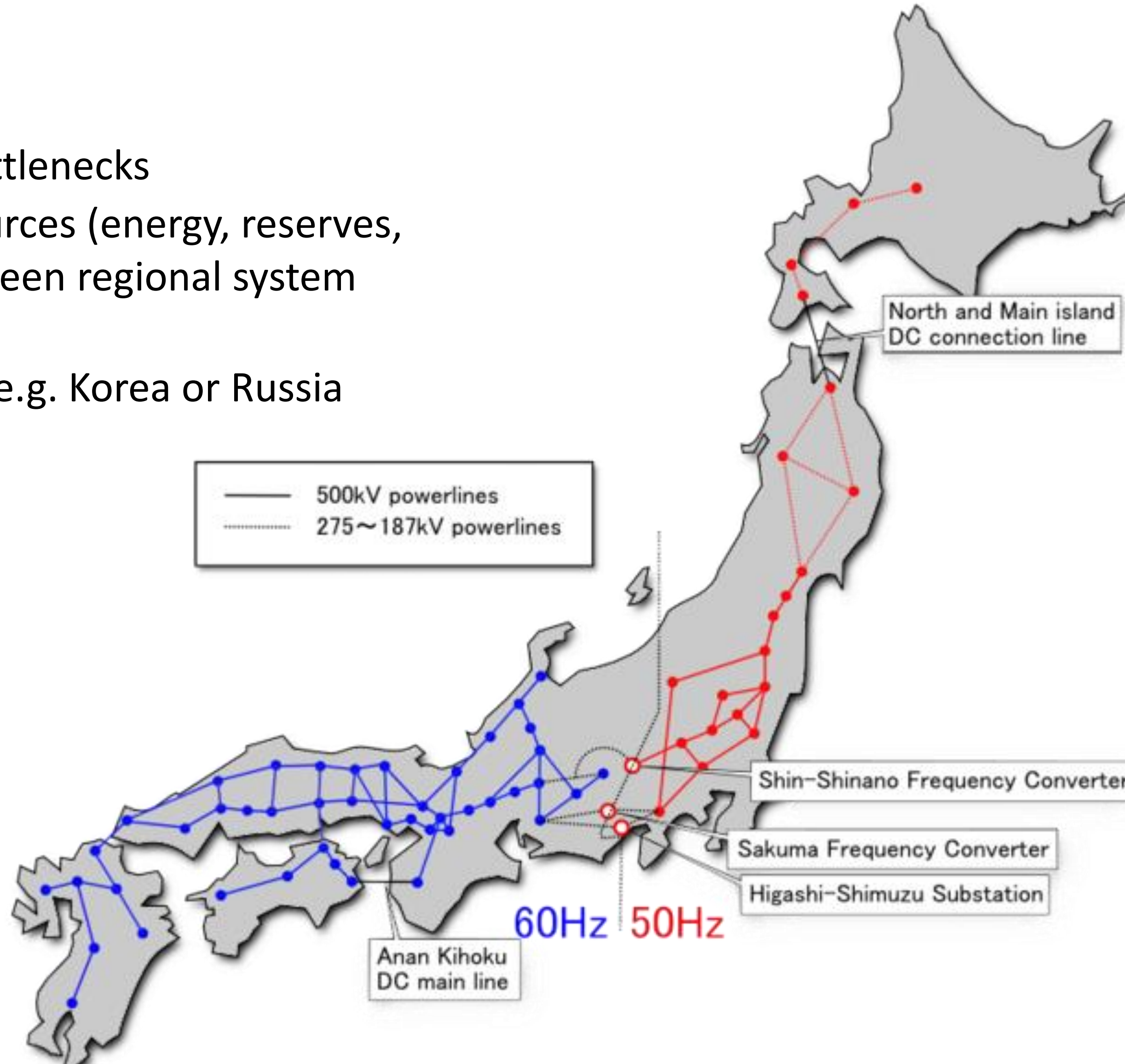
Dorte Foquet on the importance of a strong European grid framework:

- ✓ Grid operation – reliability and redundancy.
- ✓ Sharing generation resources – reducing costs by avoiding regional peaking generators
- ✓ Enhancing consumers choices – downward pressure on energy tariffs
- ✓ Enablement of large scale renewable penetration – export of RES from supply to demand

- ➢ Europe's 2020 target: 10% of all generation across interconnectors (15% by 2030?)

Grid issues in Japan

- ✓ «linear» grid structure
- ✓ Weak connections – bottlenecks
- ✓ Limited sharing of resources (energy, reserves, ancilliary services) between regional system operators (utilties)
- ✓ No interconnections to e.g. Korea or Russia



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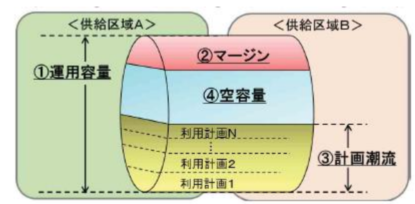
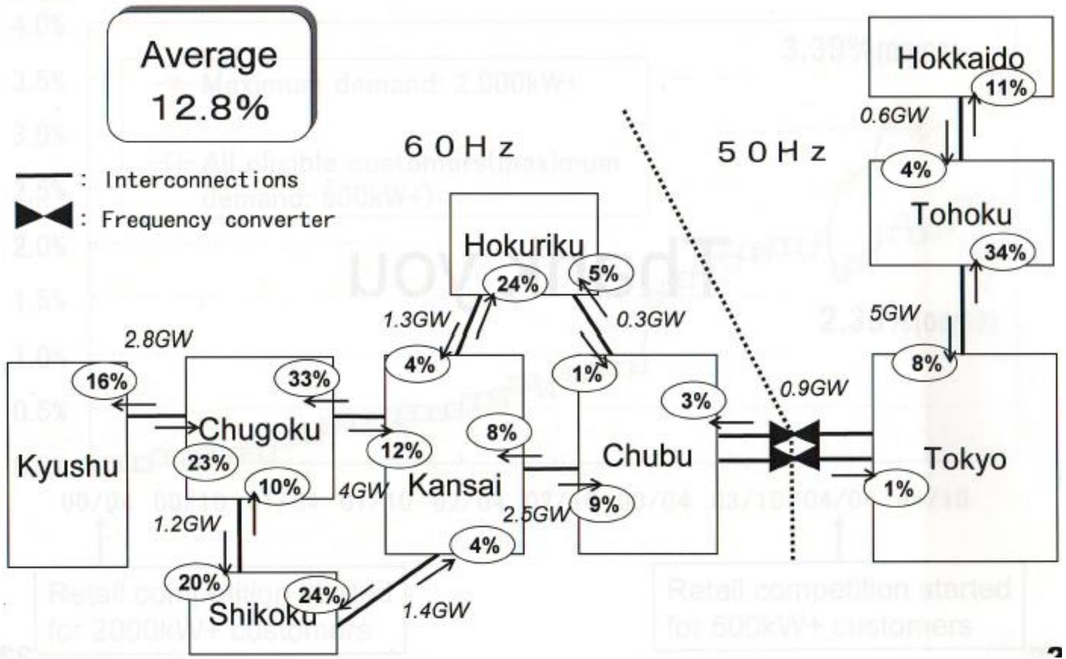
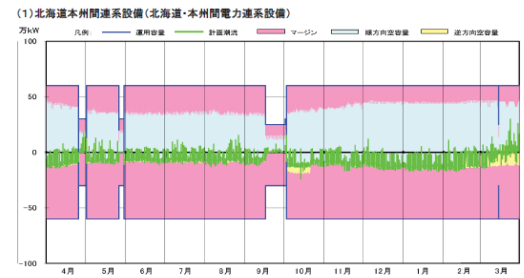
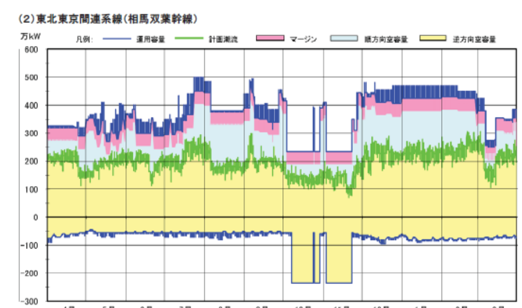
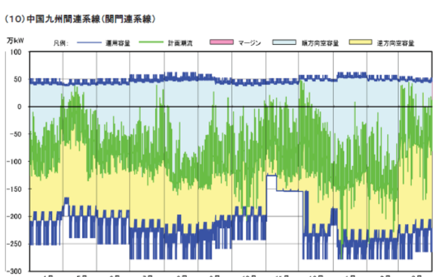
Utilization of existing interconnectors..











Source: OCCTO report, 2015

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Allocation of transmission rights

Entities that wishes to trade energy across regions must have rights to transport the energy across interconnectors.
In energy markets across the world, this is typically arranged by two schemes:

Explicit allocation:

- The grid owner, system operator or other entity allocates transmission capacity to **individual market participants** through auctions and/or longer-term agreements.
  - Many different schemes for firm vs financial rights, take-or-pay, re-allocation etc.

Implicit allocation:

- Transmission capacity is “given” to the Market Operator, and by methods of “market splitting”, the transmission capacity is socialized and shared among all market participants.

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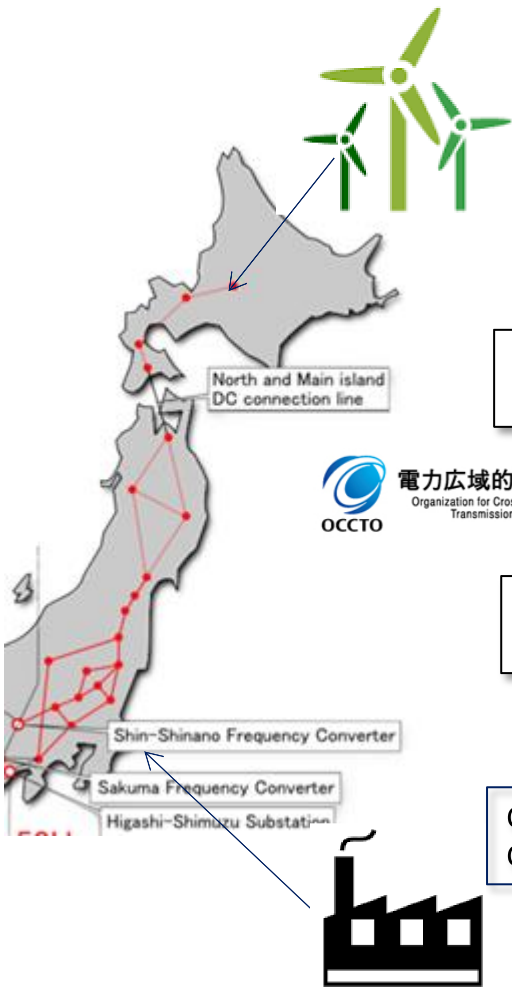
Explicit (contracted) allocation of transmission rights



Generation 10MW
Marginal cost 15JPY/kwh

Profit for generator:
5 JPY/kwh

Need 10MW transfer right
Hokkaido-Tohoku

電力広域的運営推進機関
Organization for Cross-regional Coordination of Transmission Operators,JAPAN
OCCTO

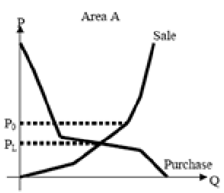
Complexity of application
Availability of transmission?
Cost of transmission rights?
Fairness and priority of rights?

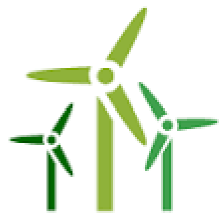
Need 10MW transfer right
Tohoku-Tokyo

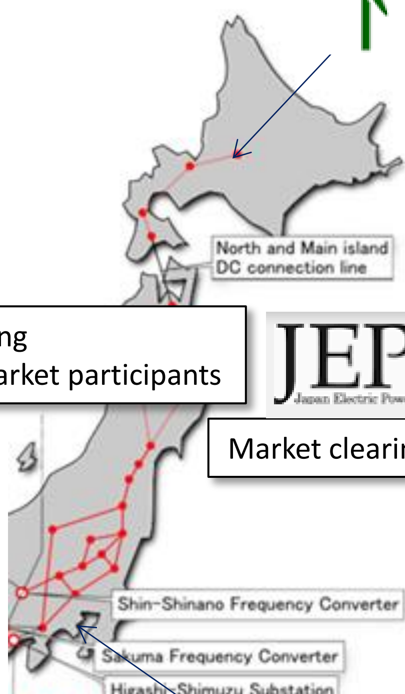
Customer (demand) 10MW
Contract price 20JPY/kwh

Cost for consumer:
20 JPY/kwh

Implicit (socialized) allocation of transmission rights







Generation 10MW
Marginal cost 15 JPY/kwh
Selling to the market for 25 JPY/kwh

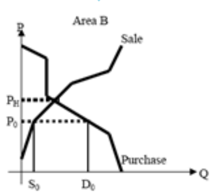
Profit for generator:
5 JPY/kwh

Power market is handling transmission for ALL market participants

JEPX
Japan Electric Power eXchange

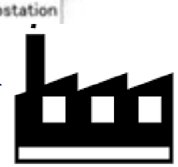
Market clearing price = 25JPY/kwh

Bilateral “contract for difference”
5 JPY/kwh



Customer (demand) 10MW
Buying from the market at 25 JPY/kwh

Cost for consumer:
20 JPY/kwh



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Renewable energy and energy storage in Japan

Intermittence and seasonality is one of the major problems with renewable energy.

- High capacity interregional grid can “smear out” local variations in e.g. solar and wind generation across larger regions.
- Local energy storage can balance out some short and long term variations.
- The current RES target in Japan is about 10-12% = 100 – 120 GW (excluding hydro)
  - Some utilities are already putting limitation on RES deployment due to balancing and grid operation issues.

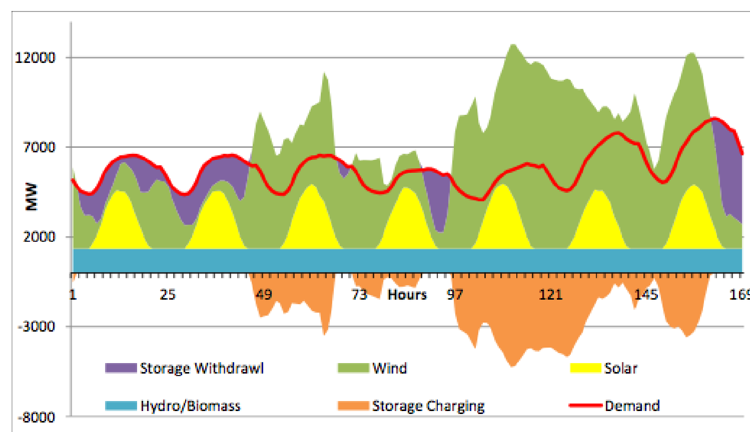

Figure III-7: Hourly supply and demand, with storage. July 11-17, 2007. *Source: IEER.*

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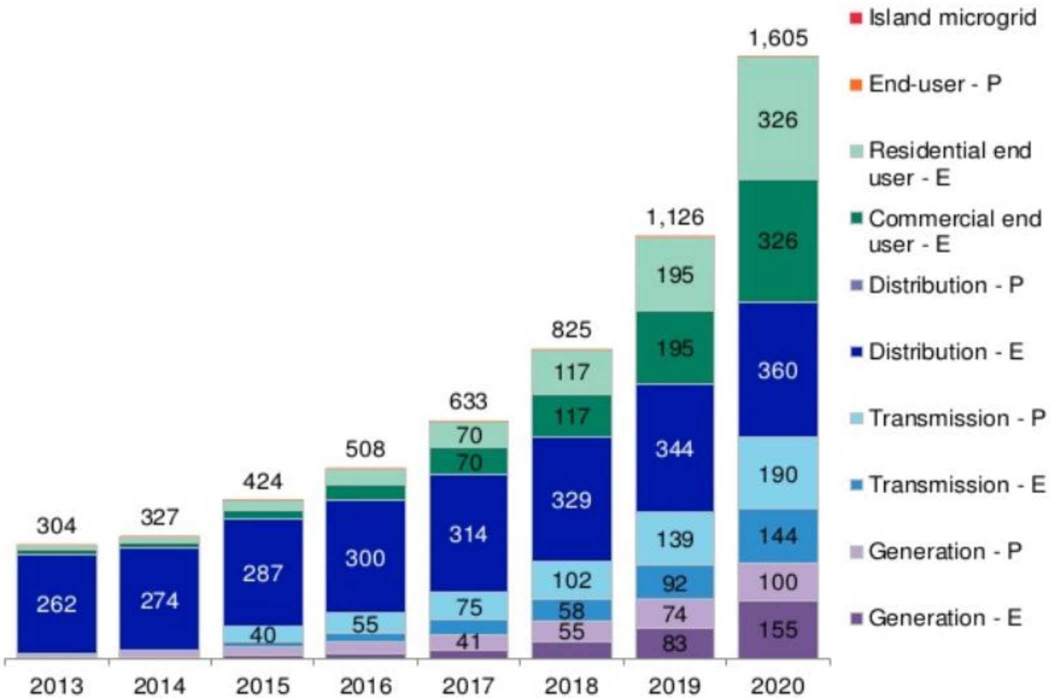
Japan will continue its role as one of the world leaders in energy storage deployment, but with more focus on the end-user side rather than the distribution side as before



- In terms of applications, generation, transmission and distribution-level applications will make up the majority of capacity before 2018.
- From 2018 onwards the end-user segments will start to grow in size at a significant rate as payback periods for end-user systems start to become more economically attractive.
- In terms of power-intensive systems vs. energy-intensive systems, the former takes 20% of the total in 2020, and the latter 80%.

Note: E is short for Energy and P is short for Power.

Source: Bloomberg New Energy Finance

What about the 25,500 MW installed pumped storage in Japan?

Major Power Pla

Japan's electric power industr
hydroelectric, thermal, nuclear, an
meet the required demand. Here
country's major power plants:

Principal Thermal Power Plants

	Name of Plant	Company	Installed Capacity (MW	
1	Tomato-atsuma	Hokkaido	1,650	
2	Higashi Niigata	Tohoku	4,864	
3	Haramachi	Tohoku	2,000	
4	Akita	Tohoku	1,300	
5	Noshiro	Tohoku	1,200	
6	Futtsu	Tokyo	5,040	
7	Kashima	Tokyo	4,400	
8	Hirono	Tokyo	3,800	
9	Sodegaura	Tokyo	3,712	
10	Anegasaki	Tokyo	3,605	
11	Chiba	Tokyo	3,548	
12	Yokohama	Tokyo	3,325	
13	Yokosuka	Tokyo	2,603	
14	Higashi Ogishima	Tokyo	2,000	
15	Goi	Tokyo	1,886	LNG
16	Kawasaki	Tokyo	1,628	LNG
17	Minami Yokohama	Tokyo	1,150	LNG
18	Shinagawa	Tokyo	1,140	LNG
19	Ohi	Tokyo	1,050	Crude
20	Hitachinaka	Tokyo	1,000	Coal
21	Kawagoe	Chubu	4,802	LNG
22	Hekinan	Chubu	4,100	Coal
23	Chita	Chubu	3,966	Crude, Fuel Oil, LNG
24	Shin Nagoya	Chubu	3,058	LNG
25	Atsumi	Chubu	1,900	Crude, Fuel Oil
26	Chita Daini	Chubu	1,708	LNG
27	Yokkaichi	Chubu	1,245	LNG
28	Nishi Nagoya	Chubu	1,190	Crude, Fuel Oil, Naphtha
29	Taketoyo	Chubu	1,125	Crude, Fuel Oil
30	Toyama Shinko	Hokuriku	1,500	Crude, Fuel Oil, Coal
31	Nanaoota	Hokuriku	1,200	Coal
32	Tsuruga	Hokuriku	1,200	Coal
33	Kainan	Kansai	2,100	Crude, Fuel Oil
34	Sakaiko	Kansai	2,000	LNG
35	Gobo	Kansai	1,800	Crude, Fuel Oil
36	Nanko	Kansai	1,800	LNG

(Continued)

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A Pumped Hydro Energy-Storage Renaissance

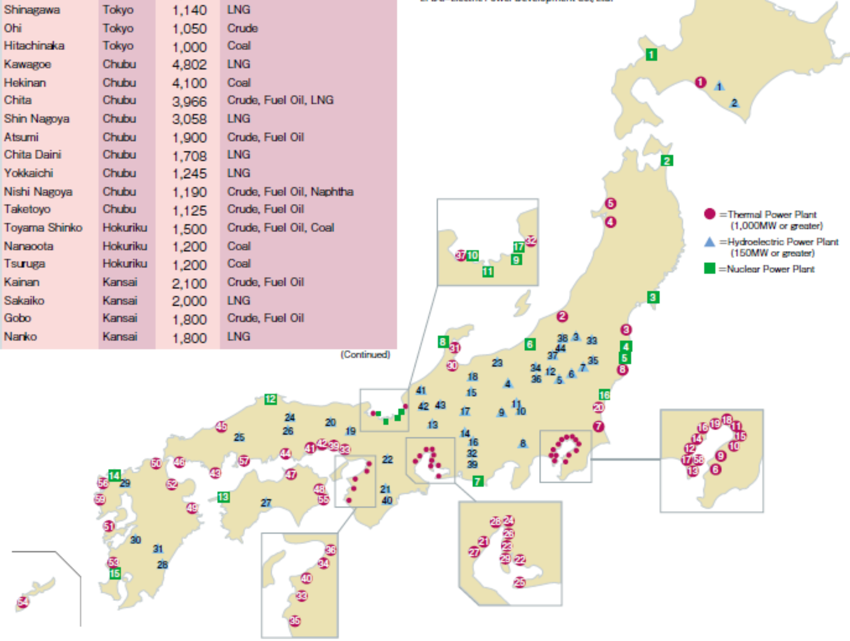
Storage plants built for nuclear power are being revamped for wind and solar

By Peter Fairley

Posted 18 Mar 2015 | 15:00 GMT

58	Isogo Shin	EPDC	1,200	Coal
59	Matsushima	EPDC	1,000	Coal

Note:
EPDC=Electric Power Development Co., Ltd.



Nuclear Power Plants

● In Operation — As of March 31, 2012

	Name of Plant	Unit Number	Company	Installed Capacity (MW)	Type of Reactor	Start
1	Tomari	1	Hokkaido	579	PWR	1989.6
		2		579	PWR	1991.4
		3		912	PWR	2009.12
2	Higashi-Dori	1	Tohoku	1,100	BWR	2005.12
3	Onagawa	1	Tohoku	524	BWR	1984.6
		2		825	BWR	1995.7
		3		825	BWR	2002.1
4	Fukushima Daiichi	5	Tokyo	784	BWR	1978.4
		6		1,100	BWR	1979.10
5	Fukushima Daini	1	Tokyo	1,100	BWR	1982.4
		2		1,100	BWR	1984.2
		3		1,100	BWR	1985.6
		4		1,100	BWR	1987.8
6	Kashiwazaki Kariwa	1	Tokyo	1,100	BWR	1985.9
		2		1,100	BWR	1990.9
		3		1,100	BWR	1993.8
		4		1,100	BWR	1994.8
		5		1,100	BWR	1990.4
		6		1,356	ABWR	1996.11
		7		1,356	ABWR	1997.7
7	Hamaoka	3	Chubu	1,100	BWR	1987.8
		4		1,137	BWR	1993.9
		5		1,380	ABWR	2005.1
8	Shika	1	Hokuriku	540	BWR	1993.7
		2		1,206	ABWR	2006.3
9	Mihama	1	Kansai	340	PWR	1970.11
		2		500	PWR	1972.7
		3		826	PWR	1976.12
10	Takahama	1	Kansai	826	PWR	1974.11
		2		826	PWR	1975.11
		3		870	PWR	1985.1
		4		870	PWR	1985.6
11	Ohi	1	Kansai	1,175	PWR	1979.3
		2		1,175	PWR	1979.12
		3		1,180	PWR	1991.12
		4		1,180	PWR	1993.2
12	Shimane	1	Chugoku	460	BWR	1974.3
		2		820	BWR	1989.2
13	Ikata	1	Shikoku	566	PWR	1977.9
		2		566	PWR	1982.3
		3		890	PWR	1994.12
14	Genkai	1	Kyushu	559	PWR	1975.10
		2		559	PWR	1981.3
		3		1,180	PWR	1994.3
		4		1,180	PWR	1997.7
15	Sendai	1	Kyushu	890	PWR	1984.7
		2		890	PWR	1985.11
16	Tokai Daini		Japan Atomic Power Co.	1,100	BWR	1978.11
17	Tsuruga	1	Japan Atomic Power Co.	357	BWR	1970.3
		2		1,160	PWR	1987.2
Total		50 Units		46,148MW		

● Under Construction — (Estimated start)

Higashi-Dori	1	Tokyo	1,385	ABWR	U.D
Shimane	3	Chugoku	1,373	ABWR	U.D
Ohma		EPDC	1,383	ABWR	U.D
Total	3 Units		4,141MW		

● Preparing for Construction — (Estimated start)

Namie-Odaka		Tohoku	825	BWR	U.D
Higashi-Dori	2	Tohoku	1,385	ABWR	U.D
Higashi-Dori	2	Tokyo	1,385	ABWR	U.D
Hamaoka	6	Chubu	1,400	ABWR	U.D
Kaminoseki	1	Chugoku	1,373	ABWR	U.D
	2		1,373	ABWR	U.D
Sendai	3	Kyushu	1,590	APWR	U.D
Tsuruga	3	Japan Atomic Power Co.	1,538	APWR	U.D
	4		1,538	APWR	U.D
Total	9 Units		12,407MW		

Principal Hydroelectric Power Plants (150MW or greater)

As of March 31, 2012

	Name of Plant	Company	Installed Capacity (MW)	Type
1	Niikappu	Hokkaido	200	Pumped Storage
2	Takami	Hokkaido	200	Pumped Storage
3	Daini Numazawa	Tohoku	460	Pumped Storage
4	Shin Takasegawa	Tokyo	1,280	Pumped Storage
5	Tamahara	Tokyo	1,200	Pumped Storage
6	Imaichi	Tokyo	1,050	Pumped Storage
7	Shiobara	Tokyo	900	Pumped Storage
8	Kazunogawa	Tokyo	800	Pumped Storage
9	Azumi	Tokyo	623	Pumped Storage
10	Kannagawa	Tokyo	470	Pumped Storage
11	Midono	Tokyo	245	Pumped Storage
12	Yagisawa	Tokyo	240	Pumped Storage
13	Okumino	Chubu	1,500	Pumped Storage
14	Okuyahagi Daini	Chubu	780	Pumped Storage
15	Takane Daiichi	Chubu	340	Pumped Storage
16	Okuyahagi Daiichi	Chubu	315	Pumped Storage
17	Mazegawa Daiichi	Chubu	288	Pumped Storage
18	Arimine Daiichi	Hokuriku	265	
19	Okutataragi	Kansai	1,932	Pumped Storage
20	Okawachi	Kansai	1,280	Pumped Storage
21	Okuyoshino	Kansai	1,206	Pumped Storage
22	Kisenyama	Kansai	466	Pumped Storage
23	Kurobegawa Daiyon	Kansai	335	
24	Matanogawa	Chugoku	1,200	Pumped Storage
25	Nabara	Chugoku	620	Pumped Storage
26	Shin Nariwagawa	Chugoku	303	Pumped Storage
27	Hongawa	Shikoku	615	Pumped Storage
28	Omarugawa	Kyushu	1,200	Pumped Storage
29	Tenzan	Kyushu	600	Pumped Storage
30	Ohira	Kyushu	500	Pumped Storage
31	Hitotsuse	Kyushu	180	
32	Shin Toyone	EPDC	1,125	Pumped Storage
33	Shimogo	EPDC	1,000	Pumped Storage
34	Okukiyotsu	EPDC	1,000	Pumped Storage
35	Numappara	EPDC	675	Pumped Storage
36	Okukiyotsu Daini	EPDC	600	Pumped Storage
37	Okutadami	EPDC	560	
38	Tagokura	EPDC	400	
39	Sakuma	EPDC	350	
40	Ikehara	EPDC	350	Pumped Storage
41	Tedorigawa Daiichi	EPDC	250	
42	Nagano	EPDC	220	Pumped Storage
43	Miboro	EPDC	215	
44	Otori	EPDC	182	

● End of Operation

Fukushima Daiichi	1(*)	Tokyo	460	BWR	2012.4
	2(*)		784	BWR	2012.4
	3(*)		784	BWR	2012.4
	4(*)		784	BWR	2012.4
Hamaoka	1	Chubu	540	BWR	2009.1
	2		840	BWR	2009.1
Tokai		Japan Atomic Power Co.	166	GCR	1998.3
Total	7 Units		4,358MW		

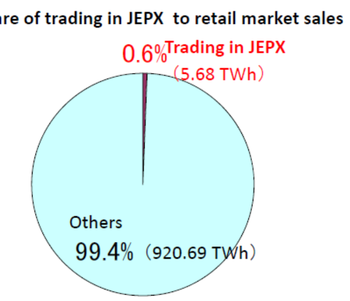
(*) In May, 2011, Tokyo Electric Power Company decided to decommission Units 1 to 4 and to abolish plans to build Unit 7 and 8 at Fukushima Daiichi Nuclear Power Station which was severely damaged due to the Tohoku-Pacific Ocean Earthquake and the tsunami that followed after on March 11, 2011.

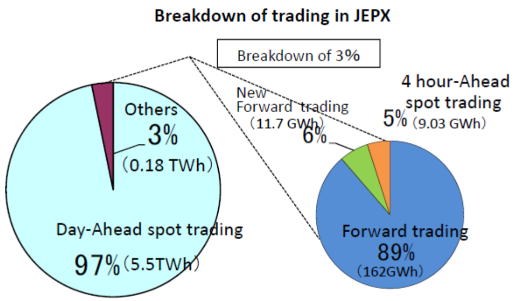
● Others

Fugen	Japan Atomic Energy Agency	165	ATR(Prototype) End of Operation
Monju	Japan Atomic Energy Agency	280	FBR(Prototype)

Note: PWR=Pressurized Water Reactor, BWR=Boiling Water Reactor, APWR=Advanced Pressurized Water Reactor, ABWR=Advanced Boiling Water Reactor, GCR=Gas Cooled Reactor, ATR=Advanced Thermal Reactor, FBR=Fast Breeder Reactor

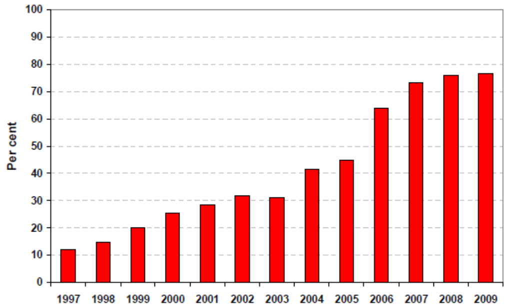
The role of the Power Exchange (JEPX) – growth potentials





- Market Liquidity
  - Today limited liquidity (< 2%):
    - Most energy is transacted within the utilities
    - Interregional trading is mainly by bilateral contract
    - IPPs have bilateral contracts with utilities

- Means to increase liquidity :
  - ✓ Transact interregional transmission capacity in the PX (implicit auction):
    - Total 52GW capacity @ 20% utilization = 100 TWh/annum
  - ✓ Transacting the pumped storage capacity in JEPX:
    - 25 GW capacity @ 10% trading = 25TWh/annum
  - ✓ System losses are bought by the system operators from the PX:
    - 5% of total 1,000 TWh = 50 TWh/annum

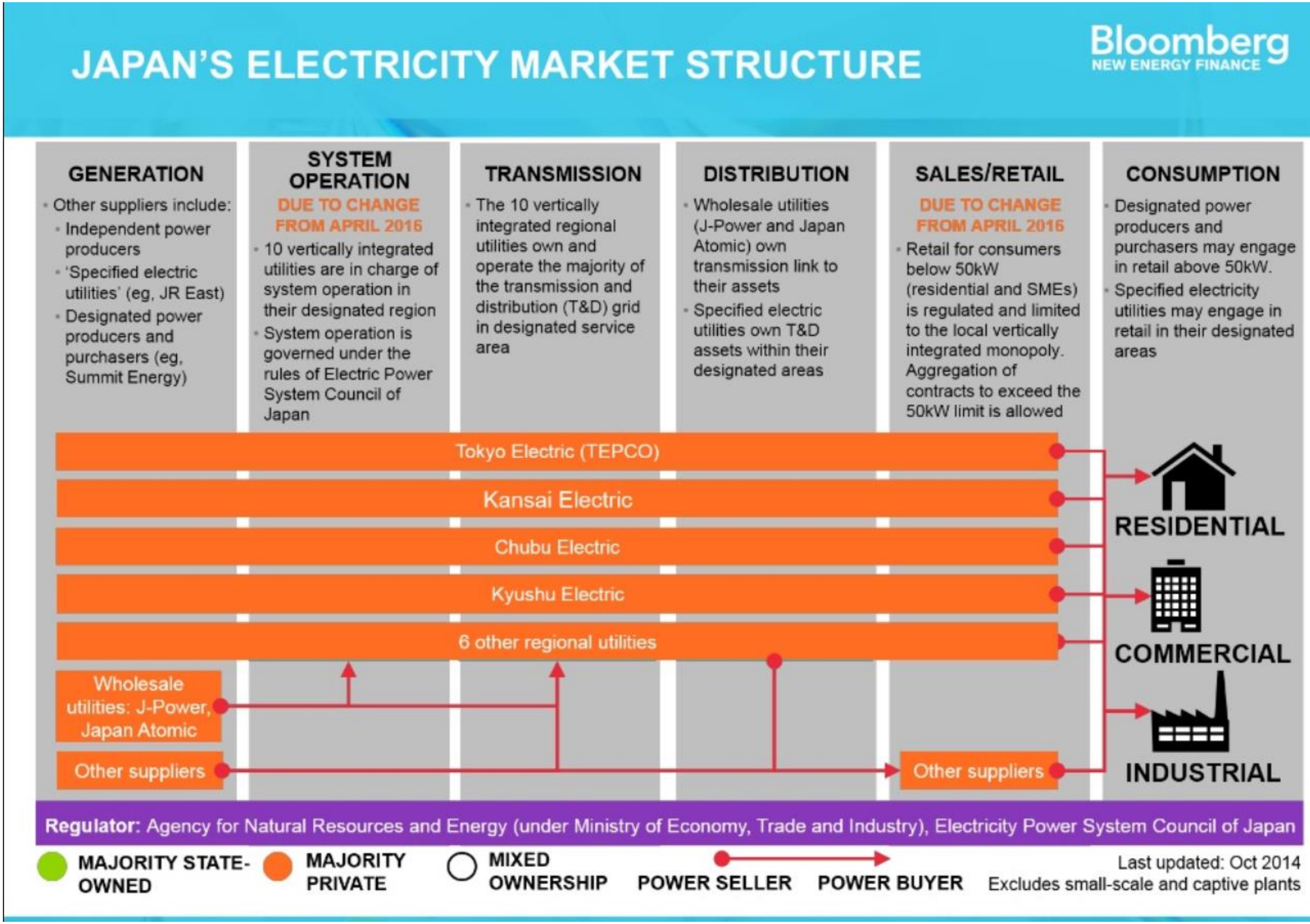


NordPool spot market share development

Comparison Japan – EU energy markets

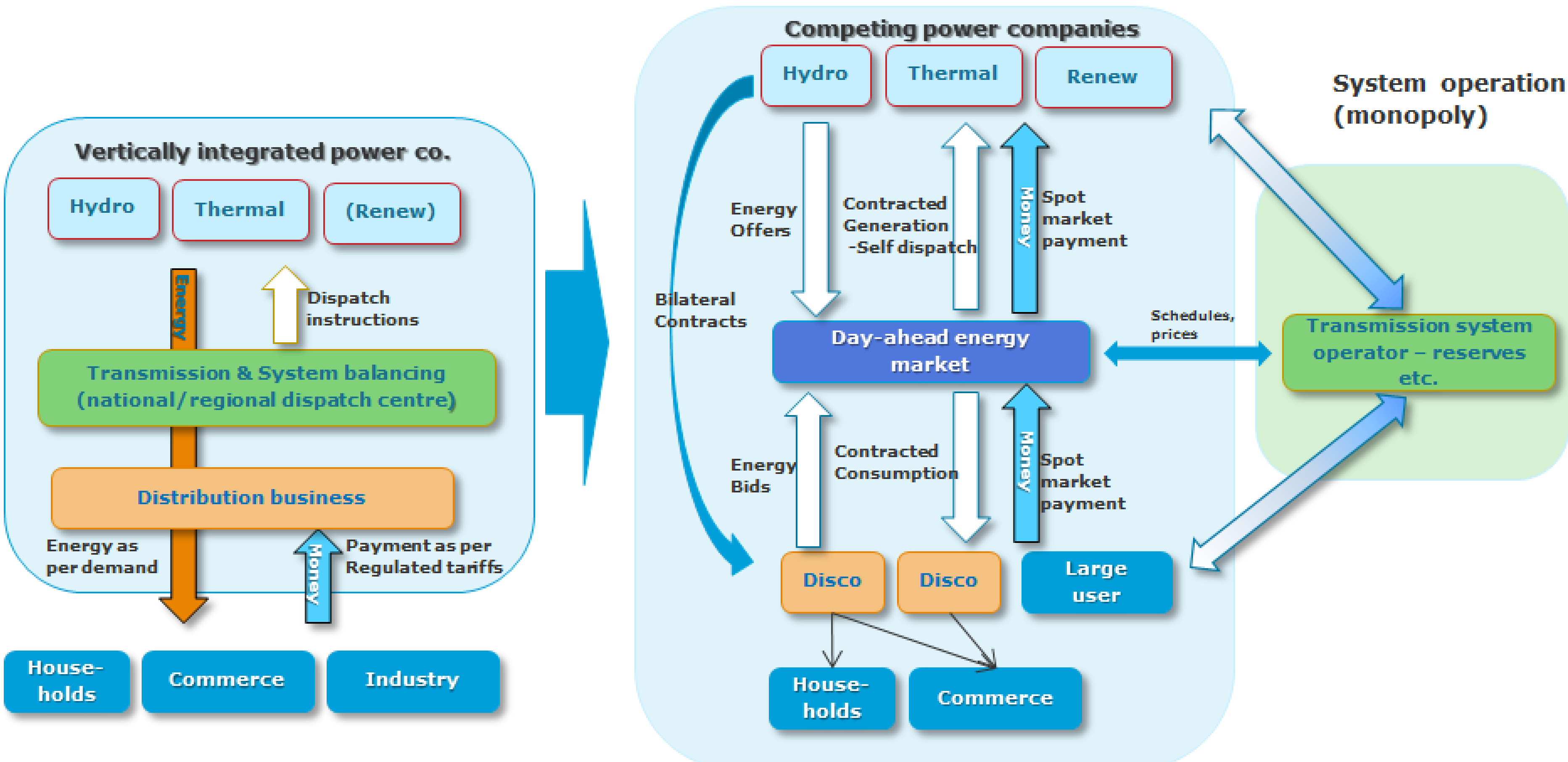
	Europa	Japan
Restructuring process	Gradually since 1989. Energy Package 2009. Market coupling 2014.	Gradually since mid 1990. JEPX 2005. Significant reform ongoing
Unbundling of utilities	Full unbundling. Separate System Operators from genco/disco.	Legal unbundling 2018-2020
Market model	"Nordpool model"	"Nordpool model"
Interregional transmission access	Implicit auction & traded transmission rights	Not concluded: currently controlled by power utilities.
Integration of renewable energy sources	Substantial amount (up to 20-40%), issues with balancing and storage.	Small, but increasing amount (1-2%), reported issues with grid stability
Energy storage	Limited, exchange between countries. Norway & Switzerland hydro storage.	Pumped storage very substantial (25,000 MW), can be utilized for RE balancing?
Power exchanges	Multiple – 5 large. Good coordination. High liquidity (+50% of market). Good reference prices. Essential part of the power market.	JEPX. Low liquidity for the moment. Will play important role in future market.

Backup slides



JAPAN'S ELECTRICITY MARKET STRUCTURE
Bloomberg NEW ENERGY FINANCE
GENERATION
Other suppliers include:
Independent power producers
'Specified electric utilities' (eg, JR East)
Designated power producers and purchasers (eg, Summit Energy)
SYSTEM OPERATION
DUE TO CHANGE FROM APRIL 2016
10 vertically integrated utilities are in charge of system operation in their designated region
System operation is governed under the rules of Electric Power System Council of Japan
TRANSMISSION
The 10 vertically integrated regional utilities own and operate the majority of the transmission and distribution (T&D) grid in designated service area
DISTRIBUTION
Wholesale utilities (J-Power and Japan Atomic) own transmission link to their assets
Specified electric utilities own T&D assets within their designated areas
SALES/RETAIL
DUE TO CHANGE FROM APRIL 2016
Retail for consumers below 50kW (residential and SMEs) is regulated and limited to the local vertically integrated monopoly. Aggregation of contracts to exceed the 50kW limit is allowed
CONSUMPTION
Designated power producers and purchasers may engage in retail above 50kW.
Specified electricity utilities may engage in retail in their designated areas
Tokyo Electric (TEPCO)
Kansai Electric
Chubu Electric
Kyushu Electric
6 other regional utilities
Wholesale utilities: J-Power, Japan Atomic
Other suppliers
Other suppliers
RESIDENTIAL
COMMERCIAL
INDUSTRIAL
Regulator: Agency for Natural Resources and Energy (under Ministry of Economy, Trade and Industry), Electricity Power System Council of Japan
MAJORITY STATE-OWNED
MAJORITY PRIVATE
MIXED OWNERSHIP
POWER SELLER
POWER BUYER
Last updated: Oct 2014
Excludes small-scale and captive plants

Electricity market reforms – from monopolies to markets



Electricity market reform road map

Objectives:

- Promote investment in new generation (conventional and renewable)
- Fair grid access ⇨ promote competition
- Smarter use of energy ⇨ smart-grid, retail competition, markets

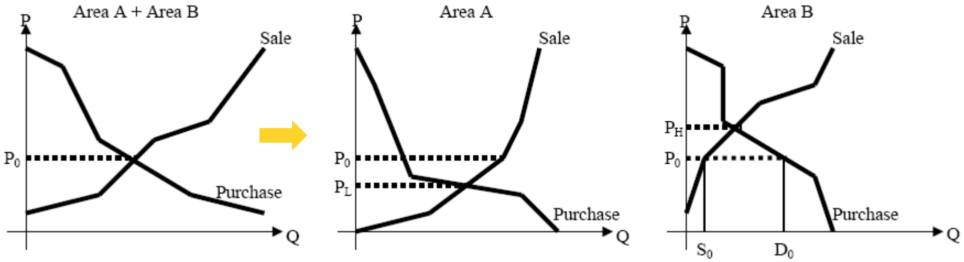
Means:

1. Establish a market regulator and an nationwide system operator (2015)
2. Full liberalization of retail market (2016-17):
   - ✓ replace fixed tariffs with market prices
   - ✓ facilitate wholesale electricity markets
3. Unbundling of the power companies (2018-20)
   - ✓ Separation of generation, transmission and distribution

Introducing the “Nordic electricity market model”

Congestion management by “market splitting”

- Implicit auction mechanism:
  - Step 0: The whole system is one market, but with predefined **bid areas**
  - Step 1: Calculate system price neglecting congestion - “Unconstrained MCP”
  - Step 2: Check transmission limits
  - Step 3: In case of congestion; split market into **price areas** and recalculate prices in each new area with the congested intertie capacity.
  - Increase price in deficit area –> more generation/less demand
  - Decrease price in surplus area -> less generation/more demand
  - Iterate until all congestion solved.
- This leads to area price differentials (zonal prices) and an income to the Market Operator
  - Income = Transmission flow * Δ price



Innovation Norway

Transmission management in deregulated markets

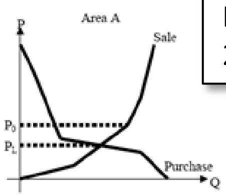
Right to interregional energy transmission is crucial for energy trading

Allocation of transmission is done differently in different markets:
- ✓ Explicit rights given directly to one or more market participants
- ✓ Auction of transmission rights
- ✓ The market operator holds all or parts of the transmission rights

Optimal utilization of transmission is important for efficient market and to lower system operation costs

Choice of transmission utilization regulation is important for deployment of renewable energy, liquidity of energy markets and cost of the market.

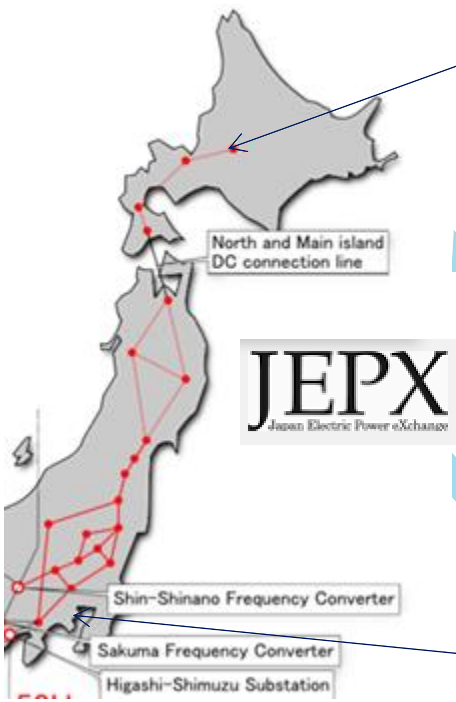
Not so lucrative position - hedge



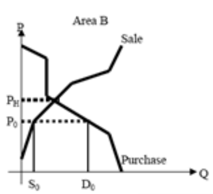
Market clearing price Hokkaido
21 JPY/kwh

Generation 10MW
Marginal cost 10 JPY/kwh
Selling to the market for 21 JPY/kwh

Profit: 15 JPY
21 JPY from JEPX +
4 JPY in CdF –
10 JPY generation cost



Bilateral “contract for difference”
4 JPY/kwh



Customer (demand) 10MW
Buying from the market at 16JPY/kwh

“Loss”: 4 JPY
Cost of CDF..

Market clearing price Tokyo
16 JPY/kwh