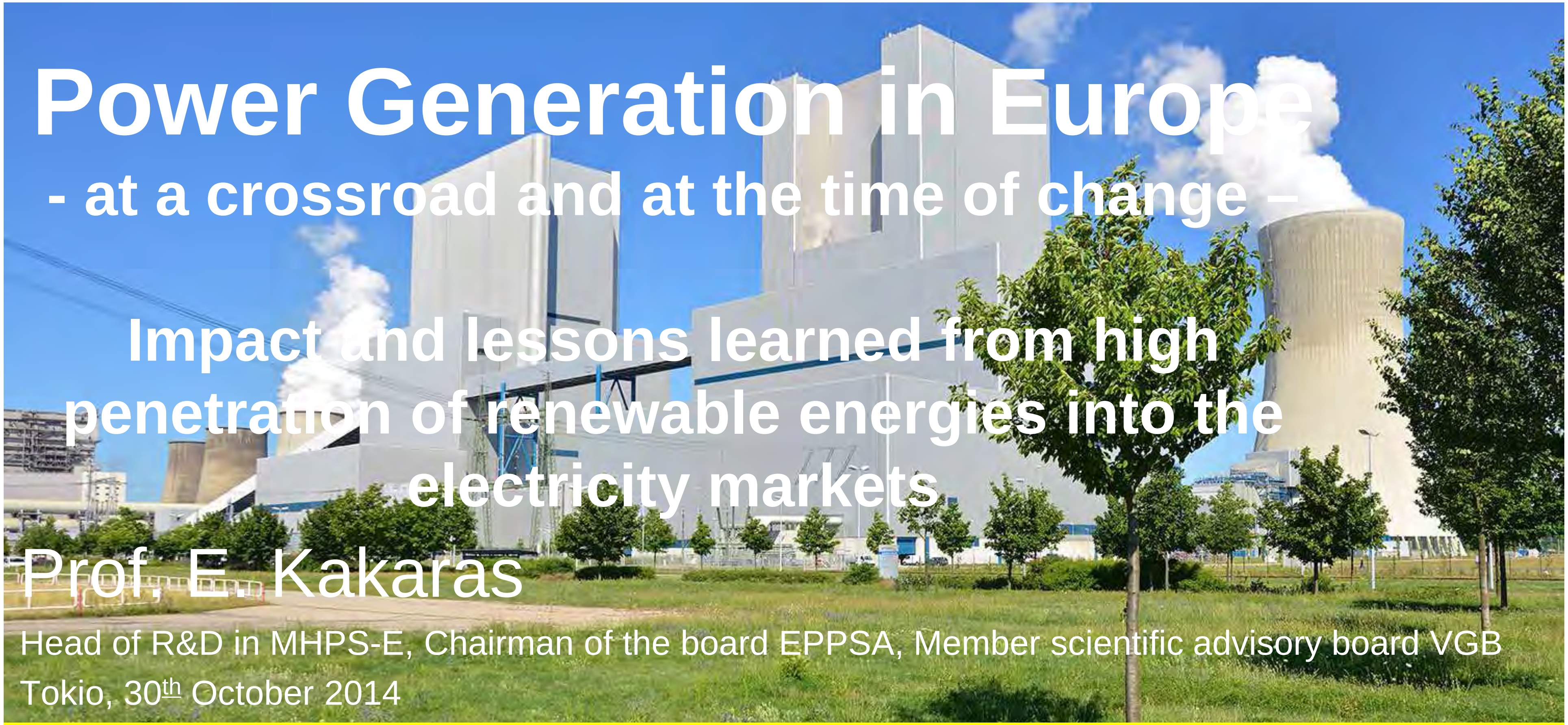


Power Generation in Europe

- at a crossroad and at the time of change –

Impact and lessons learned from high penetration of renewable energies into the electricity markets

Prof. E. Kakaras

Head of R&D in MHPS-E, Chairman of the board EPPSA, Member scientific advisory board VGB

Tokio, 30th October 2014

6th University of Tokyo Symposium on Energy and Environment

MITSUBISHI HITACHI POWER SYSTEMS EUROPE

Developing the Future eppsa

The European Power Plant Suppliers Association

is the voice, at European level, of companies supplying power plants, components and services.

EPPSA members, located throughout Europe, represent a leading sector of technology with more than 100.000 employees and annual revenue of over 30 billion euro.

Virtually, all existing Power Plants in the EU have either components from or were built by EPPSA Members

Members of EPPSA

- ABB
- ALSTOM
- ANDRITZ
- ANSALDO CALDAIE S.p.A.
- BWE
- CARMEUSE
- CLYDE BERGEMANN Power Group
- CMI ENERGY
- DOOSAN
- FLUOR
- FOSTER WHEELER
- HITACHI Inspire the Next
- Howden
- MAGALDI
- NEM OUR ENERGY, YOUR POWER
- NE NOOTER/ERIKSEN S.r.l.
- STF SpA
- STORK TECHNICAL SERVICES
- TLT-Turbo GmbH

OUR MEMBERS

European technical association for power and heat generation

VGB PowerTech e.V. is the European technical association for power and heat generation. As voluntary association VGB PowerTech brings together companies, for which the operation of power plants and the corresponding technologies form an important base for their business

Members of VGB

Fossil-fired Power Plants: 246,000 MW
Nuclear Power Plants: 120,000 MW
Hydro, Wind, et al. RE: 92,000 MW
Total: ~ 458,000 MW

EU 28: 457 Members in 22 Countries
Austria, Belgium, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Poland, Portugal, Romania, Slovenia, Spain, Sweden, the Netherlands, United Kingdom

Remaining Europe: 16 in 4 Countries
Norway, Russia, Switzerland, Turkey

Outside Europe: 11 in 9 Countries
Argentina, Australia, Brazil, China, Israel, Japan, Mongolia, South Africa, USA

Total: 484 in 35 Countries

VGB represents ~ 458,000 MW installed power capacity

Department Innovation & New Products in MHPS-E

The Department

INNOVATION &

NEW PRODUCTS

within

MHPS-E

Number of staff

25

consisting of:

5 PhD

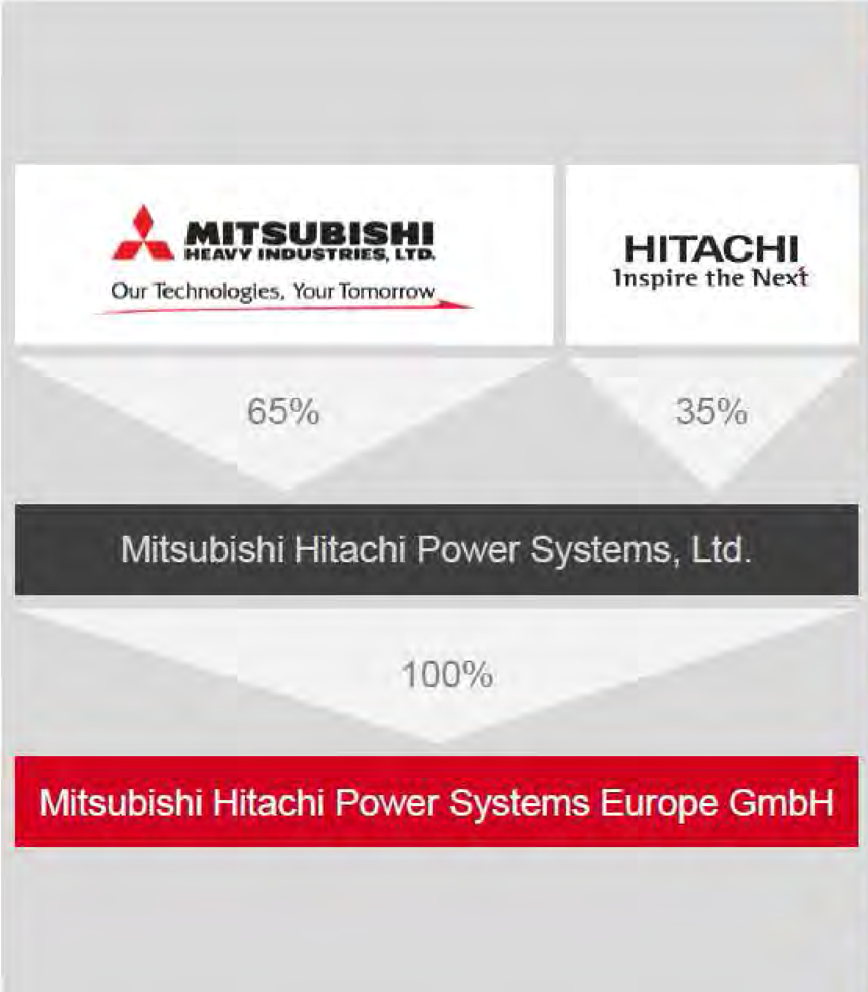
10 Engineers

2 Assistants

5 Master students

2 Bachelor students

and Prof. Kakaras



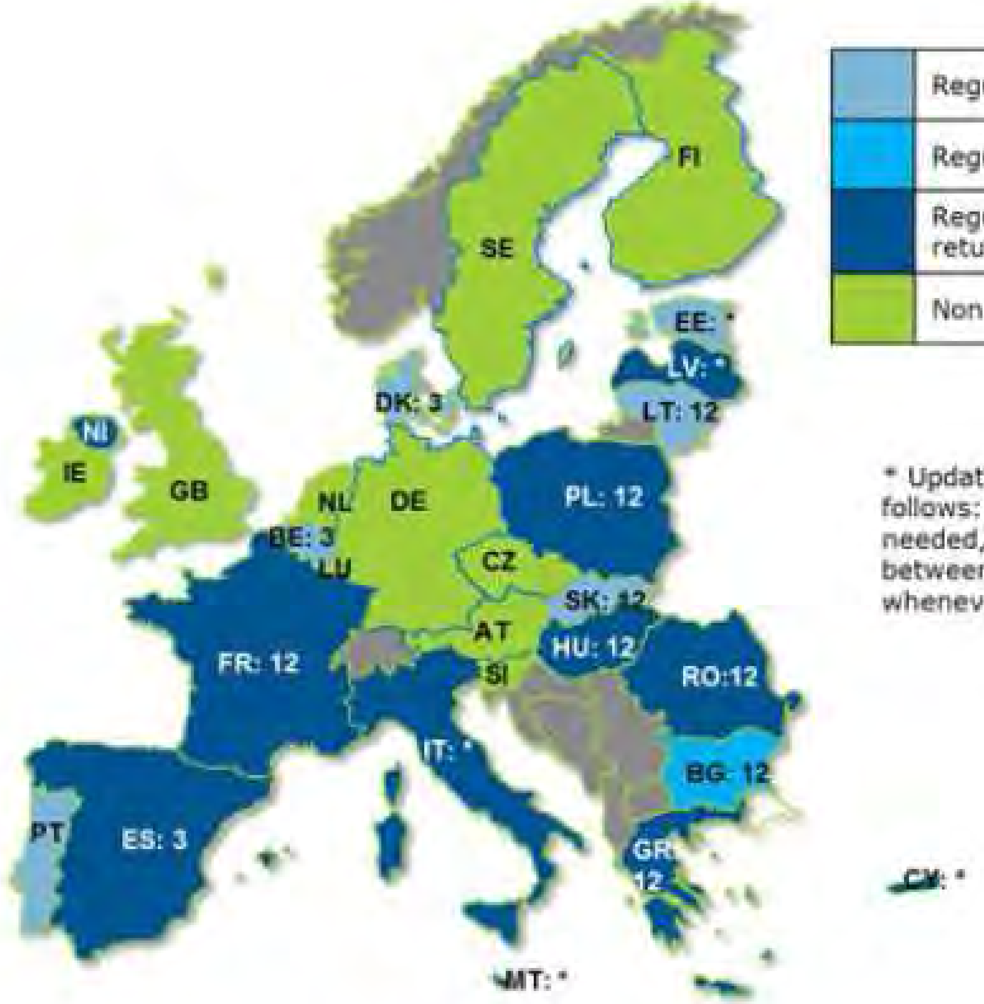
De-Regulation of Electricity in Europe

	Publication date	Transposition deadline	Directive /Regulation
First Package	19/Dec/96	19/Feb/99	Directive 96/92EC[17] concerning common rules for the internal market of electricity
Second package	15/Jul/03	01/Apr/04	Directive 2003/54EC[18] concerning common rules for the internal market of electricity
	26/Jun/03	01/Jul/04	Regulation (EC) 1228/2003 on conditions for access to the network for cross-border exchanges of electricity
	9/Nov/06		Commission Decision 2006/770/EC amending the annex ("Congestion Management Guidelines") for regulation 1228/2003
Third package	13/Jul/09	03/Mar/11	Directive 2009/72/EC[19] concerning common rules for the internal market of electricity
			Regulation (EC) 714/2009 on conditions for access to the network for cross-border exchanges of electricity
			Regulation (EC) 713/2009 on establishing an Agency for the Cooperation of Energy Regulators (ACER)

Before the deregulation, starting in the ´1990th most markets have been regulated in Europe

Source: Adapted from REKK & KEMA (10), EC, DG Energy

Price Regulation in Europe

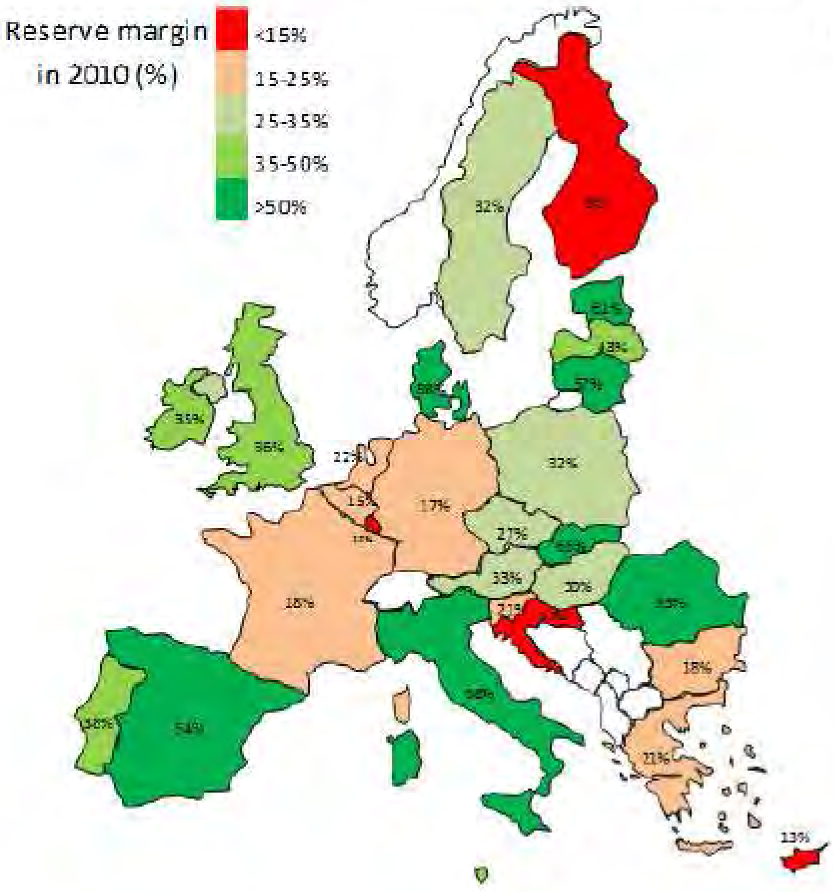


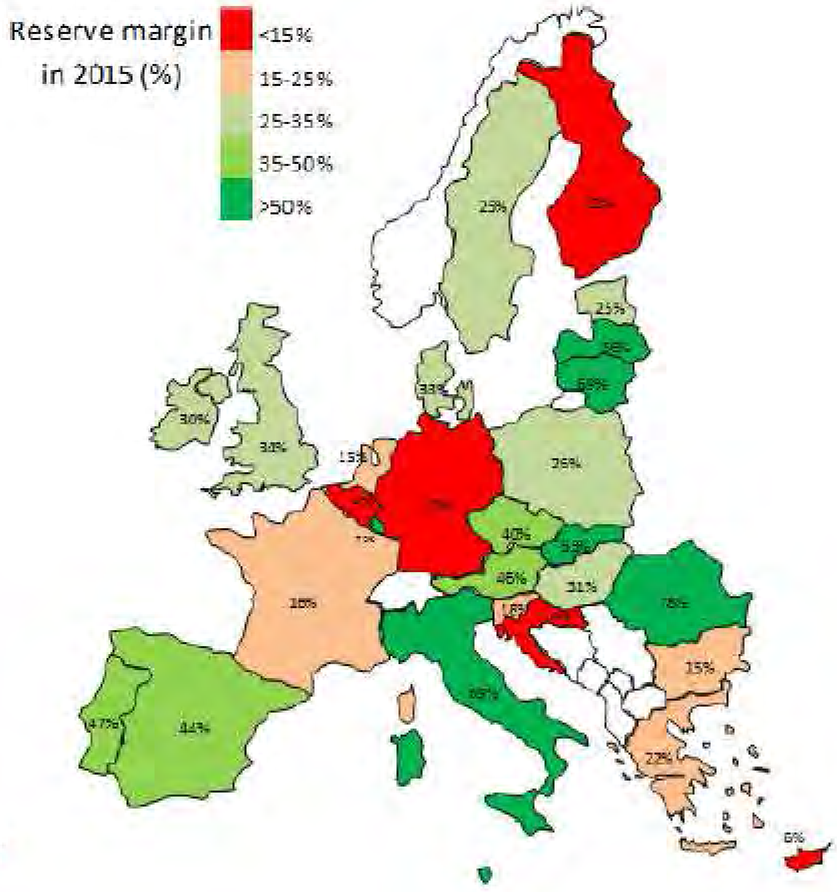
- Regulated, Price cap
- Regulated, Revenue Cap
- Regulated, Rate of return/Cost-plus
- Non-regulated prices

* Updates of the regulated price are as follows: Latvia and Malta - whenever needed, Cyprus- ad hoc basis, Italy – between quarterly and yearly, Estonia – whenever the supplier seeks a new price.

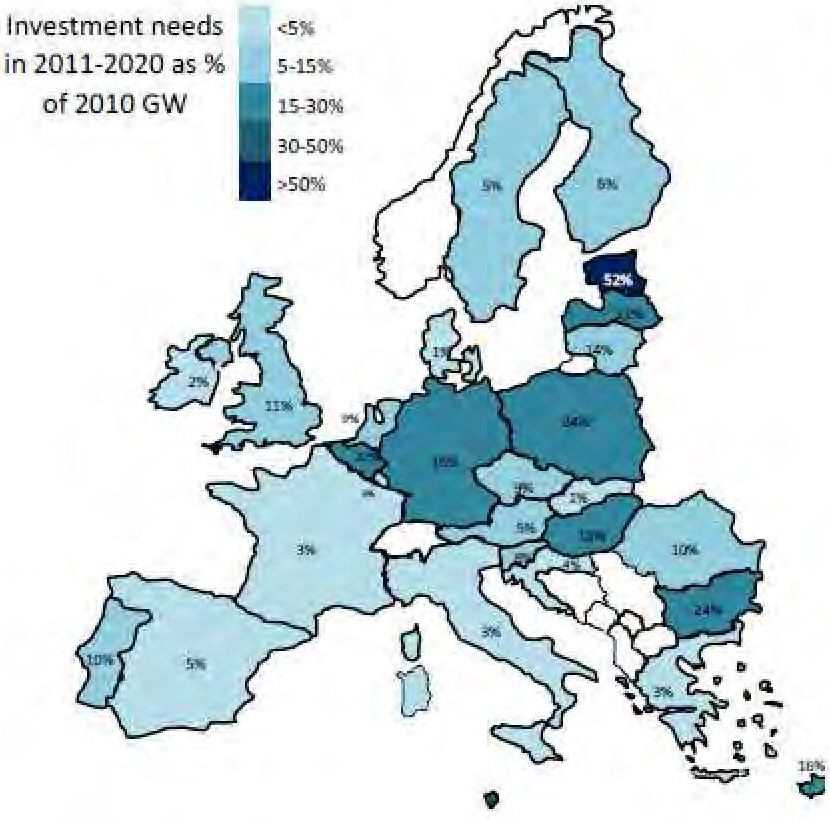
Source: The CEER national indicators database and ACER questionnaire on regulated prices (2013)

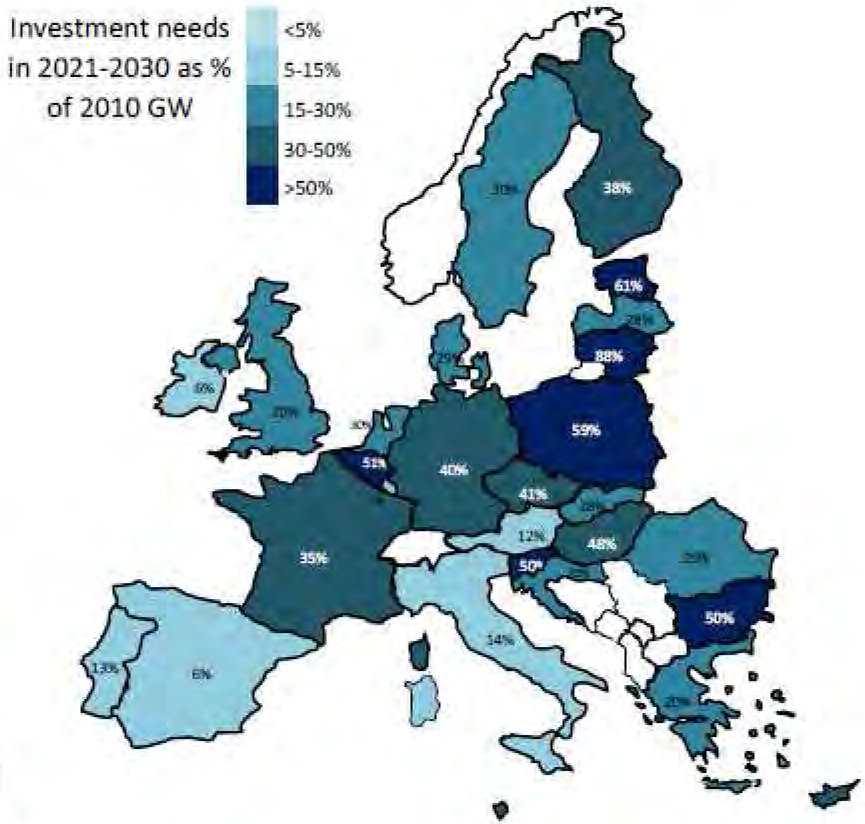
Reserve Margin in the System in the EU





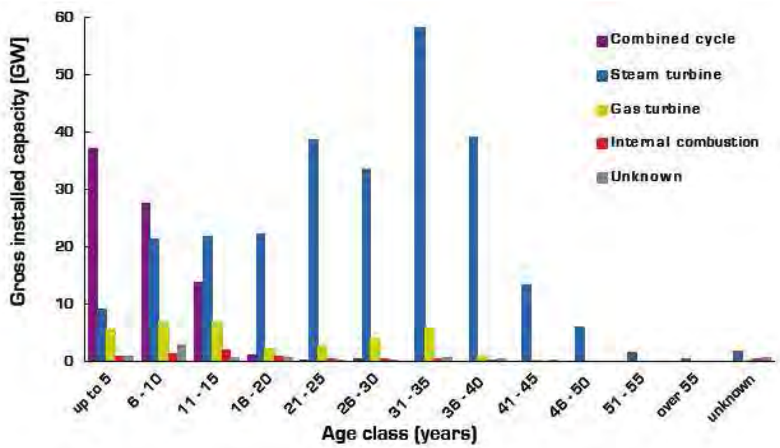
Resulting Investment Needs in EU

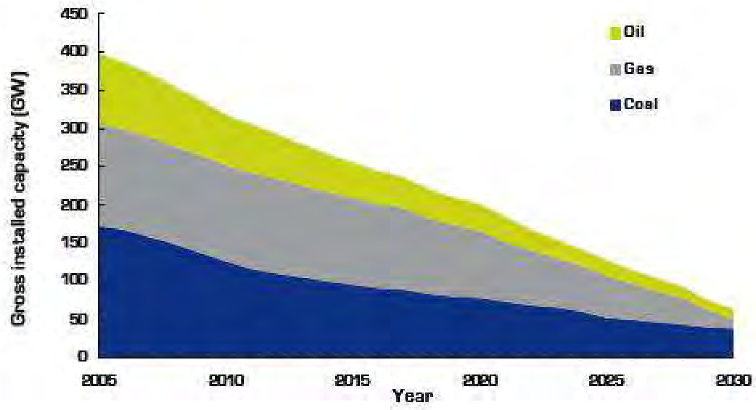


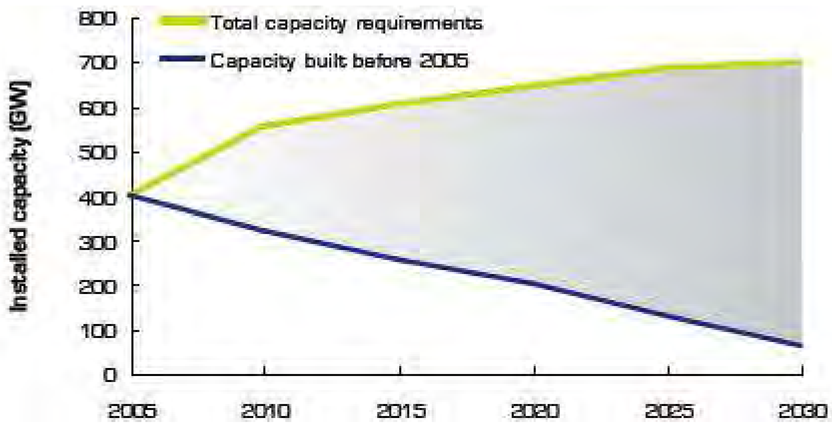


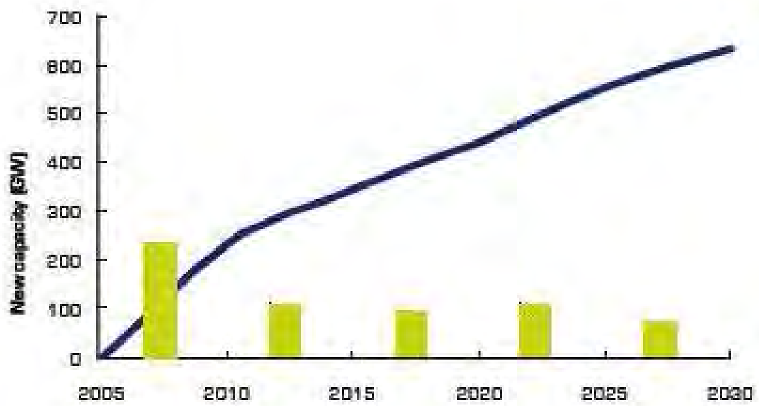
Capacity Drop in the EU until 2030

There is still an overcapacity in the EU, but this will change in the future …









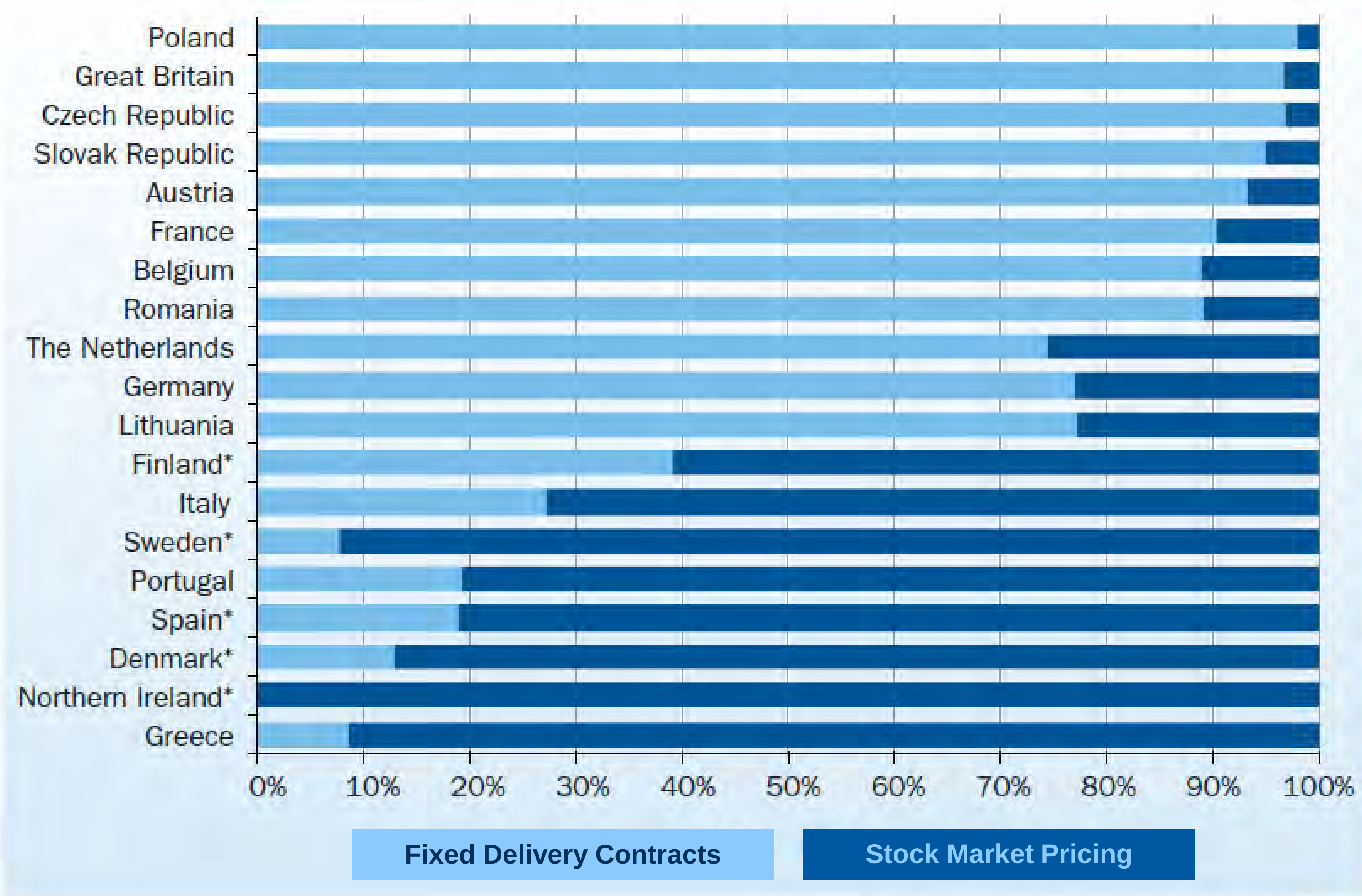
Future Fossil Fuel Electricity Generation in Europe: Options and Consequences

JRC EUROPEAN COMMISSION

E. Tzimas, A. Georgakaki and S.D. Peteves

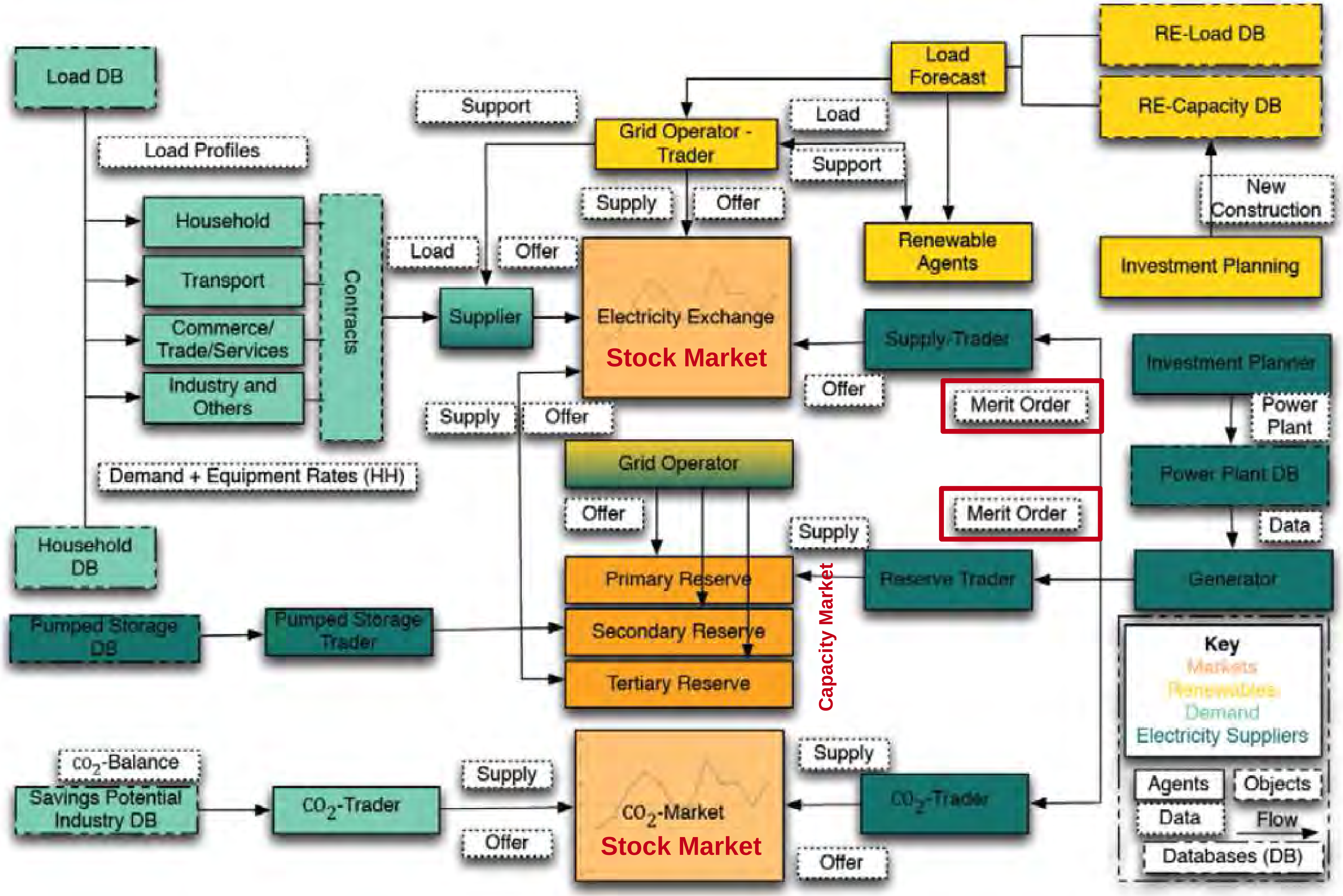
2009

Free Trade Capacity in the Markets (% per Market)



Sources: European Parliament (1), Cornwall, N (2006) (2)

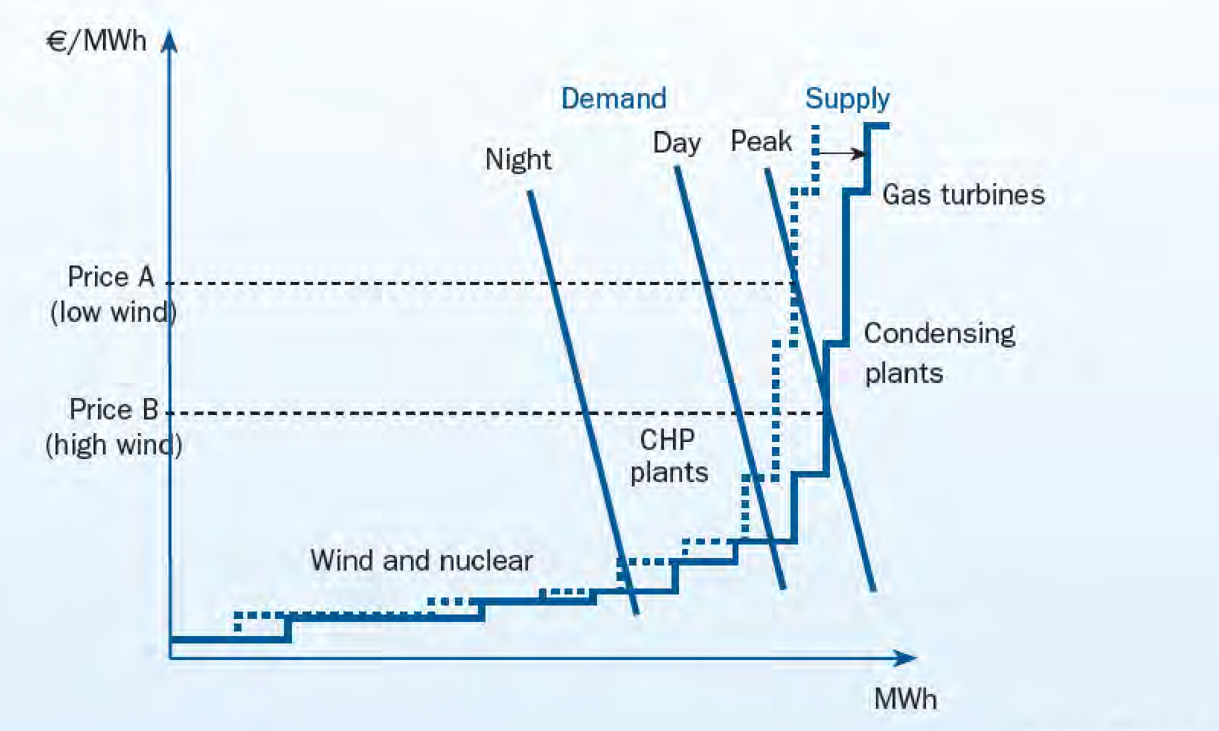
Free Trading System Principle in the EU



Electricity Stock Market (Merit Order Effect)

Stock marked trade is common for several products in the electricity market

Intra-Day Trade	Day ahead Trade	Week ahead Trade

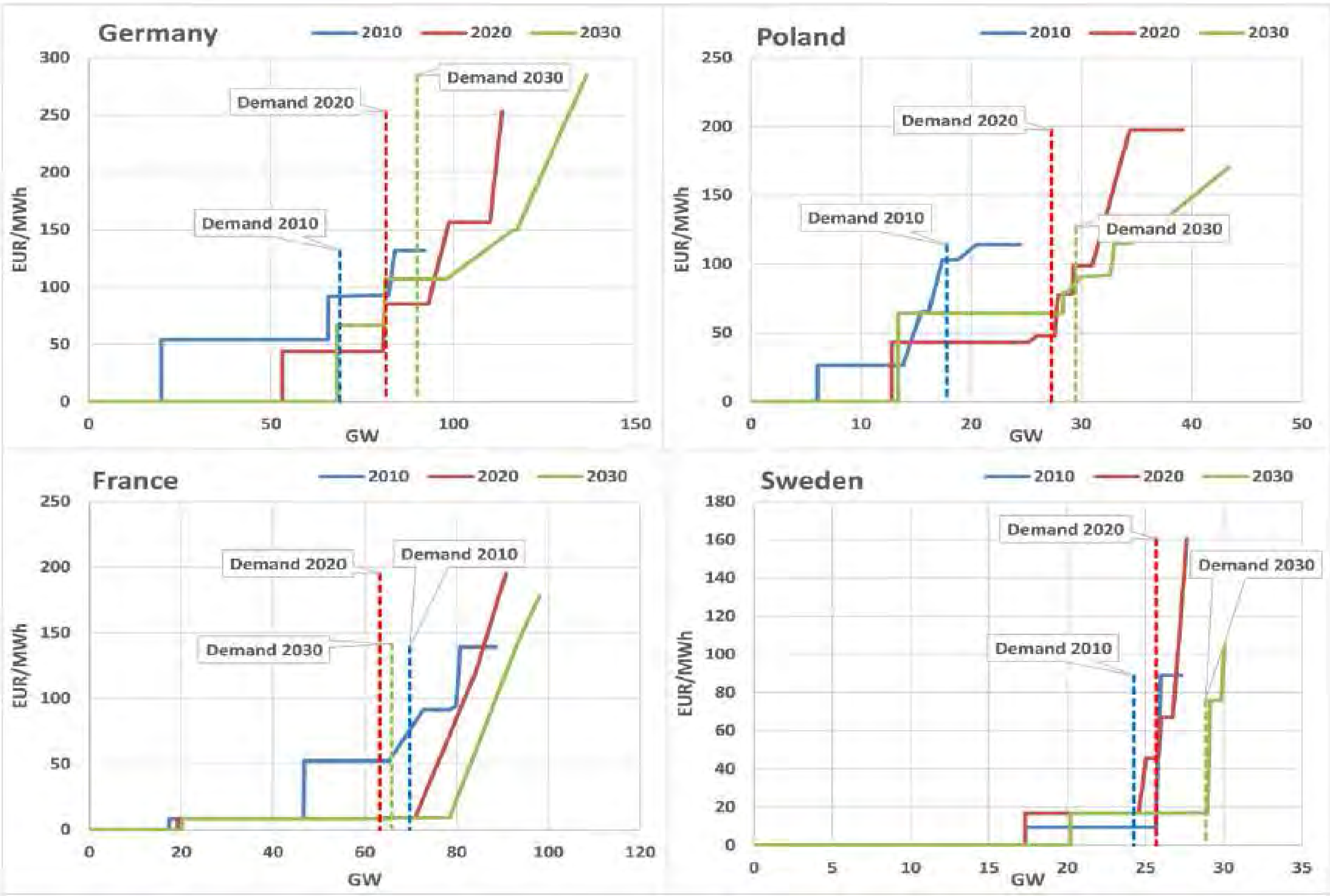


Source: Risø DTU

	Market operator	Intraday
Austria	EXAA	x
Belgium	BELPEX	√
Bulgaria	TSO	x
Cyprus	TSO	x
Czech Republic	EPX	x
Denmark	NordPool Spot	√
Estonia	NordPool Spot	√
Finland	NordPool Spot	√
France	APX-ENDEX	√
Germany	APX-ENDEX	√
Great Britain	N2X	√
Greece	HTSO	x
Hungary	HUPX	x
Ireland	SEMO	x
Italy	GME	√
Latvia	NordPool Spot	x
Lithuania	BaltPool	x
Luxembourg	BELPEX	x
Malta		x
Northern Ireland	SEMO	x
Norway	NordPool Spot	√
Poland	POLPX	√
Portugal	OMIE	√
Romania	OPCOM	√
Slovakia	OKTE	x
Slovenia	Borzen*	x
Spain	OMIE	√
Sweden	NordPool Spot	√
Netherlands	APX-ENDEX	√
	Intraday	15
	No intraday	14

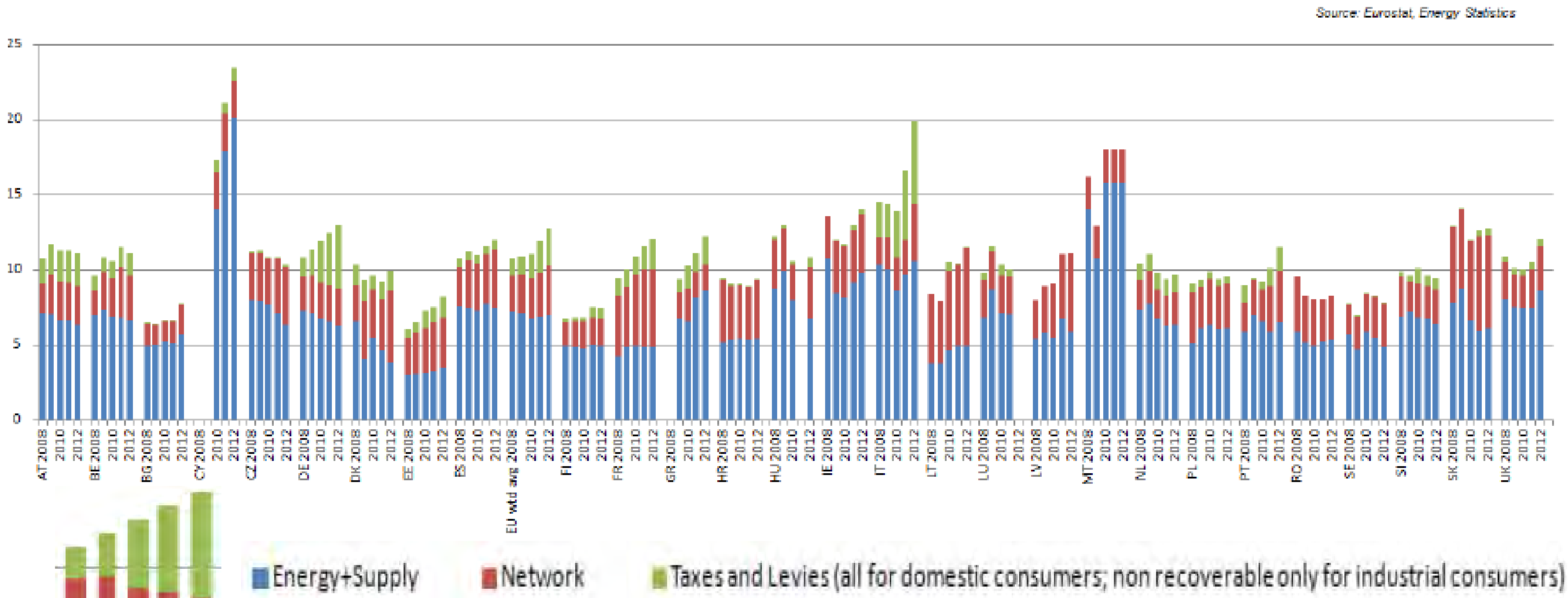
Source: EWEA

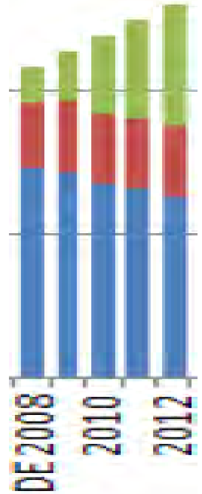
Example Countries and Prediction Intraday Trade



Price Development for industrial Customers

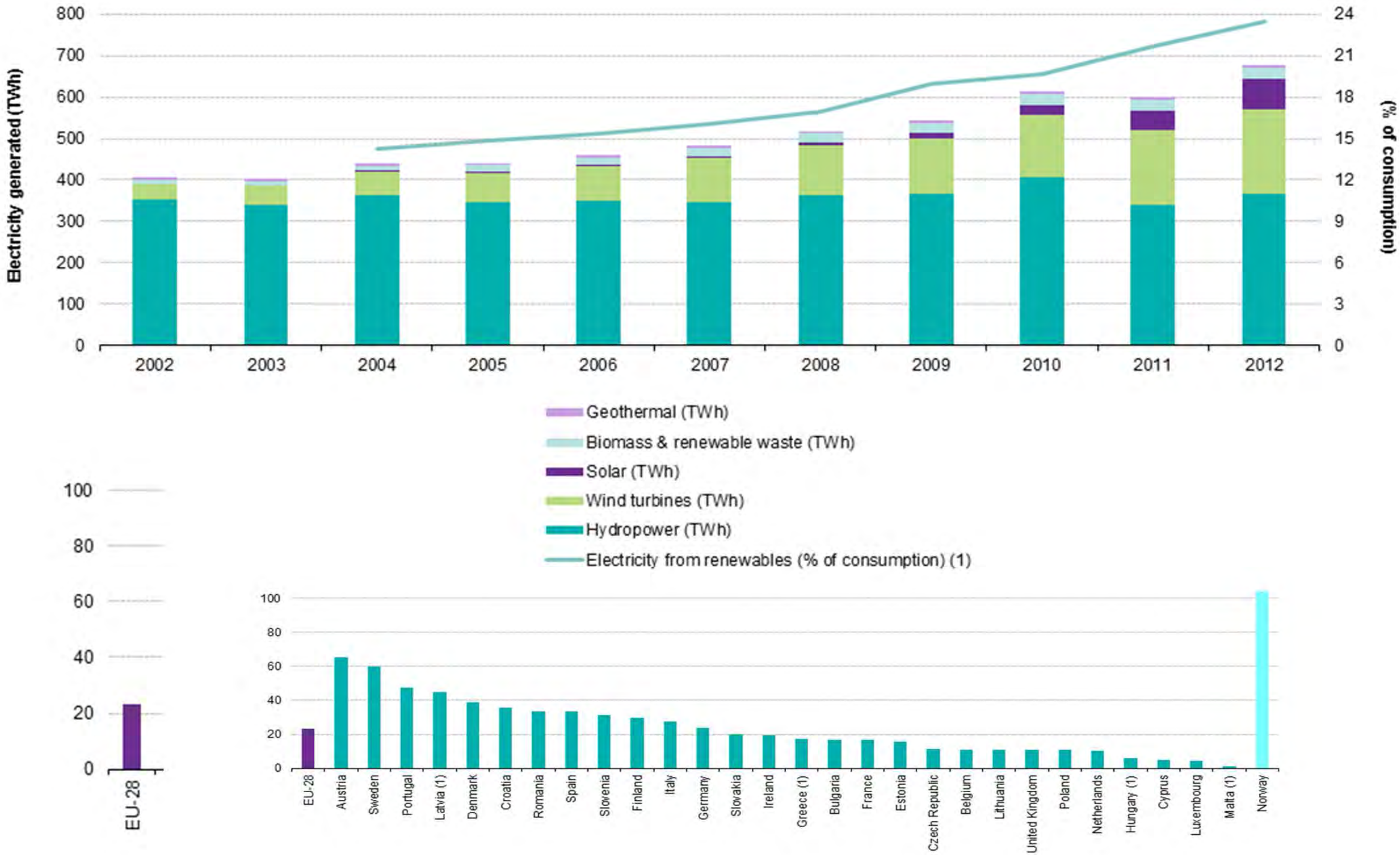
Retail prices for Electricity, industrial consumers, Band IC (500 MWh < Consumption < 2 000 MWh); 2nd half 2008 - 2nd half 2012; centsEuro / kWh





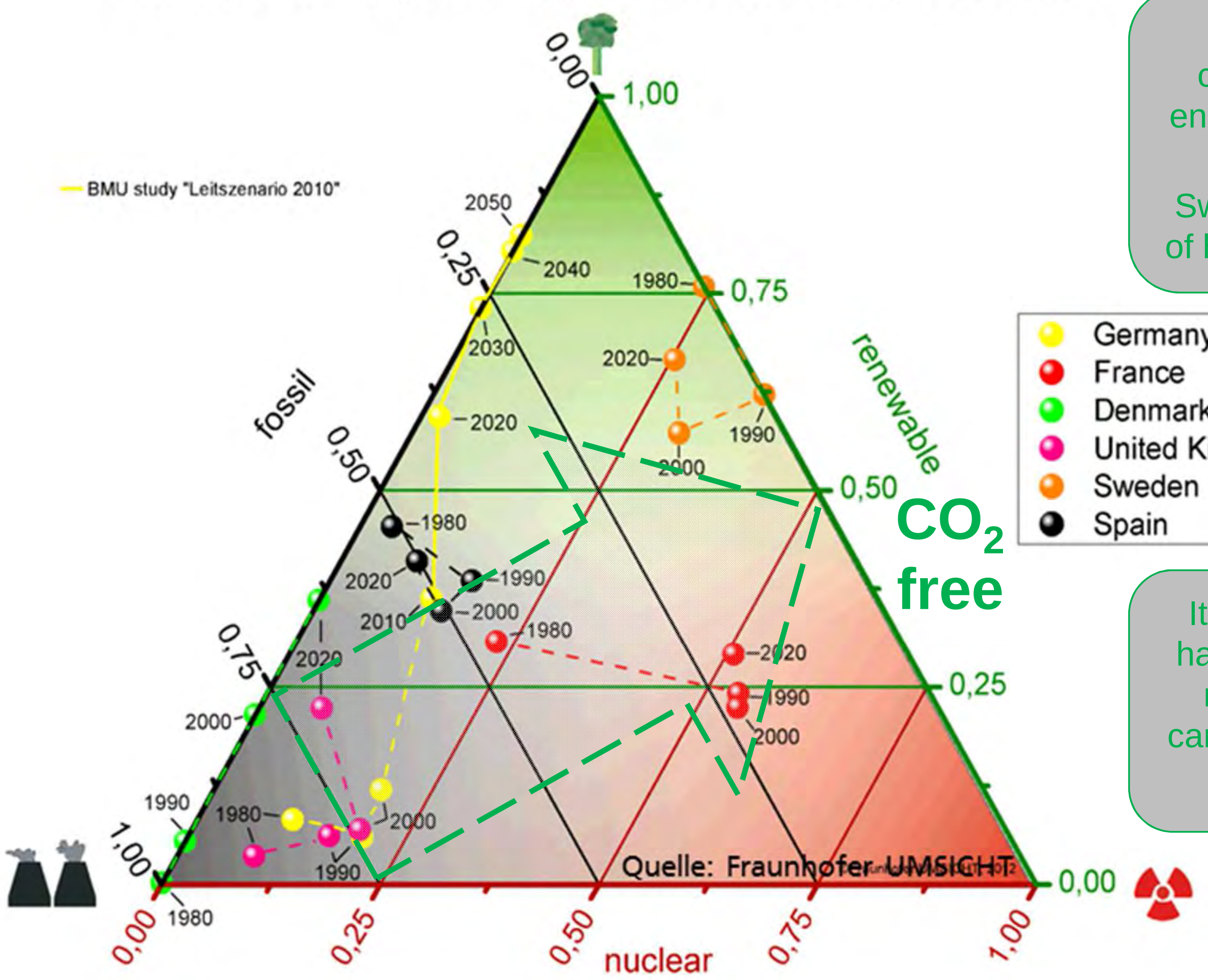
At an extreme in Germany the sales prices for generation dropped, while at the same time the industrial customer prices went up …

Electricity generated from RES in the EU



Ways for EU Countries getting CO2 free

Installed electricity generation power in different european countries

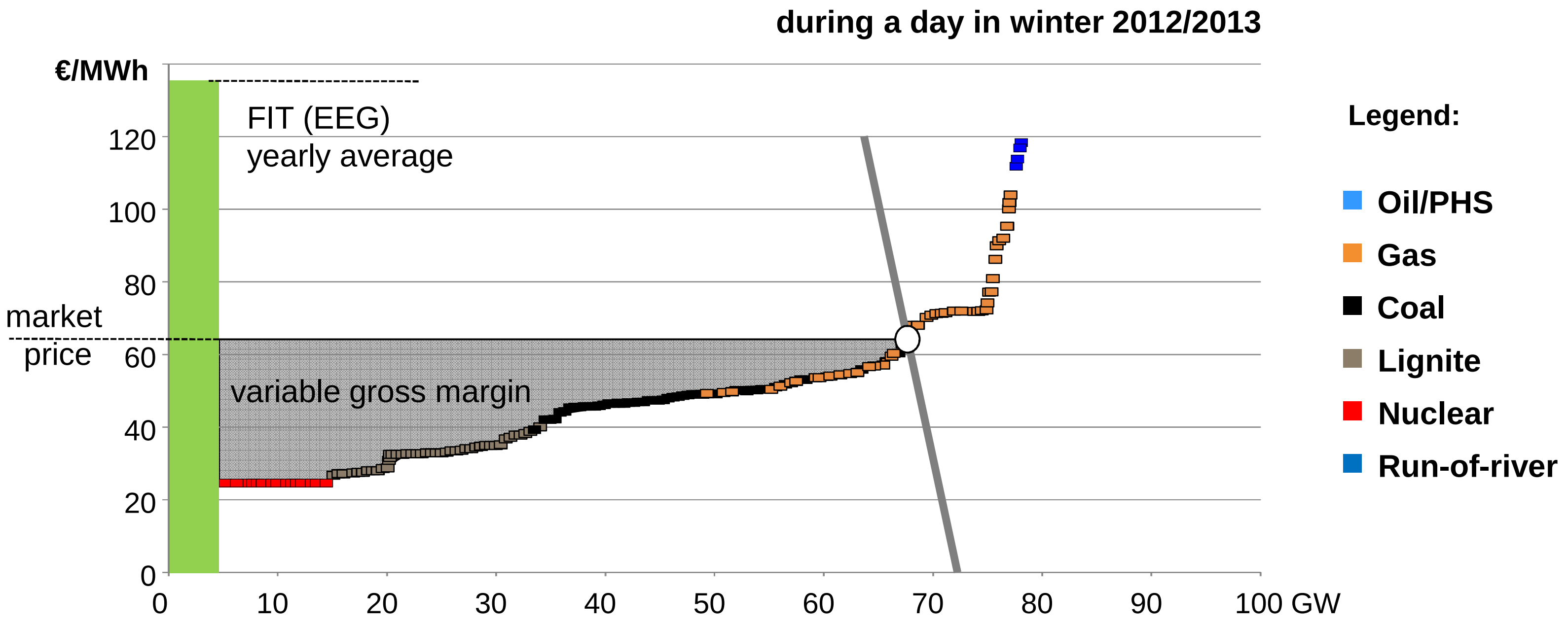


France electricity is competitive low carbon energy due to high nuclear production.

Sweden is green because of hydro and nuclear power

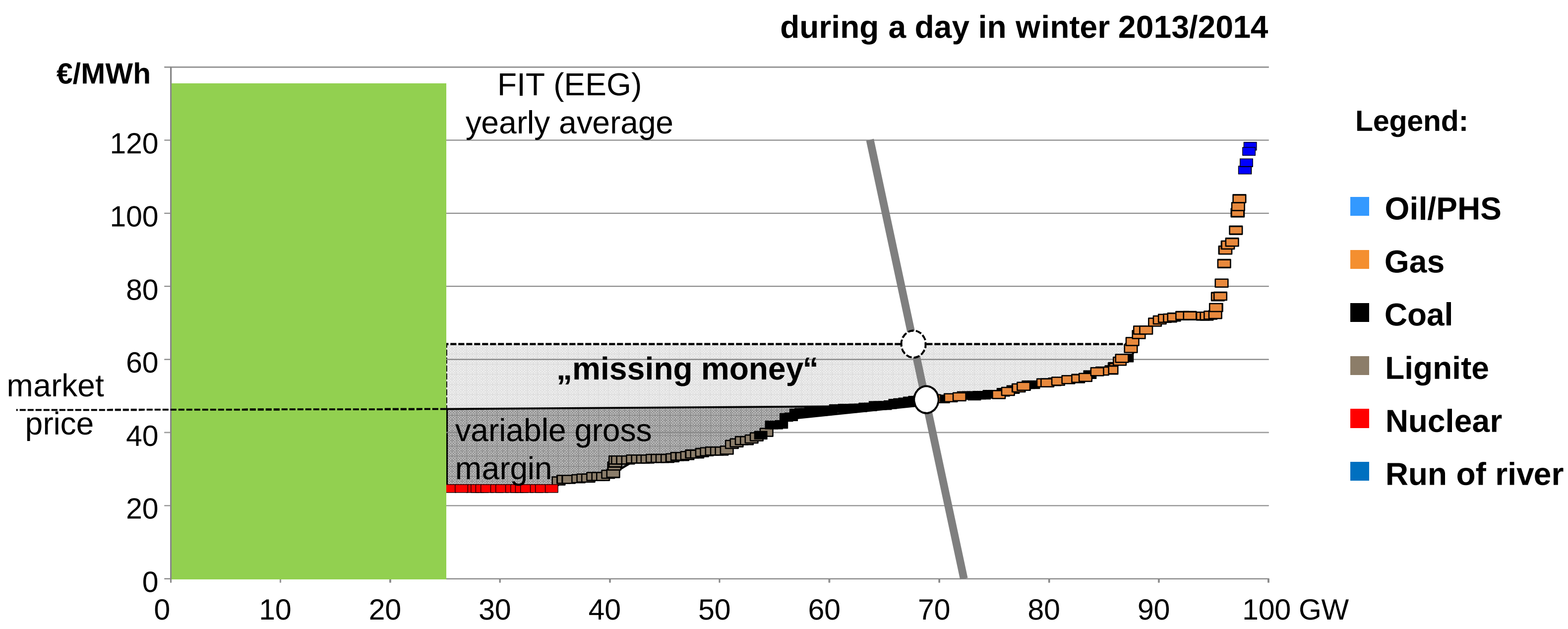
It shows that it is getting hard for Germany to get a nuclear free and a low carbon society at the same time …

Merit Order – Example Situation in Germany



As long as the production of the RES is low the variable gross margin is enough to "make money" in the free market, but the RES production is growing rapidly …

The „Missing Money“ Problem



Reduced margin of conventional PP

- **Less operational hours**
- **Increased number of startups & higher fuel cost**
- **Daily peak covered by PV**
- **CHP plants lose money on electricity sales**
- **Many CCGT plants mothballed**

A consequence is that the most efficient power plants are not running!

With the SGT5-8000H, Siemens has achieved a world record of 60.75 percent, but …
… operates less than 500 h/a

If flexibility is a key requirement for the foreseeable future and power plants are asked to run efficiently at part-load, one can ask:

Is efficiency at part-load of equal importance as at base-load ?

How can investment costs cope with less operating hours?

…but if nothing happens an INVESTMENT-STOP occurs !!!

The Solution can be Capacity Mechanisms

Overview of Capacity Mechanisms

	Capacity payment	*Strategic reserve*	*Capacity markets*		
			Capacity obligation	Capacity auction	Reliability option
Market wide or targeted	Can be both Loads not included	Targeted. Loads may be included	Both, but typically market wide	Both, but typically market wide	Both, but typically market wide
Present or future obligation	May be both	May be both	May be both Incentives for long-term contracts	May be both	Future, specifically designed to strengthen investment incentives
Adequacy calculation	Not required	Required (reserve margin)	Required (reserve margin)	Required (total capacity)	Required (total capacity)
Reliability requirements	Not required	Required	Rules for approval / standard certificates	Rules for approval / standard certificates	Linked to market price (strike price)
Payment	Set by regulator May depend on peak reserve margin	By tender / auction	Market based: Bilateral contracts or certificate trade	Through centralized auction	Through centralized auction
Cost allocation	Fee on LSEs (uplift on energy charges)	System charges	Charge on energy sales by LSEs	Charge on energy sales, peak load or system charges	Charge on consumers (peak load)
Rules for activation	None. Generation sold in wholesale market	Activated on call Only loads bid in market	Expected to bid in wholesale markets	Expected to bid in wholesale markets	Required to bid in wholesale market when price exceeds strike price

Existing Capacity Mechanisms in the EU

1990 — **Denmark**
- Regulated price

2014 — **UK**
- Capacity auctions starting in 2014 for winter 2018/19

2005 — **Ireland**
- Capacity payments

2002 / **2015** — **France**
- Until now strategic reserve
- Capacity options for utilities starting 2015

2007 — **Spain and Portugal**
- Capacity payments

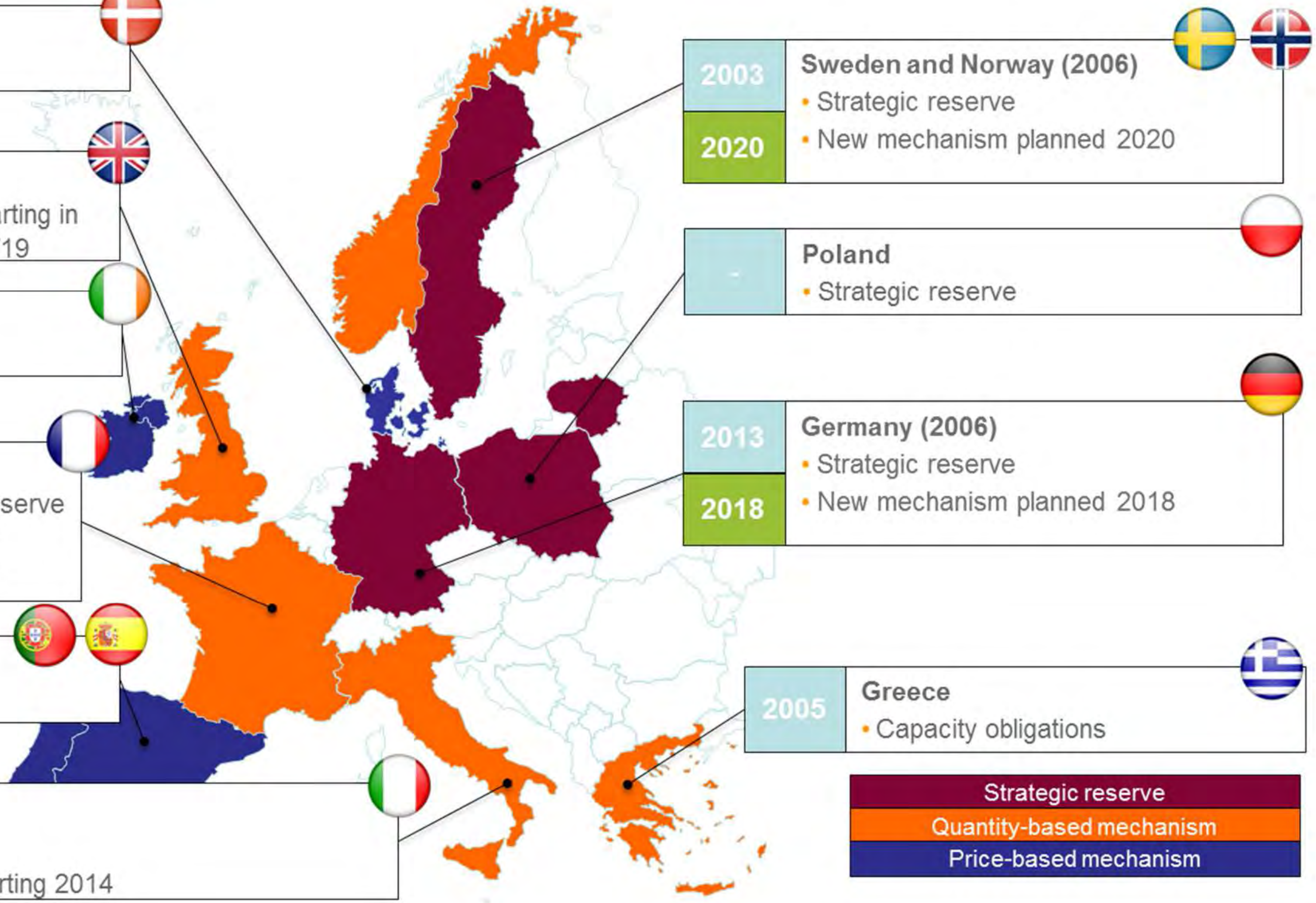
2004 / **2014** — **Italy**
- Capacity payments
- Capacity options starting 2014

2003 / **2020** — **Sweden and Norway (2006)**
- Strategic reserve
- New mechanism planned 2020

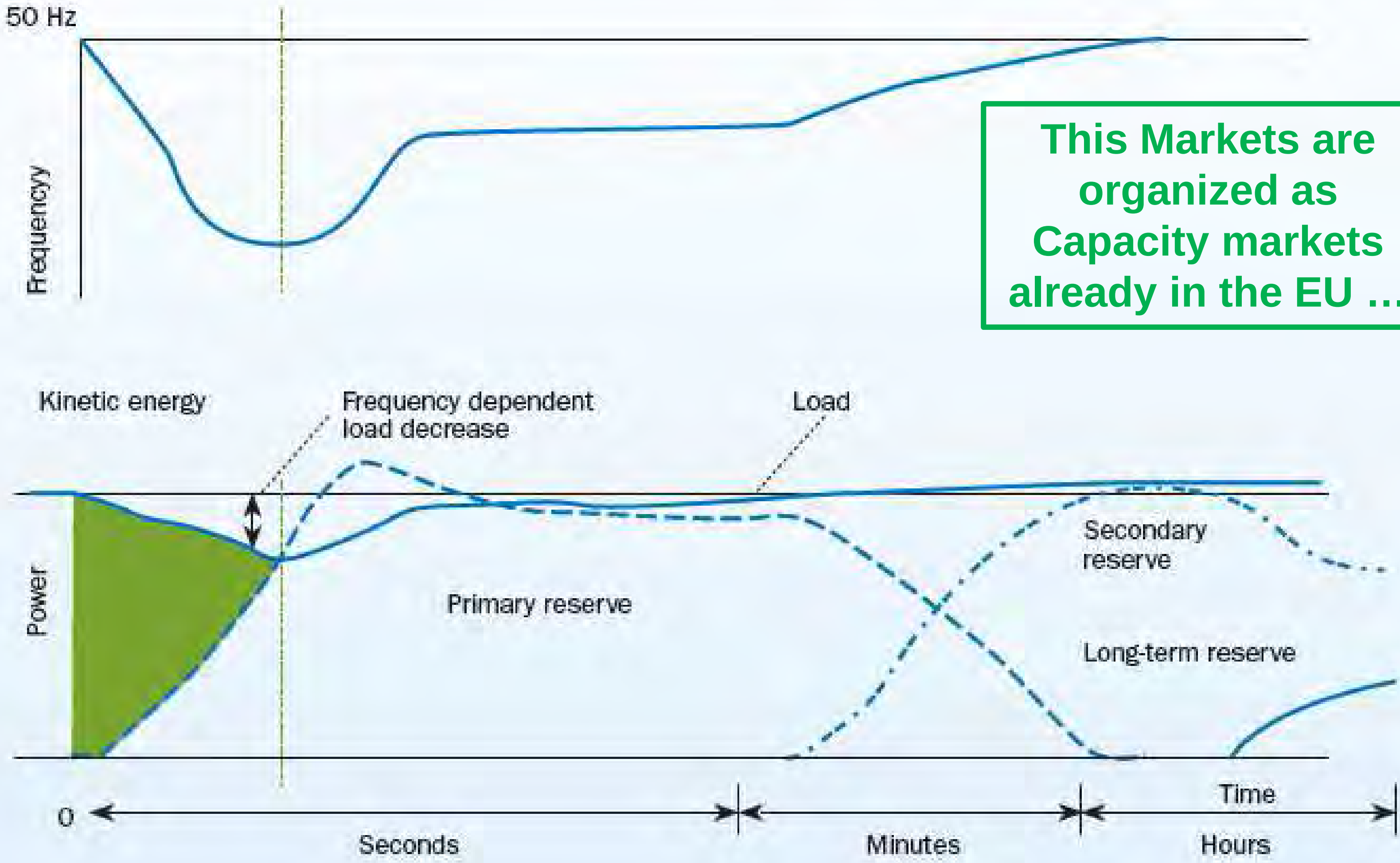
- — **Poland**
- Strategic reserve

2013 / **2018** — **Germany (2006)**
- Strategic reserve
- New mechanism planned 2018

2005 — **Greece**
- Capacity obligations



Additional Markets: Balancing Services

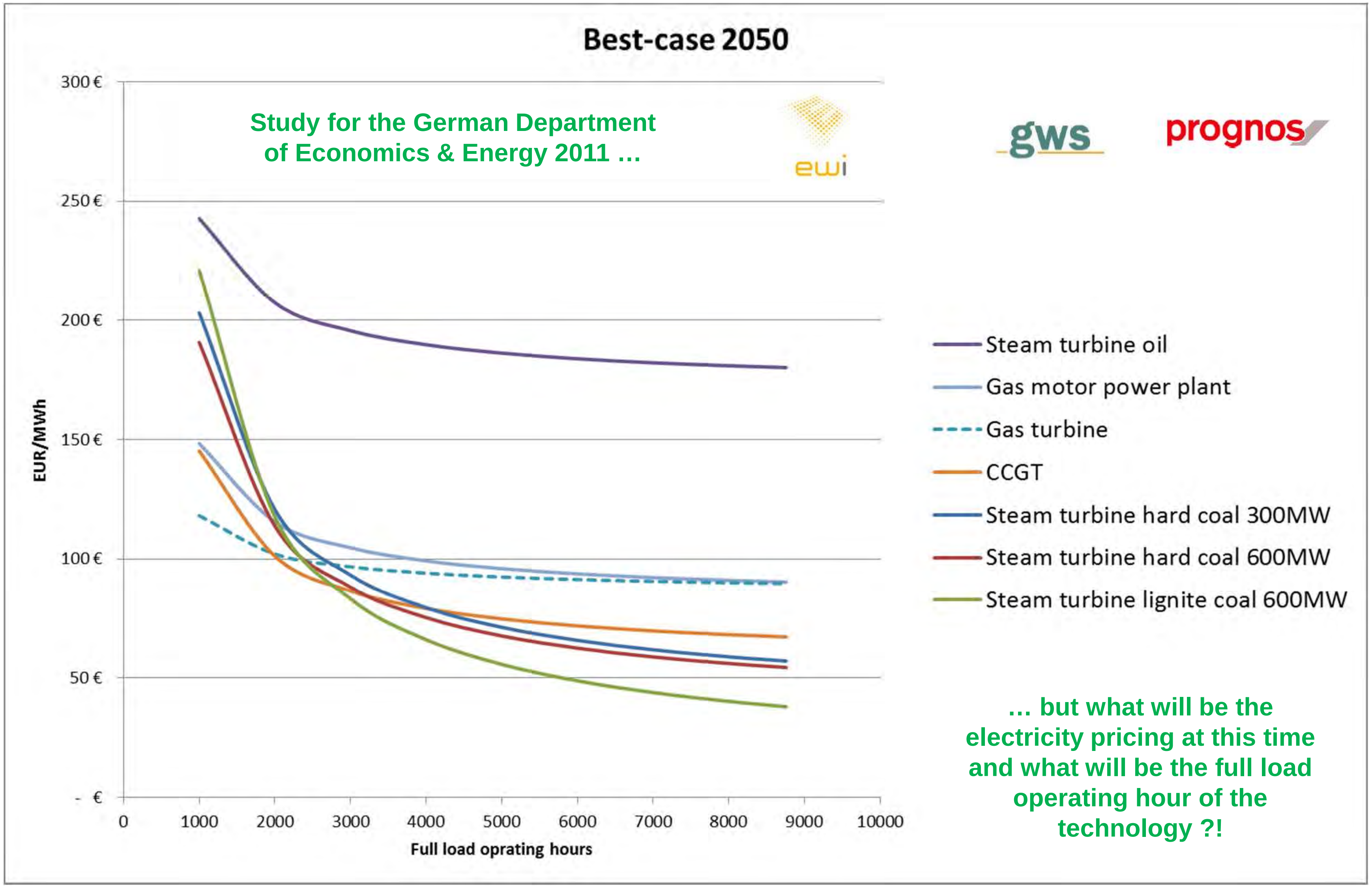


This Markets are organized as Capacity markets already in the EU …

… but this will be a separate topic and can this Markets can not solve the capacity problem

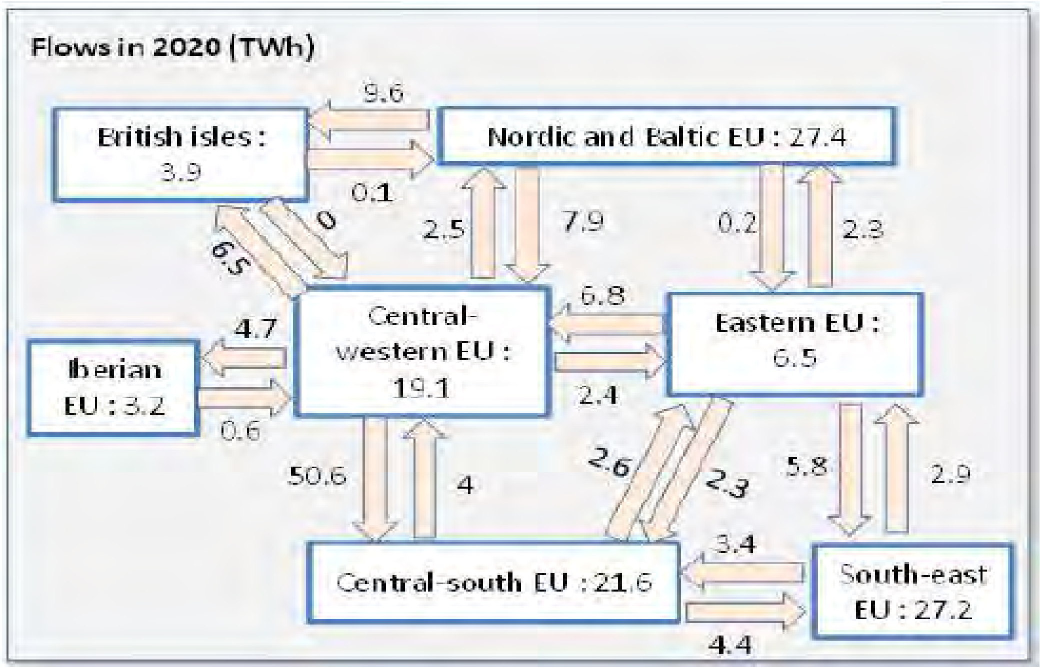
Sources: ETSO (8) and EWEA (9)

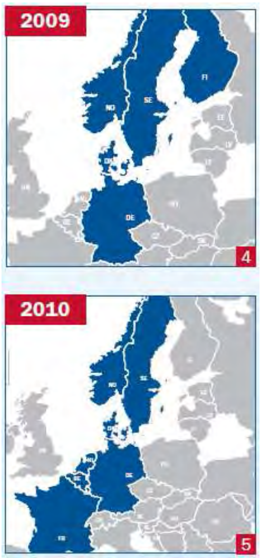
Future full Operating Cost – Power Plants by Type

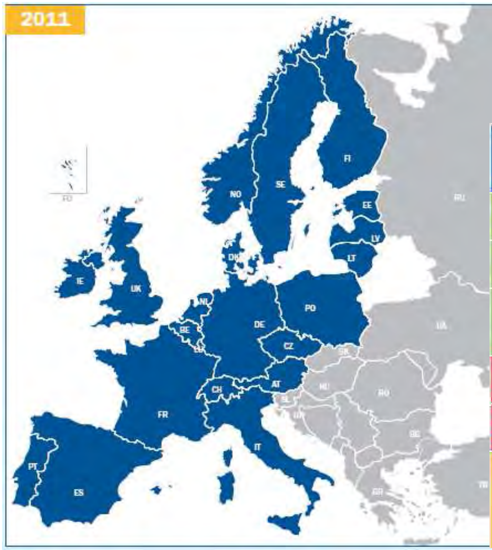


One additional Solution: Market Coupling in the EU

The coupling of electricity markets leads to a better utilization of the energy sources and lower electricity prices, because its becomes an ideal market

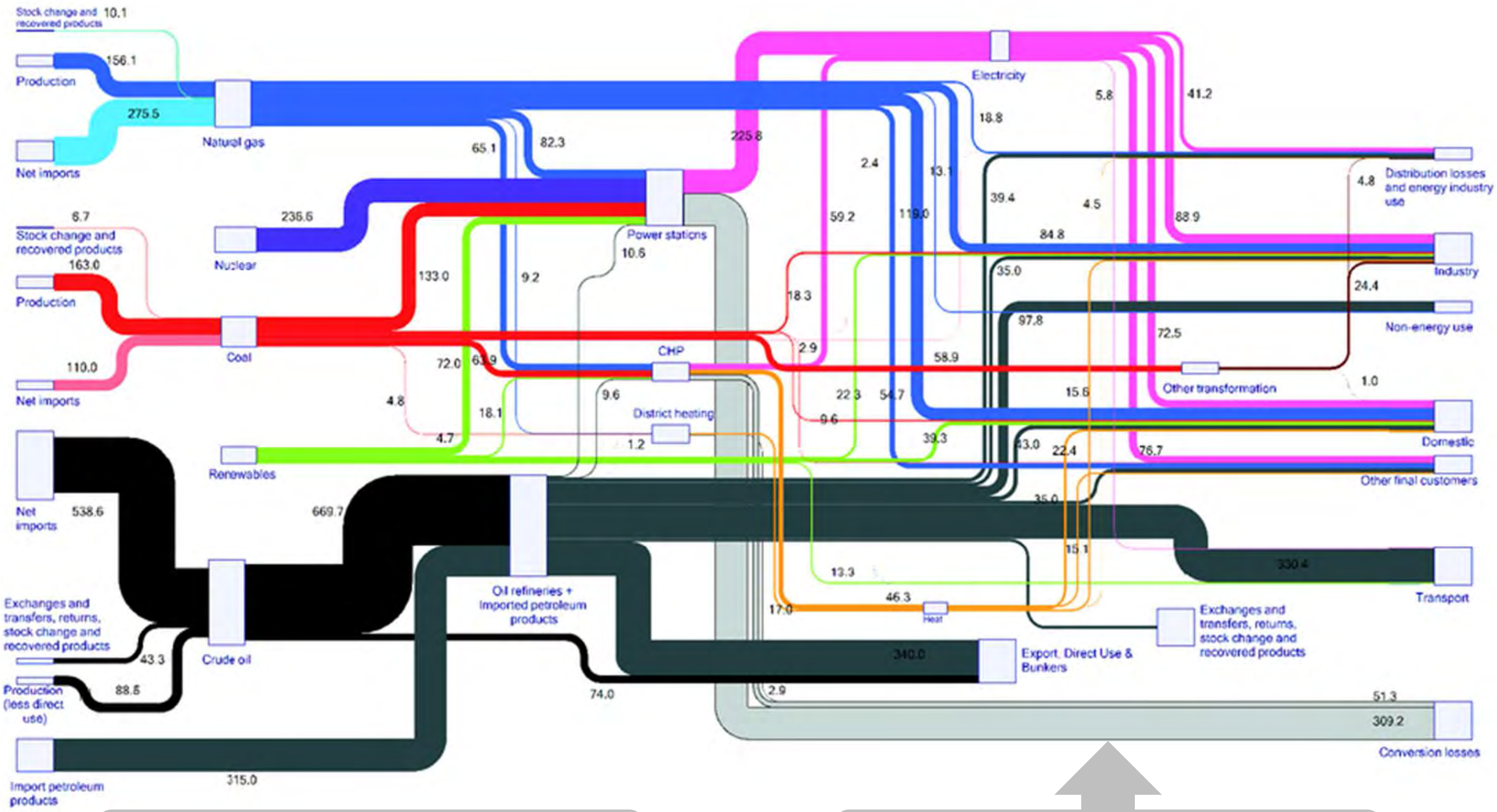






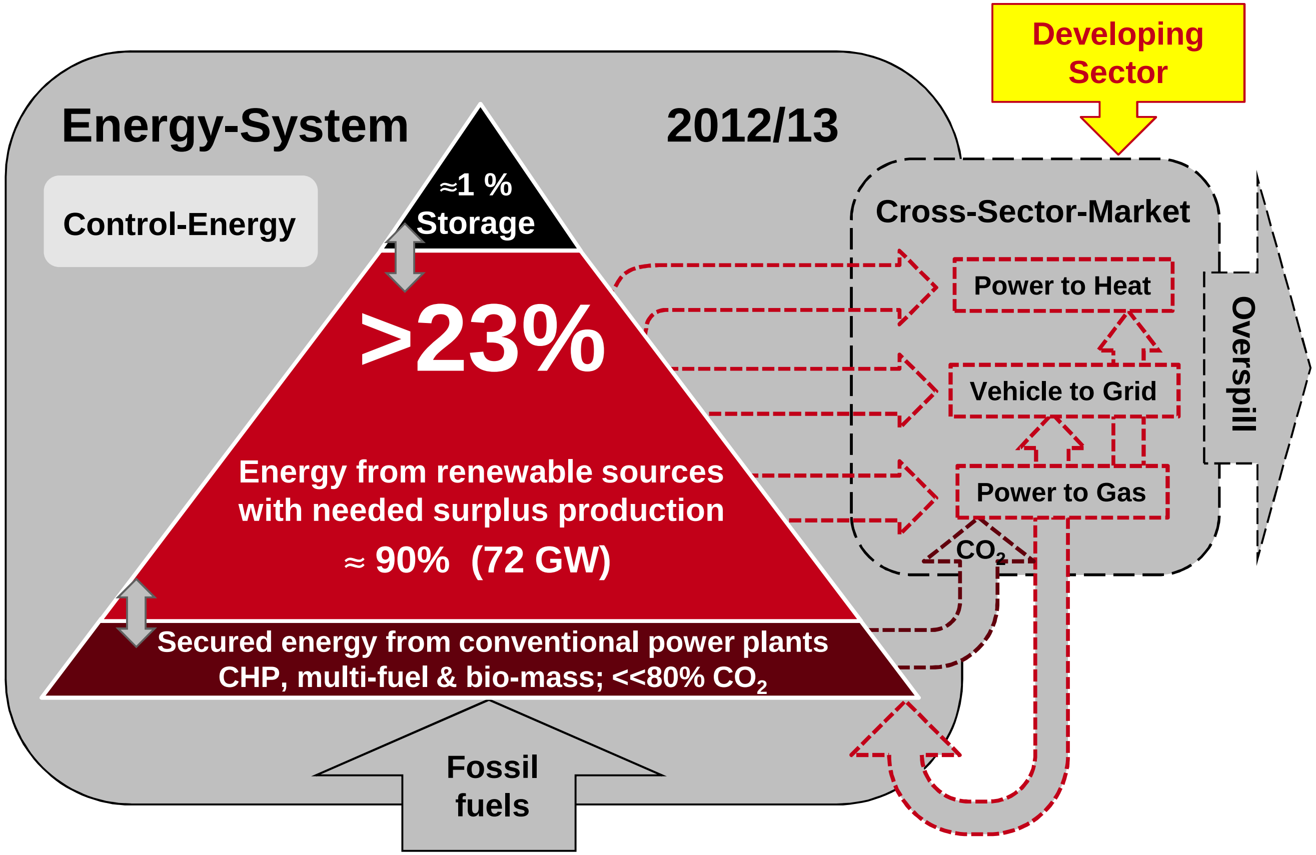
	Market Integration mechanism	Region /countries
1	Price Coupling	2000 - Nordic Market Integration: Norway, Sweden, Finland and Denmark
2		2006 - Trilateral Market Coupling: France, Belgium and The Netherlands
3		2010 - Market Coupling Mechanism Central West Europe (CWE): Germany, Belgium, France, Luxembourg, Netherlands
4	Tight Volume Coupling	2009 - European Market Coupling Company (EMCC): Nordic region and Germany
5		2010 - CWE and Nordic region
6	Price Coupling of Regions	2011* CWE, Nordic and SWE regions. (Portugal, Spain, Italy, Belgium, the Netherlands, Great Britain, France, Germany, Austria, Switzerland, Denmark, Norway, Sweden, Finland and the Baltic, including the price coupling on SwePol-link to Poland)

Primary Energy in the EU and Usage of Energy



European Energy flow in 2010 in Mtoe (million tonnes oil equivalent)

Energy conversion losses can be minimized using more CHP in the EU



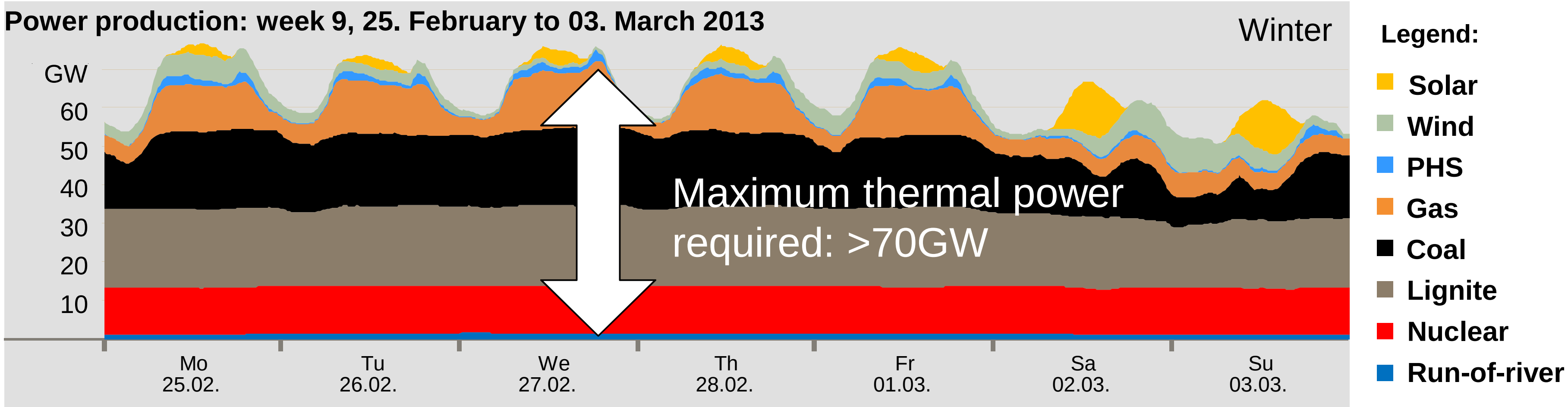
state 2012/13

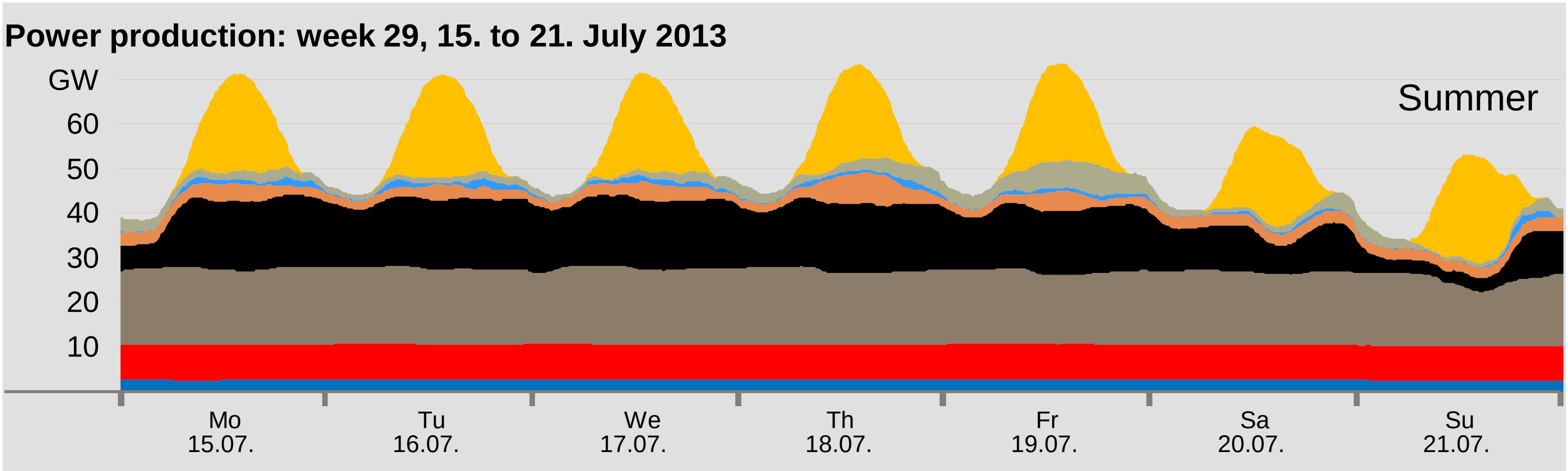
87 GW max. load demand
194 GW available capacity
106 GW conventional pp
72 GW renewables
7 GW storage
3 GW cross- sector
6 GW biomass

- Already today, the feed in from RES in Germany may for a short time and locally lead to a 100% coverage of the load.
- Nevertheless a backup is always required.

Max. Peak load 87 GW, 65 GW normal Max.

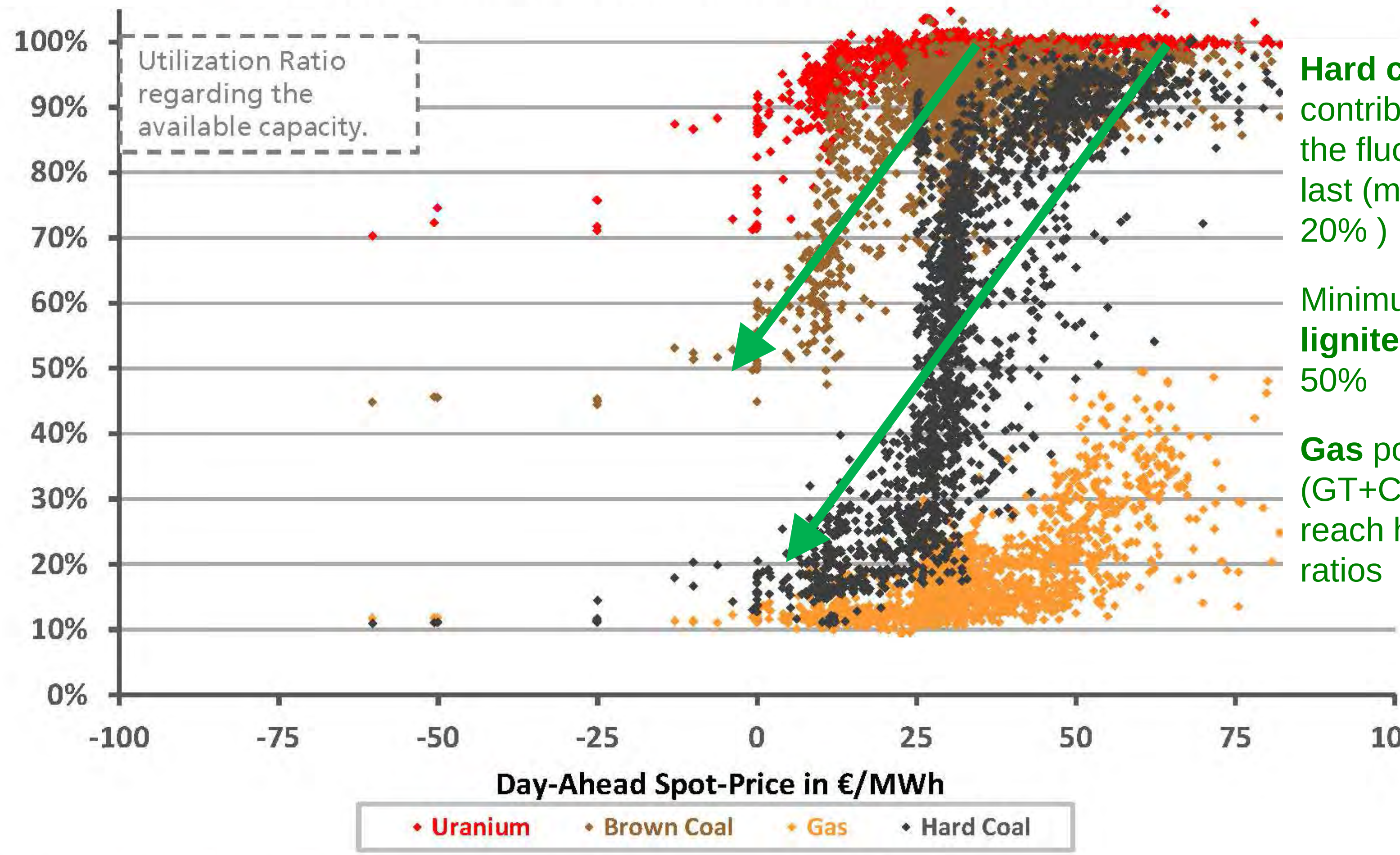
Situation in Germany





- **The share of renewable energy is continuously increasing**
- **Peak power demand will remain high – fossil plants still will be needed**
- **The electricity market has changed dramatically**

Plant System Utilization over Day-Ahead Prices (Germany)



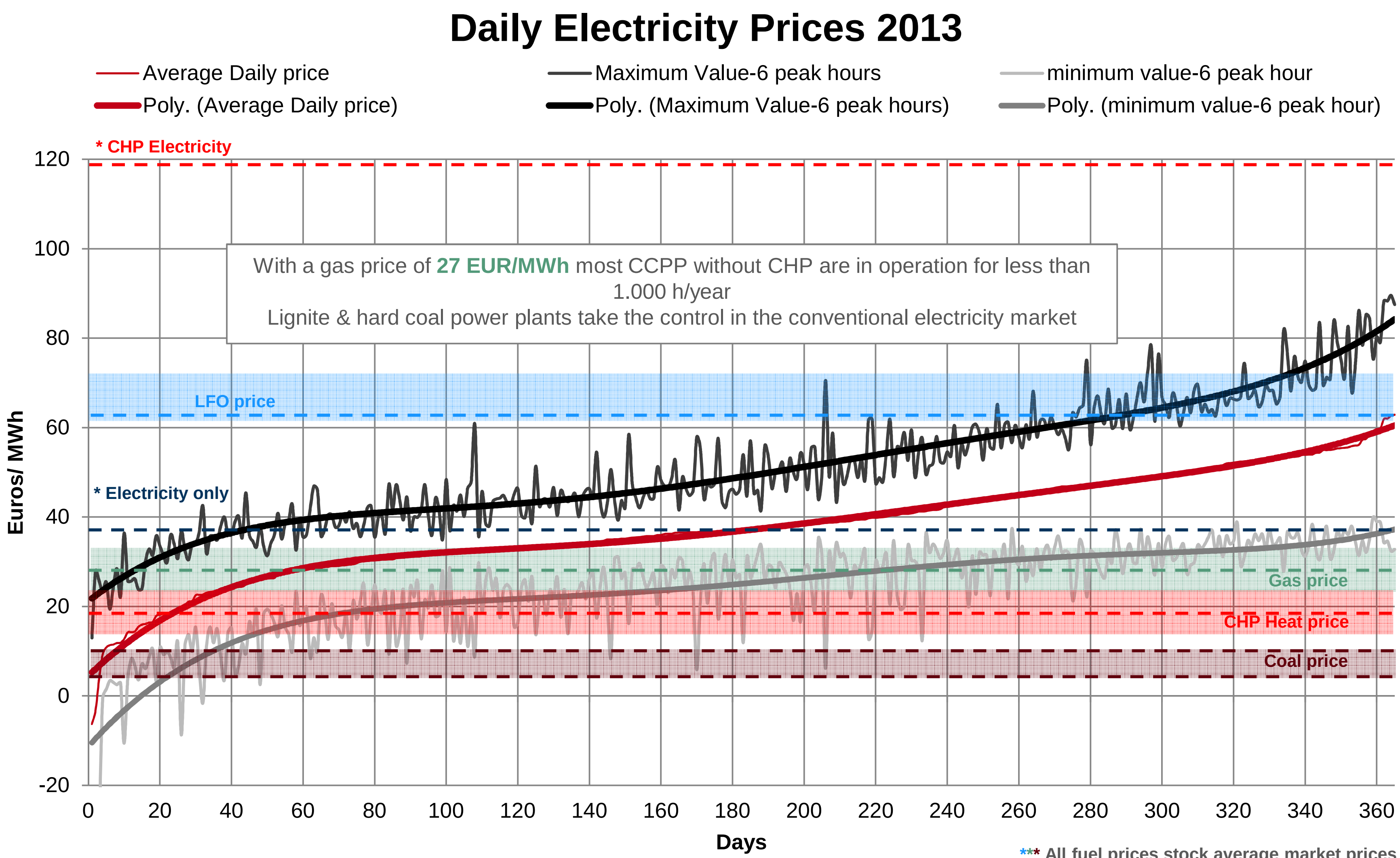
Hard coal power plants contribute in covering the fluctuating residual last (minimum load: 20%)

Minimum load for most **lignite** power plants: 50%

Gas power plants (GT+CCGTs) do not reach high utilisation ratios

Source: Fraunhofer ISE,
Johannes Mayer, Bruno Burger, 2014

Energy Pricing in Europe (Example PHELIX)

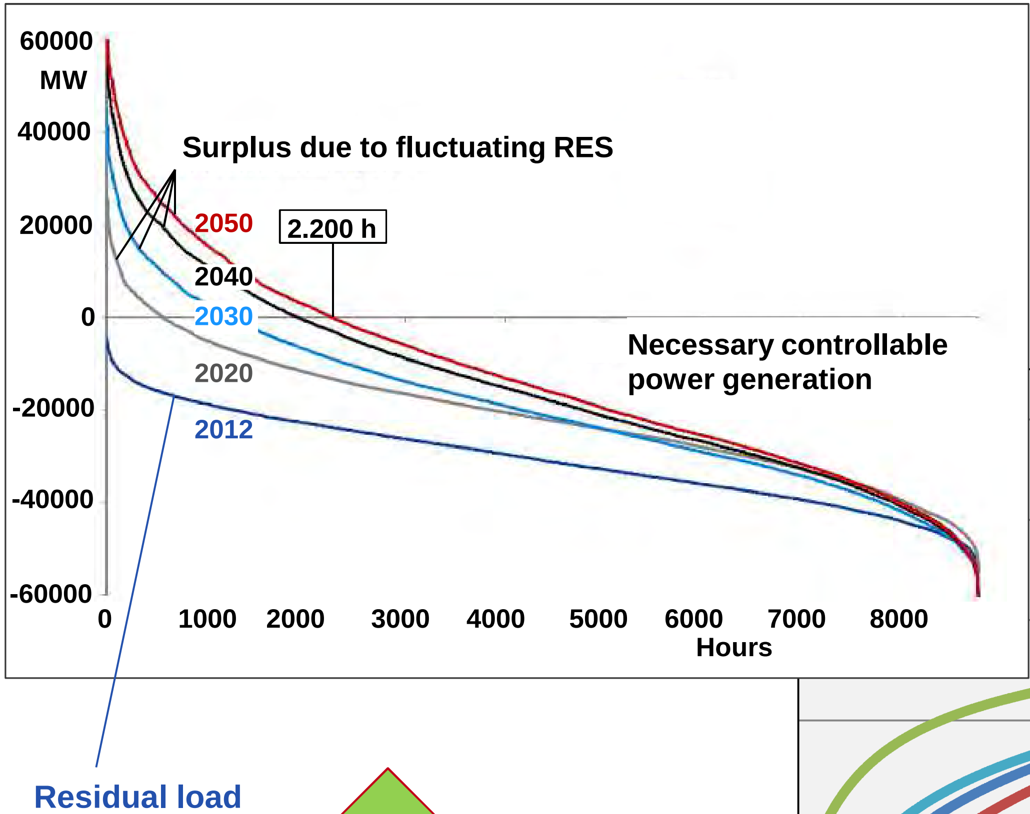


*** All fuel prices stock average market prices

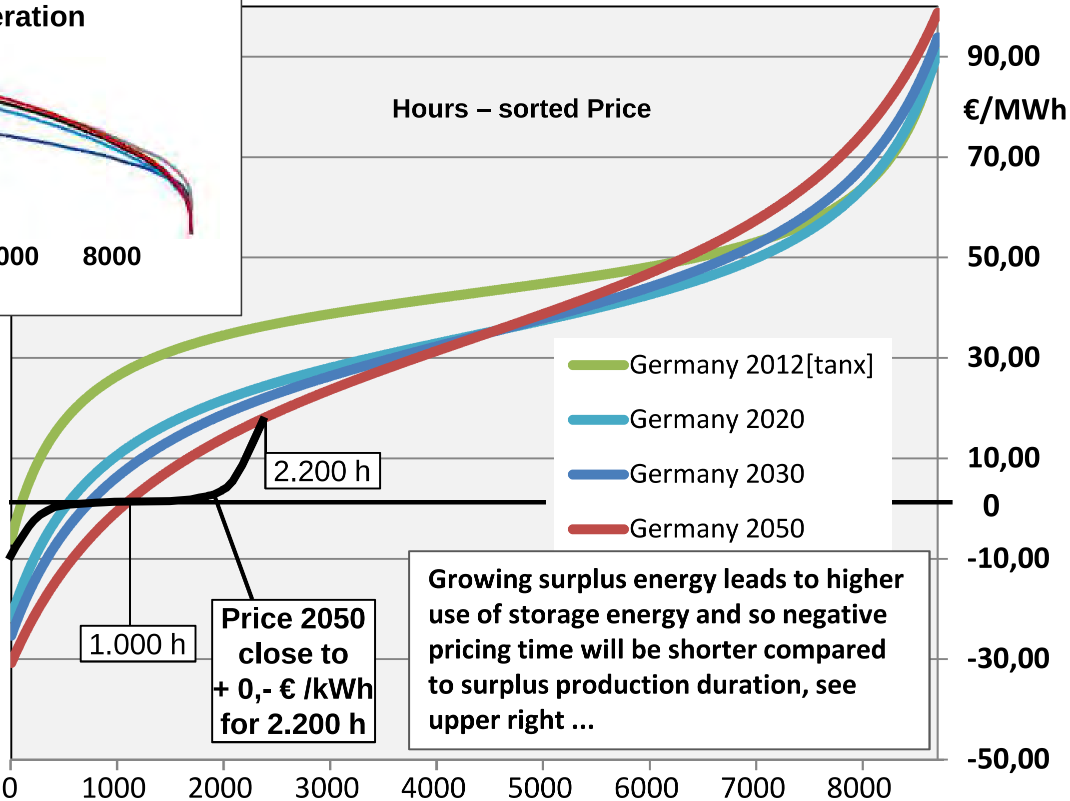
* Electricity average price 2013 ≈ 37,- EUR/MWh

* CHP Electricity loss MW_{el}/MW_{th} ≈ 0,15 → CHP Electricity equivalent price is ≈ 120,- EUR/MWh

Energy only Electricity Price Development

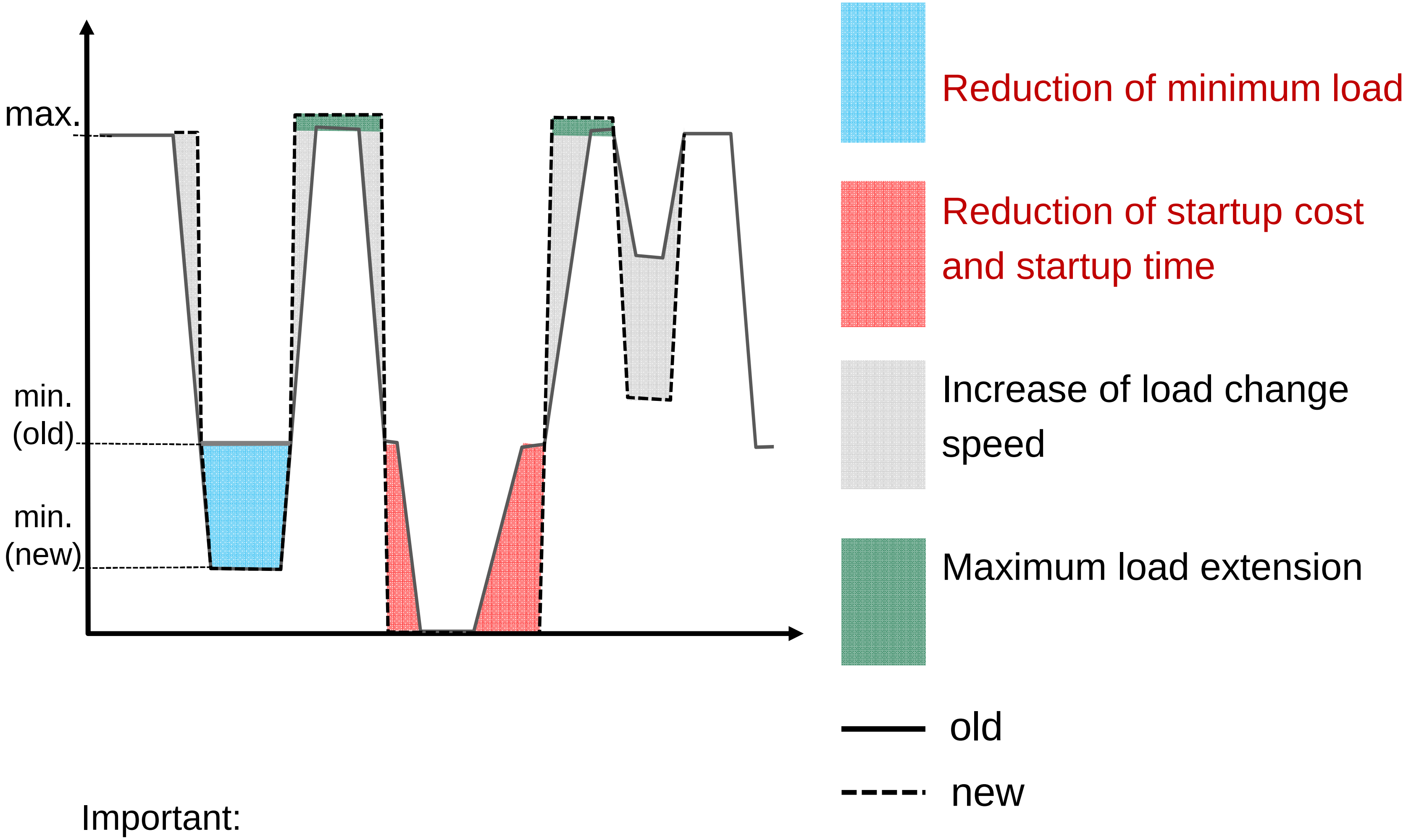


Development of electricity pricing



Development of Residual Load

This needs Flexibility – New or retrofitted Power Plants



Important:

- Maintain maximum possible part load efficiency
- Maintain highest possible operational hours

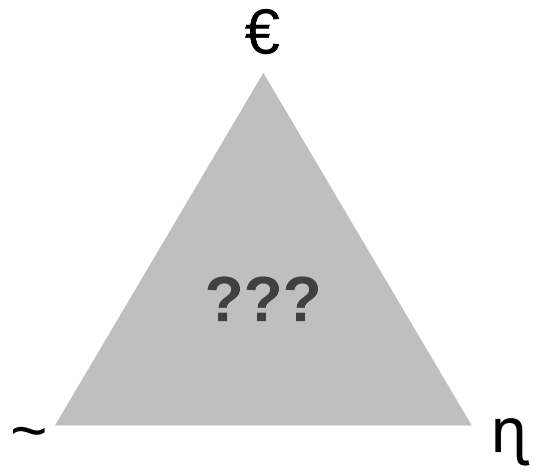
Flexibility
> Characteristics for coal power plants

Parameters / characteristics	Currently operating PP fleet (PPs erected in the 20. century) 1)	Current BAT (PPs erected in the 21 century) 1)	Targets
Minimum load for continuous operation [%]	**15-20** for hard coal **>50** for lignite 4)	**15-20** for hard coal 2) **35-40** for lignite 3) 4)	**~15** (considering alternative & low carbon solid support fuels and their blends)
Ramping rate [%/min]	**2-3**	**5**	**~10**
Frequent start-up and shut down ability (cold/warm/hot)	Specific nr. of start-ups /shut downs foreseen per year (limited to few cold start-ups)	Possible daily start-up for hard coal PP (usually hot/warm daily, cold over the weekend)	Possible daily variations between 15-100% to avoid daily start ups
Emissions and plant efficiency MUST BE KEPT DURING PART-LOAD	Optimum design for high efficiency and lowest emissions at full load	Optimum design for high efficiency and lowest emissions at full load and some low loads	Optimum design for high efficiency and lowest emissions (IED) for load following operation

1) Best possible known, and documented
2) Usual min load operation for recent new built plants still is only around 30-40% due to lowest marginal cost of all hard coal units
3) Oil/gas may be required as supporting fuel for lignite
4) Plants are existing in Germany or are being retrofitted with dry lignite firing to operate in the range of 20%-30% load

Flexibility > importance and compromise

- Security of supply
  - Residual load
  - Total load in a cloudy windless winter day
- Stability of grid system
  - Balancing energy for frequency control
  - Reactive power supply for voltage support
- Secure quality of electric energy
  - Damping of frequency gradients via inertia of rotating masses → min load operation
- MCP for day-ahead market and balancing energy due to energy stock exchange (merit order)
- Flexible PPs need to be:
  - **continuous load following within the range of 10% to 100%,**
  - **load changing rates of up to 10% per minute**
  - **partial load efficiency ≥ 85% of full load efficiency**
  - design optimized for **2.000-4.000 annual, full load equivalent, operational hours** with 100.000 h lifetime (instead of 8.000 hours with 250.000 h lifetime typically used for existing power plants)



Flexibility increase options > Overview of measures

Turbine

- GT Repowering
- Reduction of auxiliary power

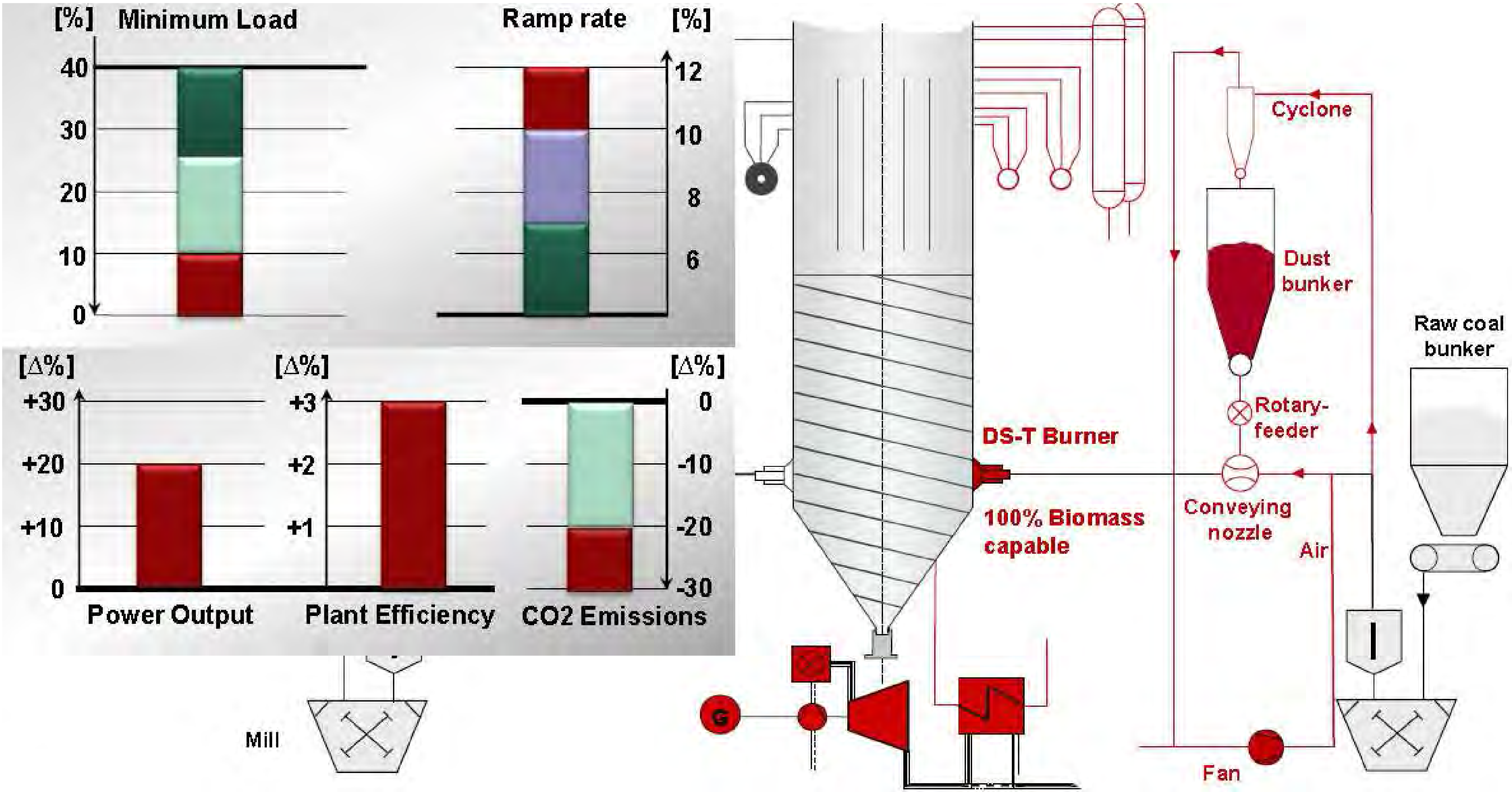
Boiler

- Optimization of steam cycle layout:
  - Increased number of lines, headers, separators
  - Thinner wall components
- Continuous component monitoring
- Reduced lifetime design
- Auxiliary GT (gas topping)
- Incorporation of energy and thermal on-site storage
- Combined / Indirect Firing

Burner

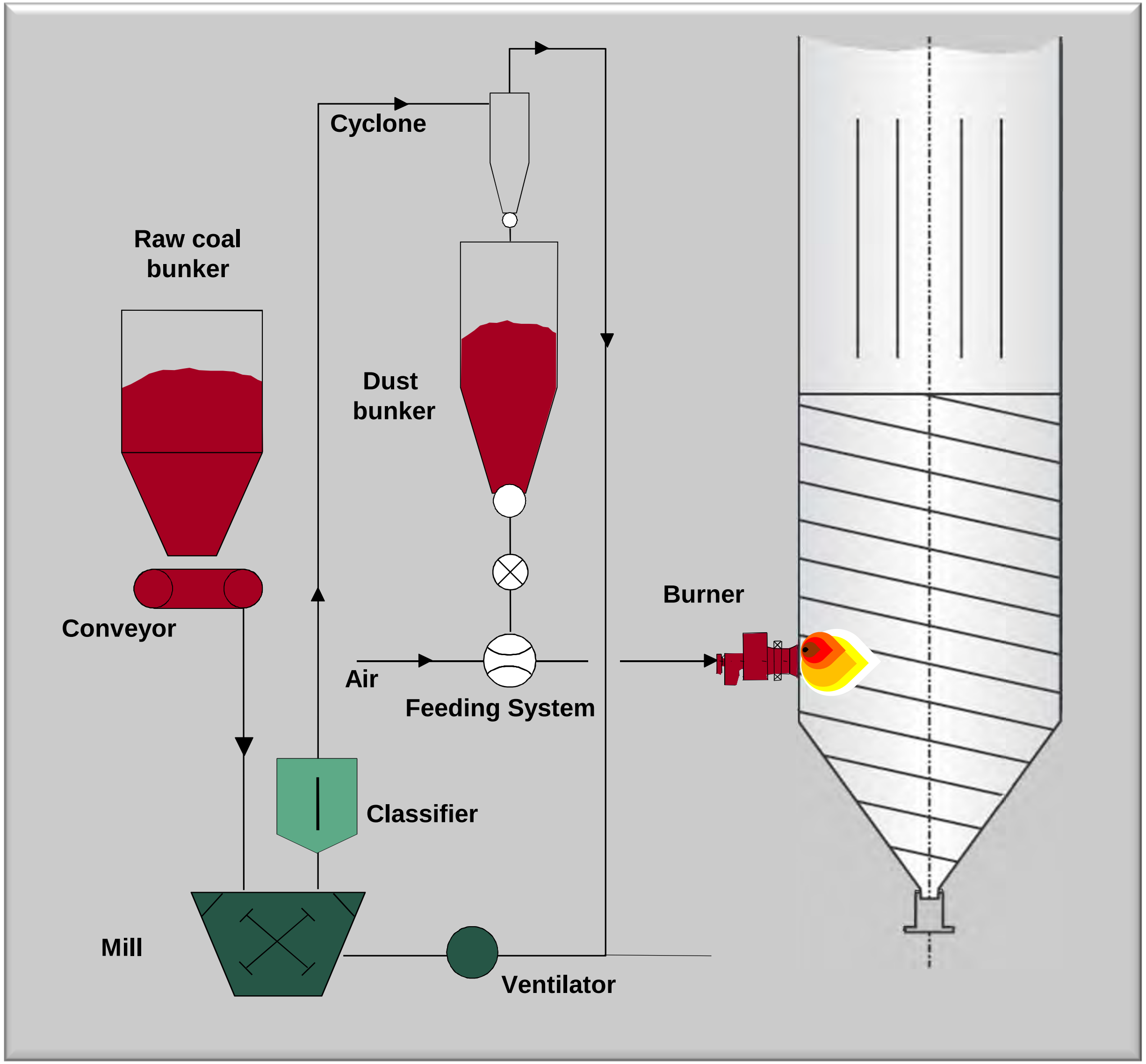
- DS-T ® and DS ® burner optimized for operation at lower loads
- Alternative ignition systems
  - Heated burner nozzle
  - AC plasma

Flexibility > Boiler



- Increased number of lines, headers, separators; thinner wall components
- Auxiliary GT (gas topping)
- Combined / Indirect Firing

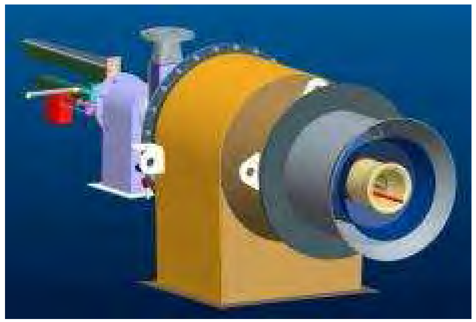
Flexibility increase options > Firing system



Indirect Firing (IF)

- Min. Load <10 %
- 95% less start-up fuel
- Excess Air <12 %
- Milling in optimal operation range

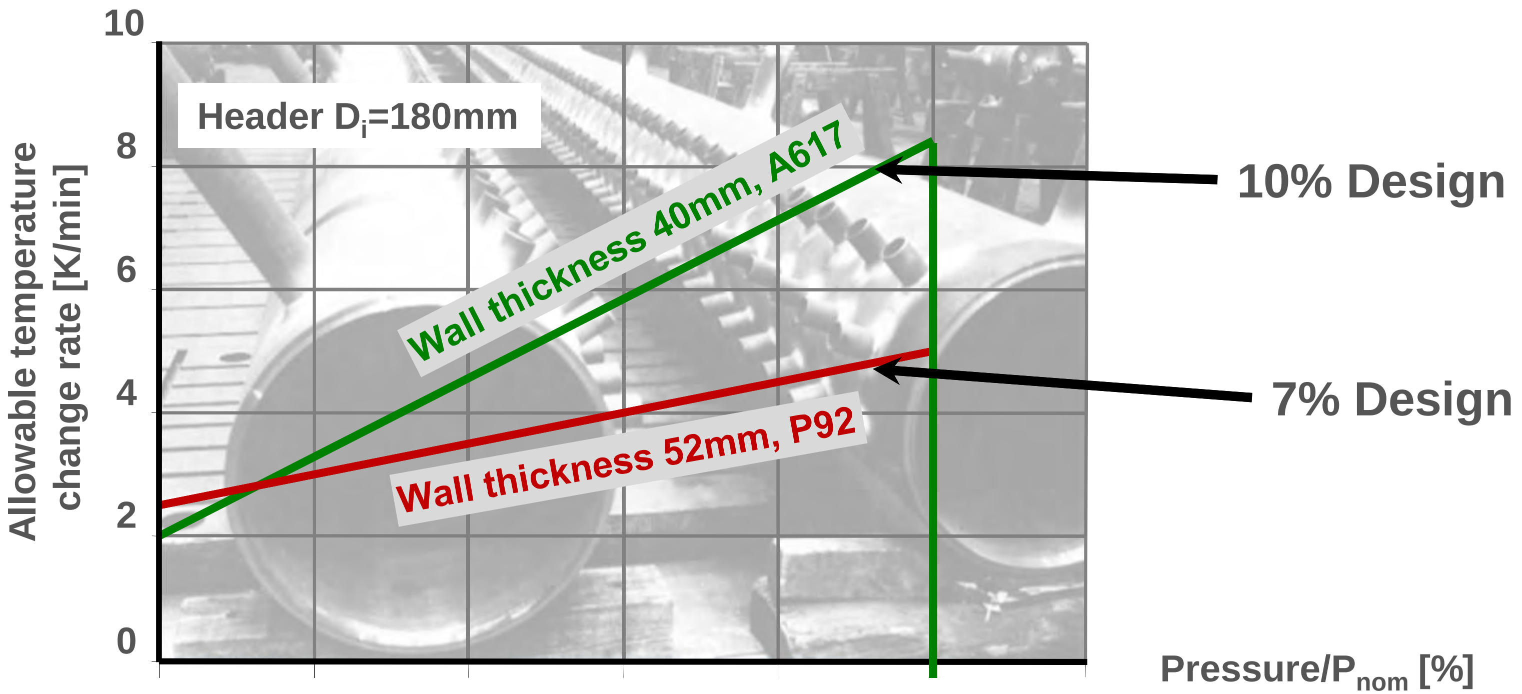
DS-T Brenner®
DS-T burner



Flexibility increase options > Boiler

Reduced wall thickness and higher number of headers

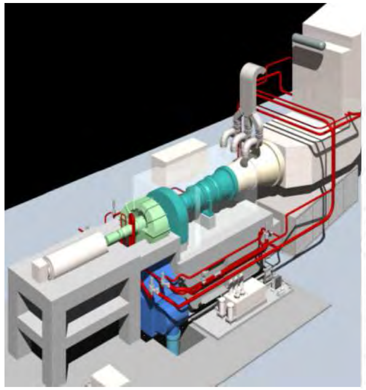
- 2 line to 4 line design leads to reduction with factor of 0,707 of header wall thickness
- increase the number of separators/ headers
- use of superior materials, e.g. A617 instead of P92

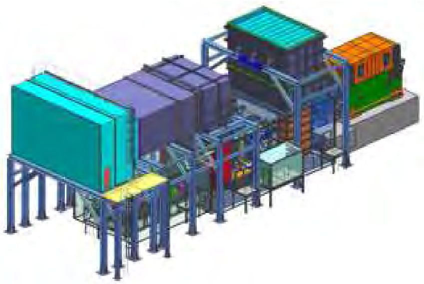


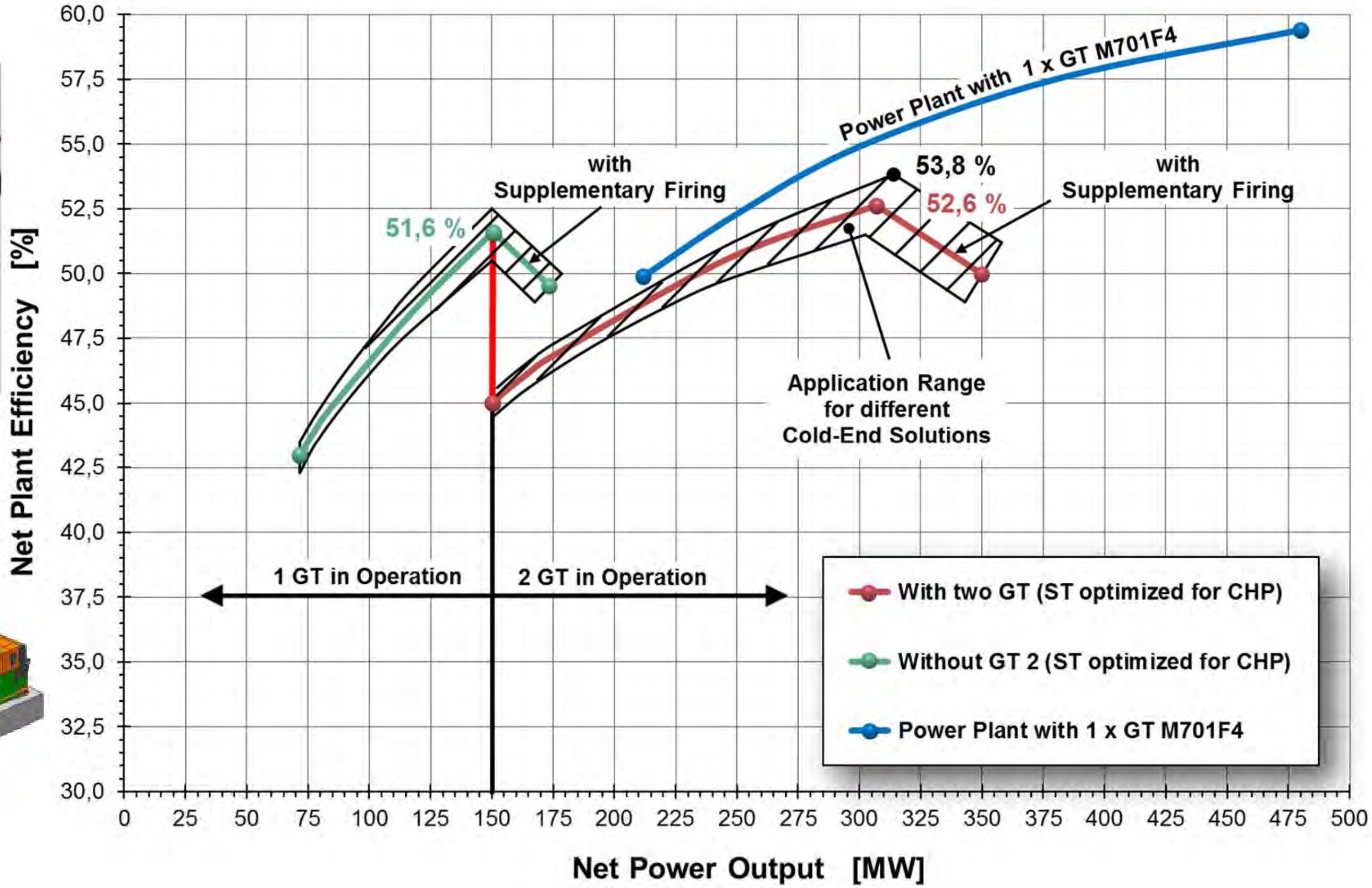
Possibility ➲ 10 % load change

Flexibility with Combined Cycle by Concepts

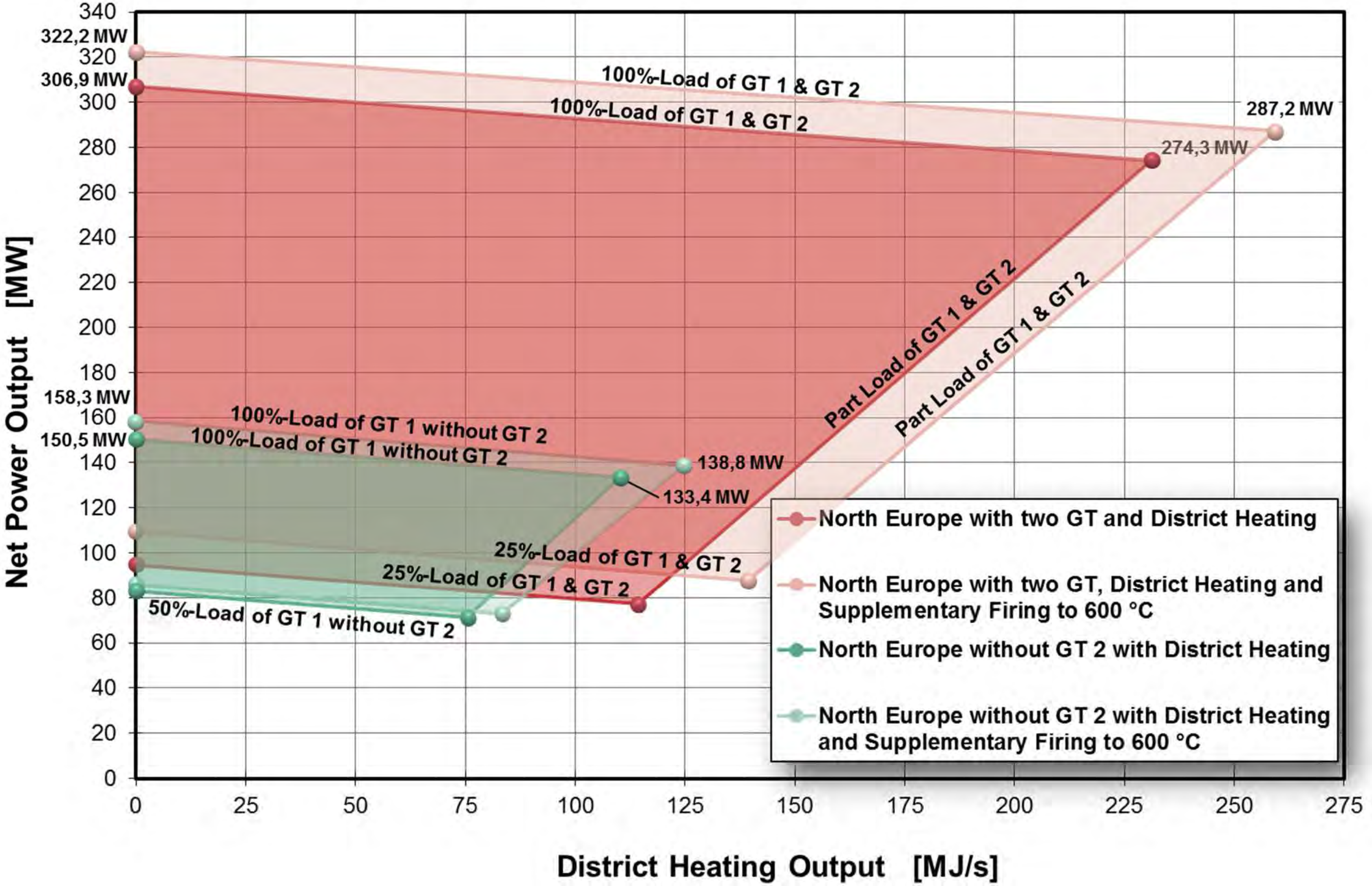
The use of more than one GT lead to more Flexibility in CCGT Operation



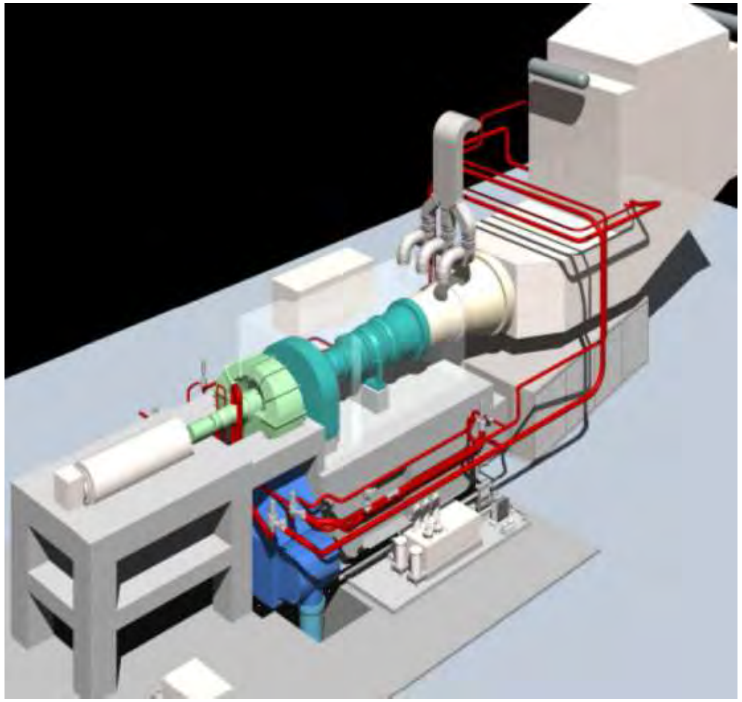


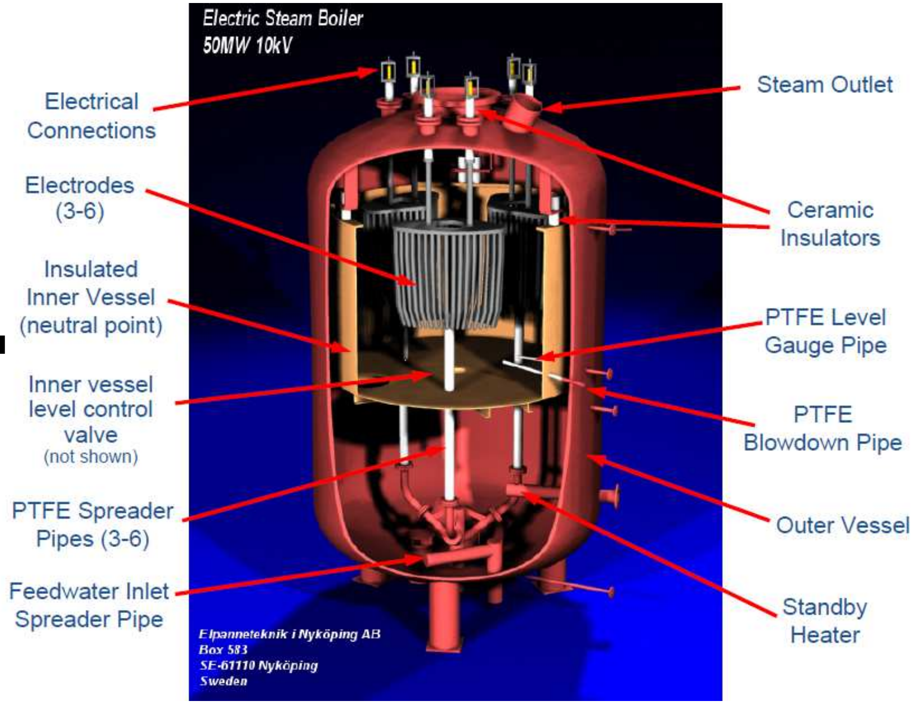


Load Diagram for multi Shaft CCGT



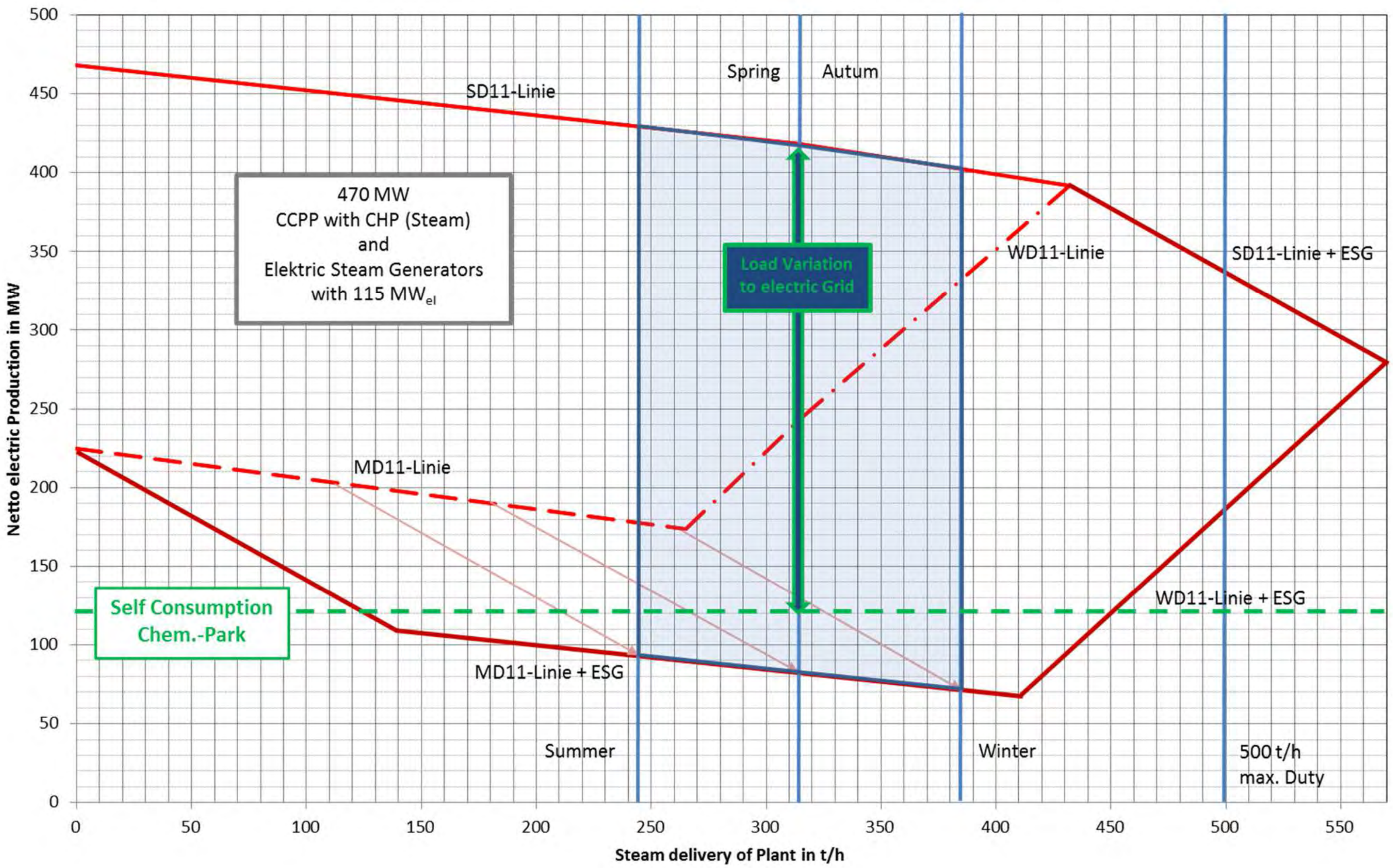
Further Flexibility with CCGT and electric Boiler



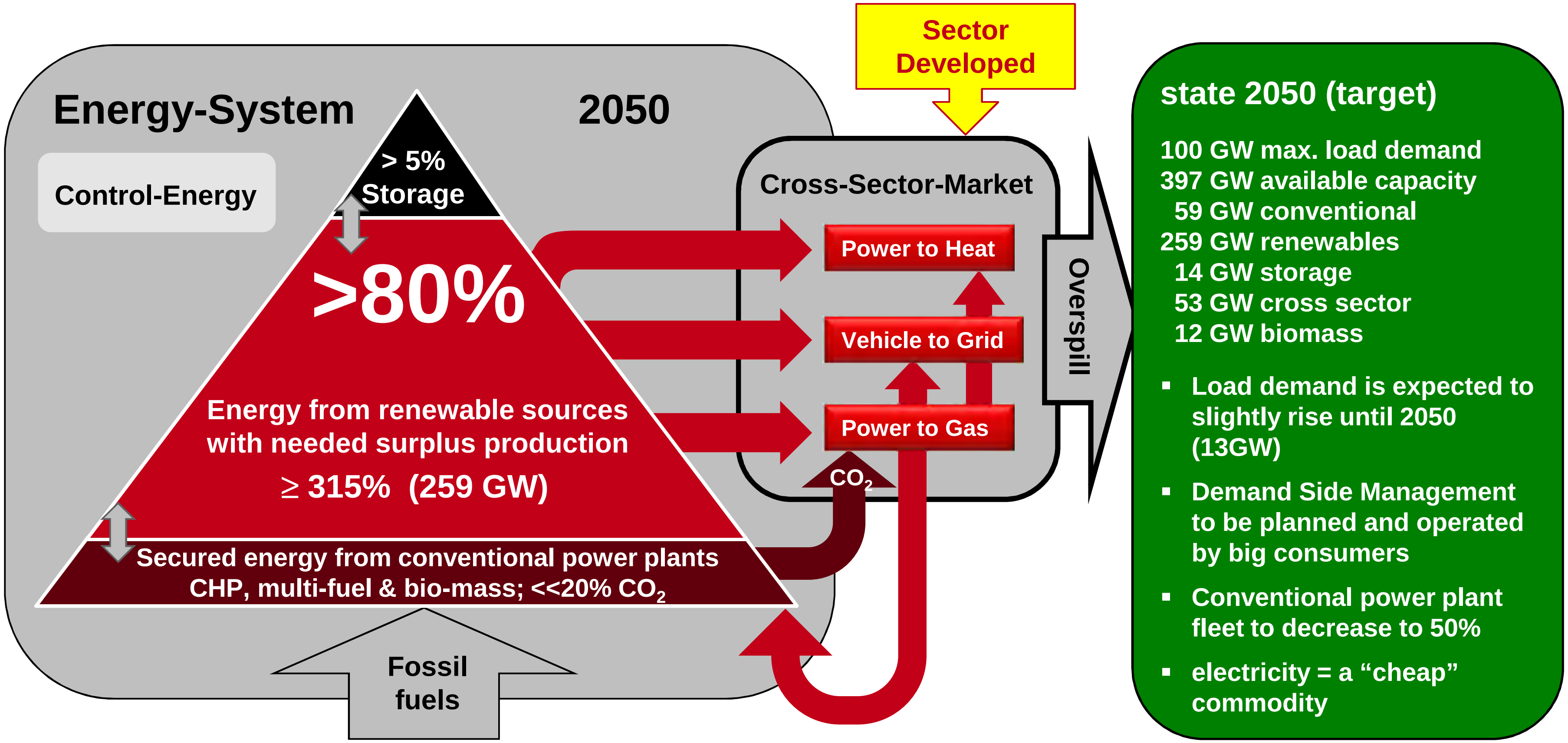


Process Steam for Process Industry

Load Diagram for CCPP with ESG



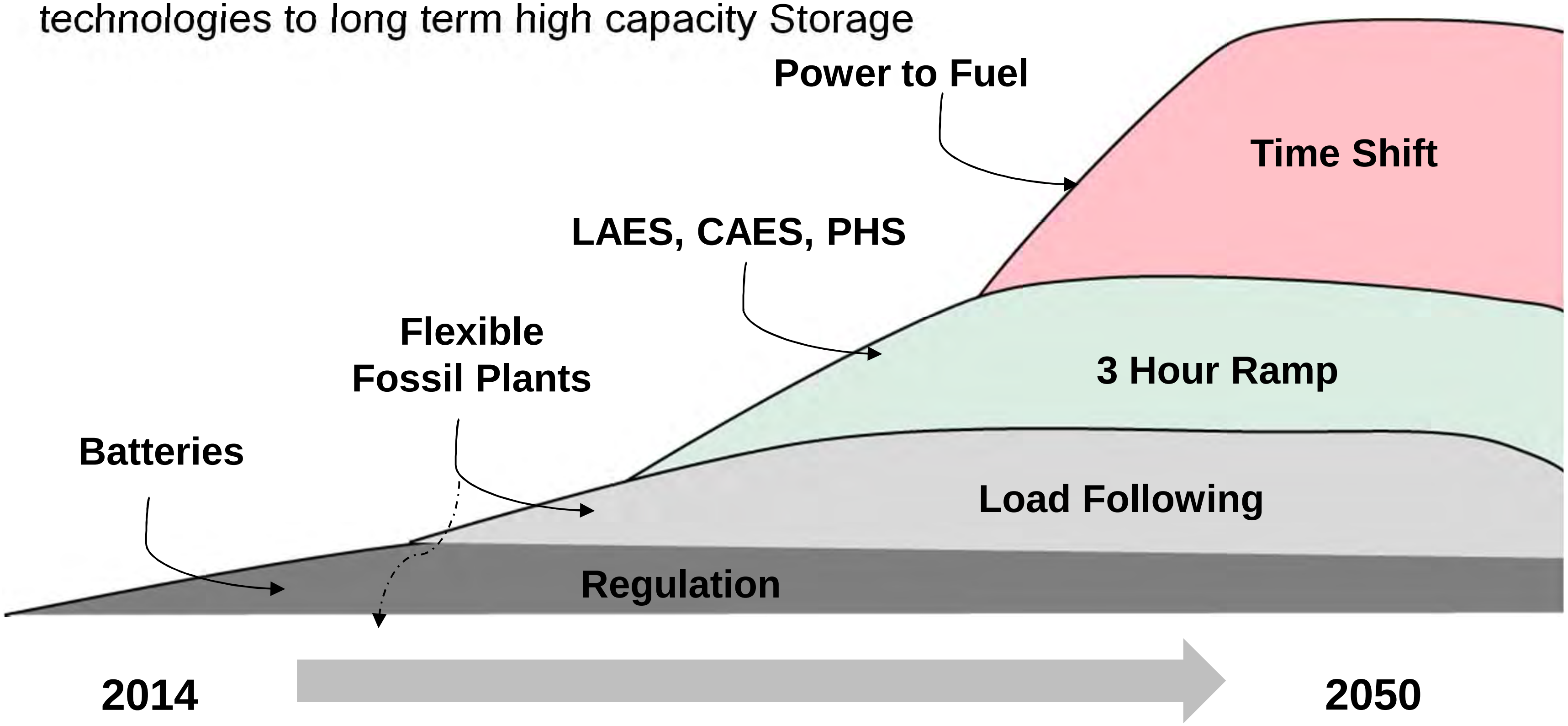
Energy system in Germany: 2050 prediction



Maximum load 87 GW + 13 GW in Demand Side Management (DSM)

Future Market Development for Energy Storage

- Increased RES share creates the shift from Instant Storage and load following technologies to long term high capacity Storage

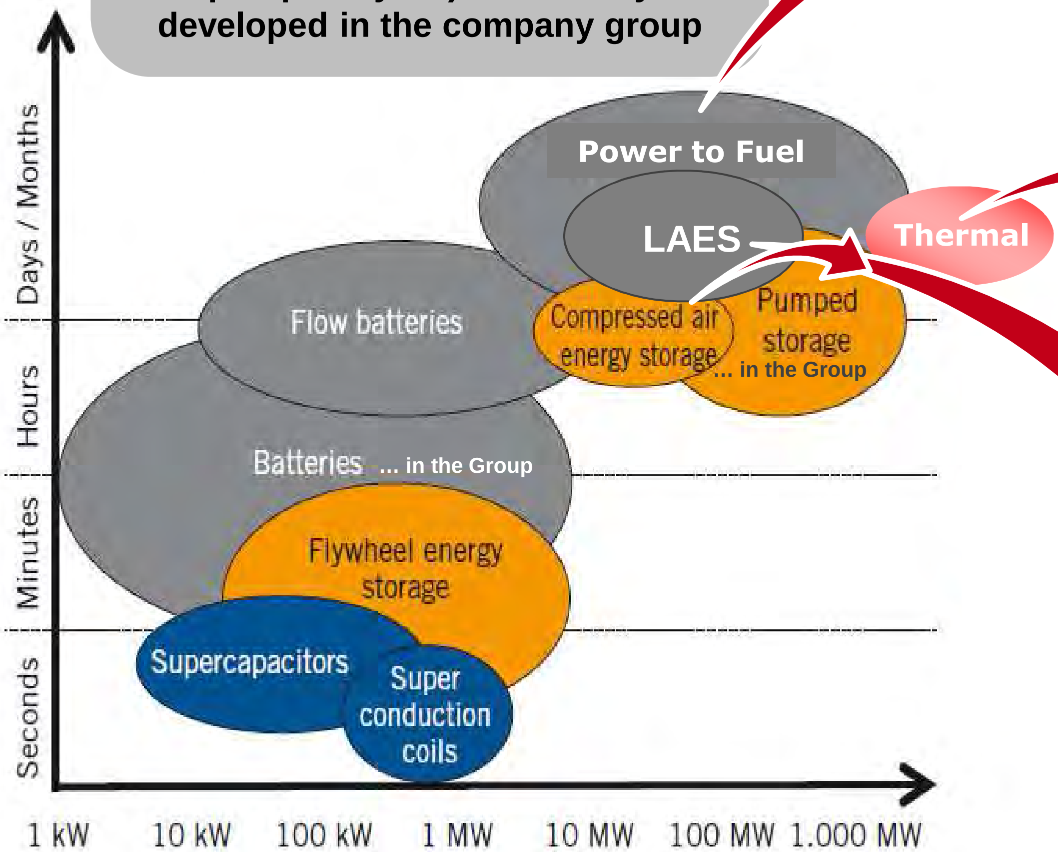


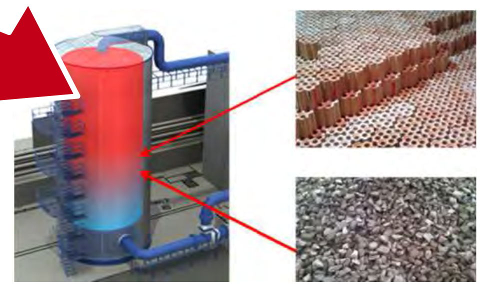
- Power to Fuel is the best choice for long term, large scale energy storage
- LAES is the only large scale electricity storage to be applied without any geological restriction both on brownfield and greenfield sites

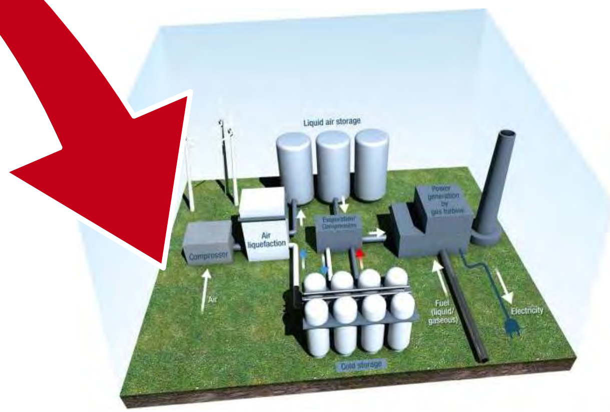
Storage technologies within MHPS-EDE

MHPS-EDE is focusing on storage technologies granting for also the possibility of long term storage, necessary in the future.

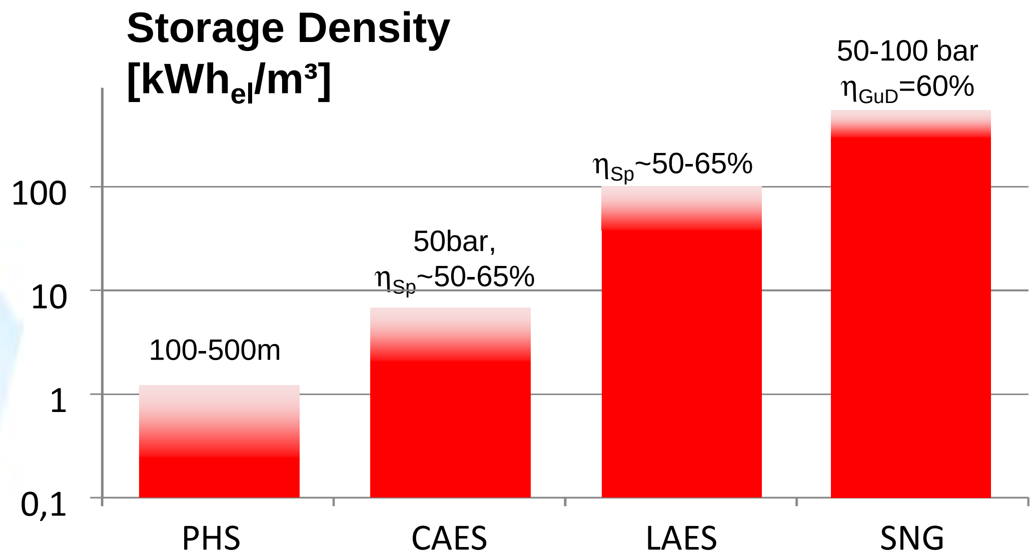
Other technologies (e.g. batteries & pumped hydro) are already developed in the company group





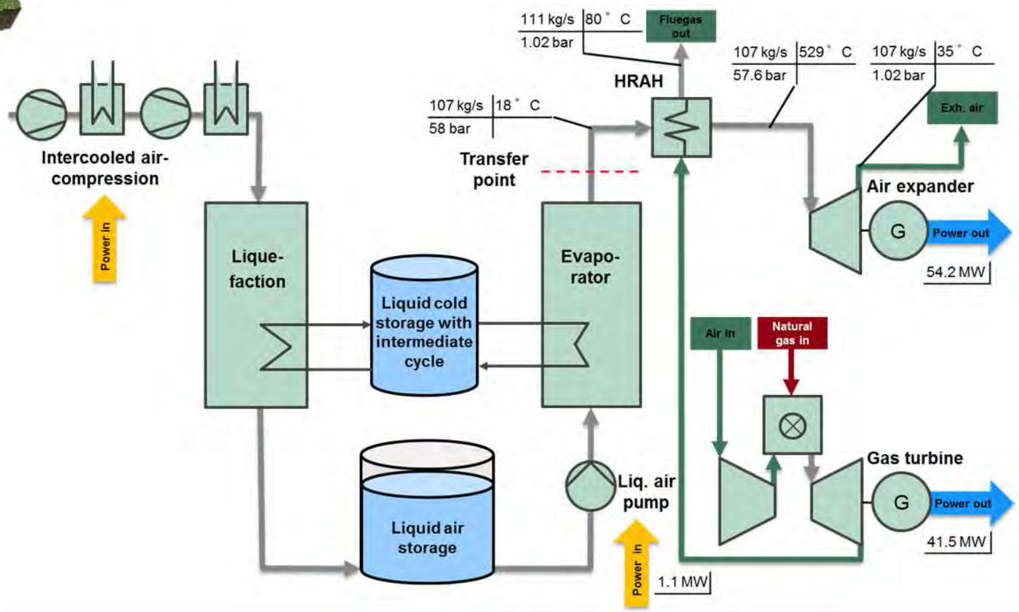


Bulk Electricity Storage and Back-up Power
Liquid Air Energy Storage – as two in one

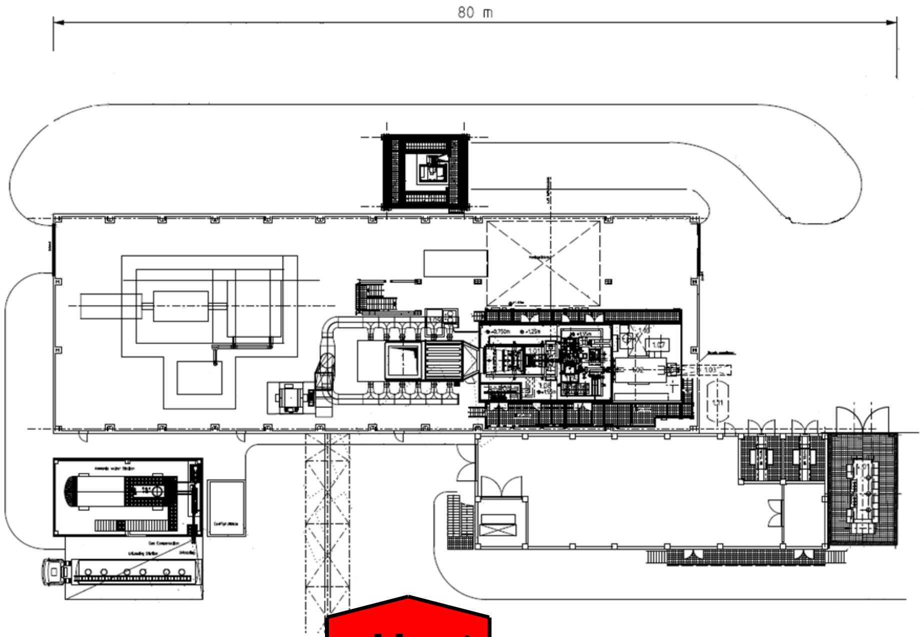


LAES is an energy storing technology, which is producing liquid air and heat (district heating) while charging and is producing electric energy from natural gas and liquid air while discharging.

The efficiencies of the technology are u**p to 65%** without district heating and above this calculating also the produced heat as “used”

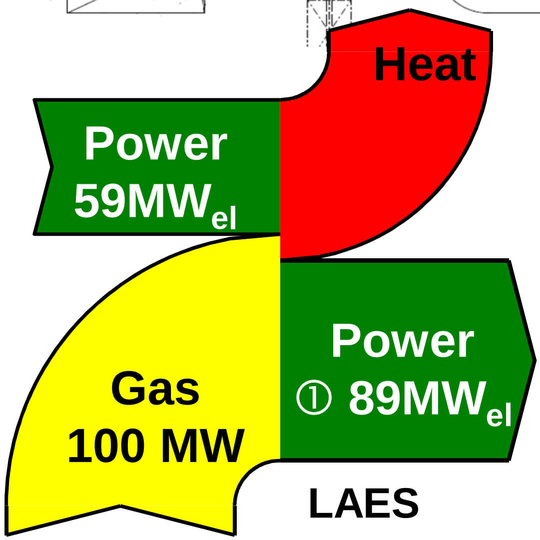


Liquid Air Energy Storage



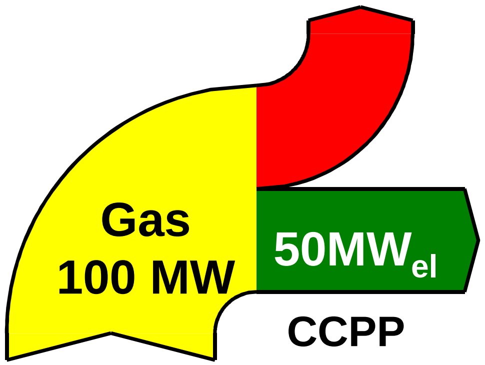
① 356 MWh powering

② 156 MWh from storage



LAES

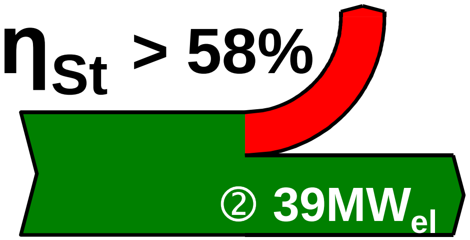
η_{RT} > 52%



CCPP

η_{CC} = 50%

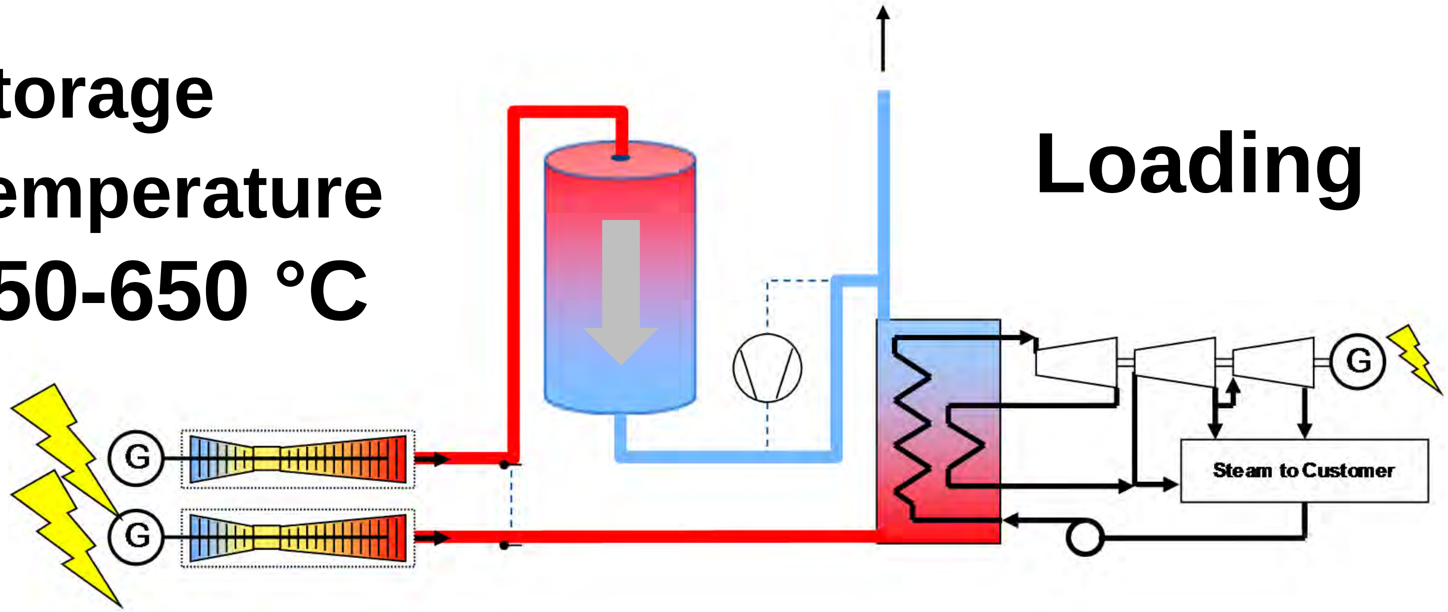
η_{St} > 58%

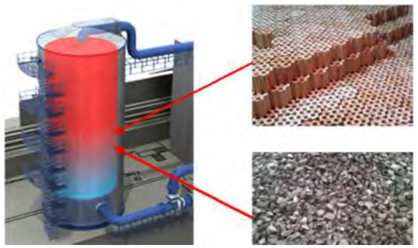


LAES Storage eff.
(Difference)

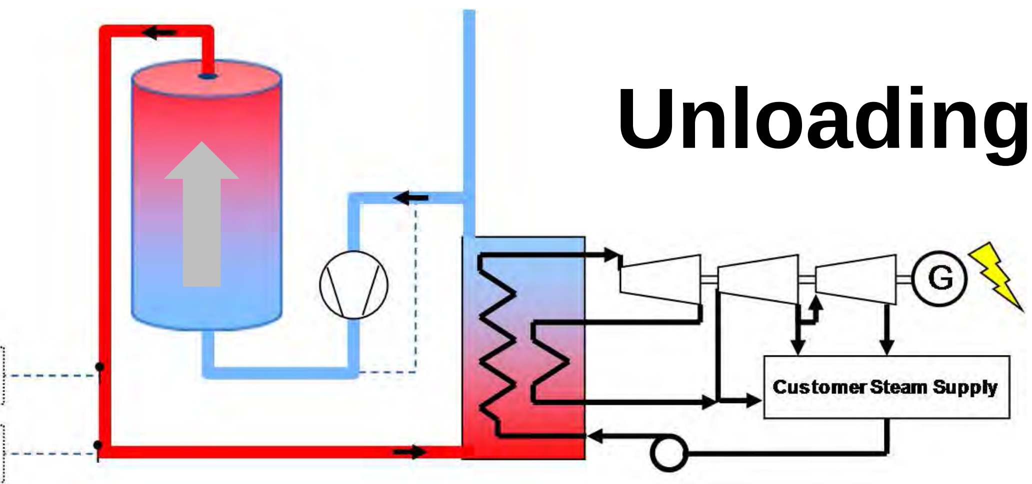
High Temperature Heat Storage

Storage Temperature 550-650 °C

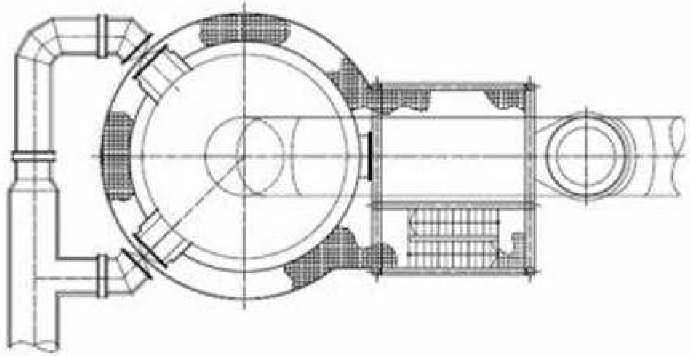


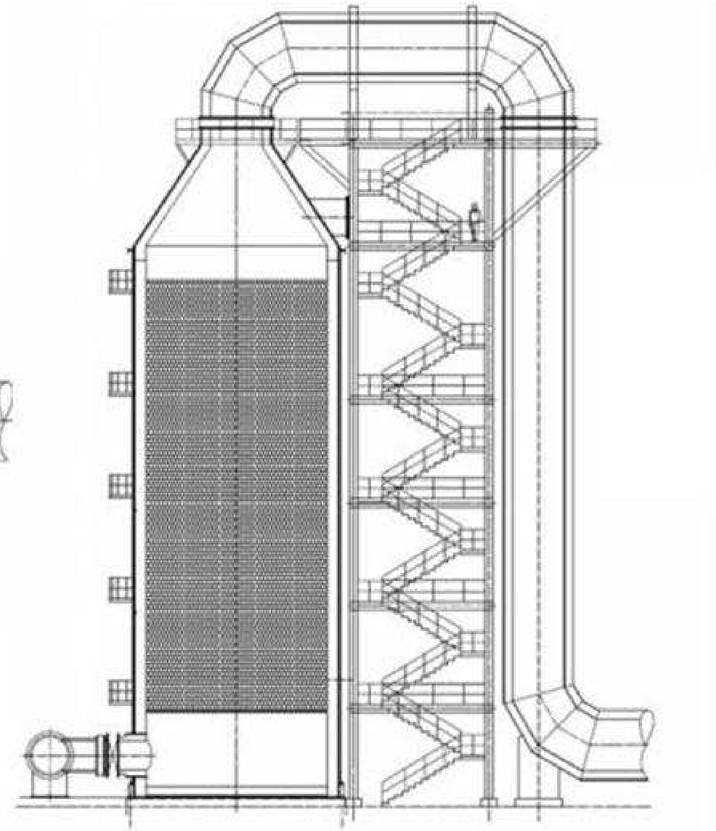


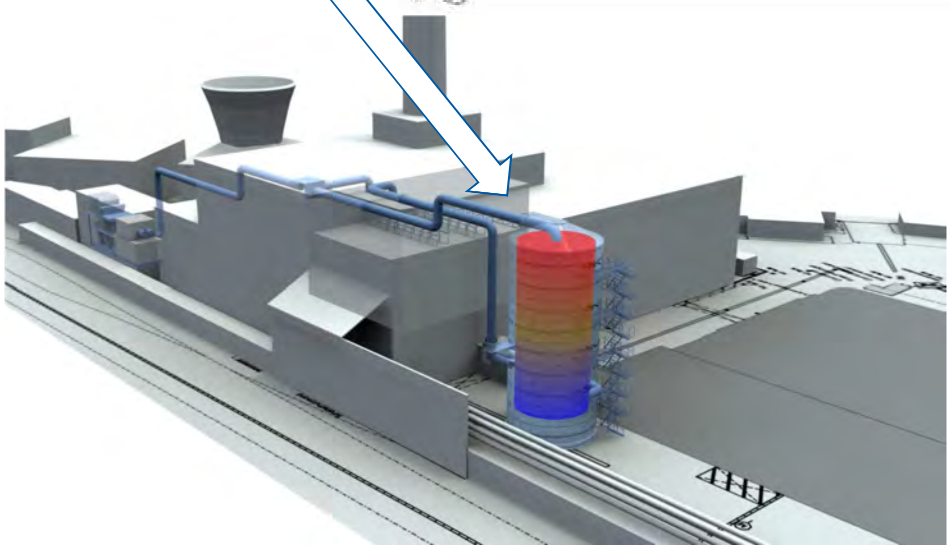
Storage in Rocks



High Temperature Heat Storage



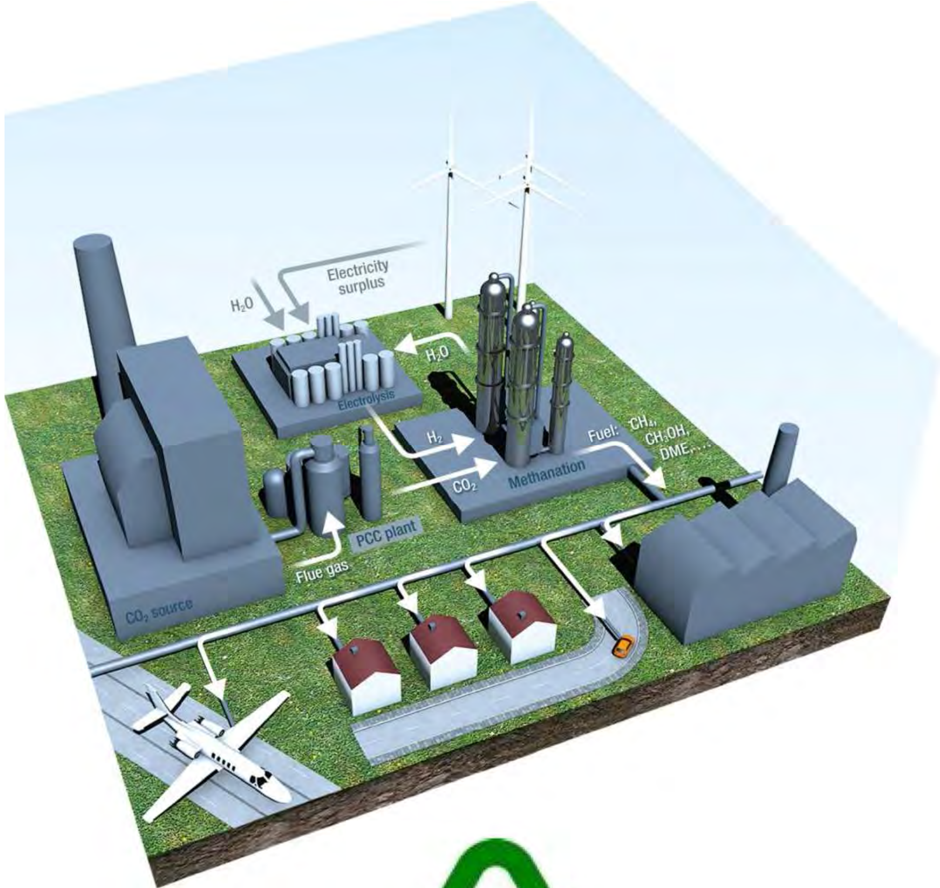




Preliminary technical data:

- ❑ **Storage capacity : 150 MWh**
- ❑ **Storage/release time: 16 h / 8 h**
- ❑ **Hot gas temperature: 555°C**
- ❑ **Height of storage vessel: 30 m**
- ❑ **Diameter of storage vessel: 8 m**
- ❑ **Mass of storage material: 2000 t**

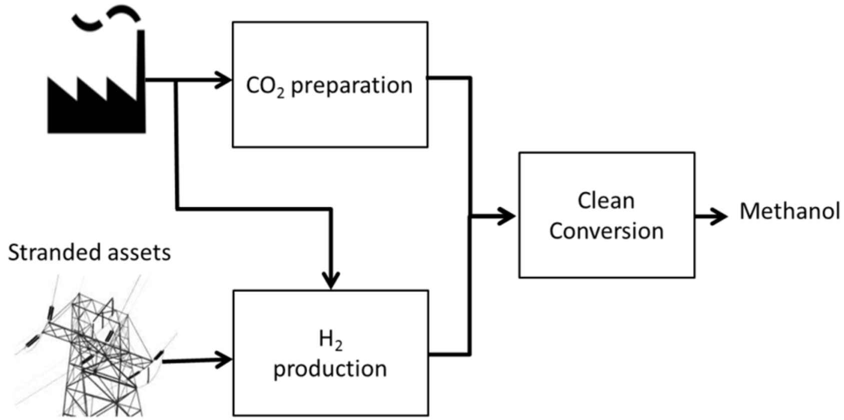
Power to Fuel in Power Plants



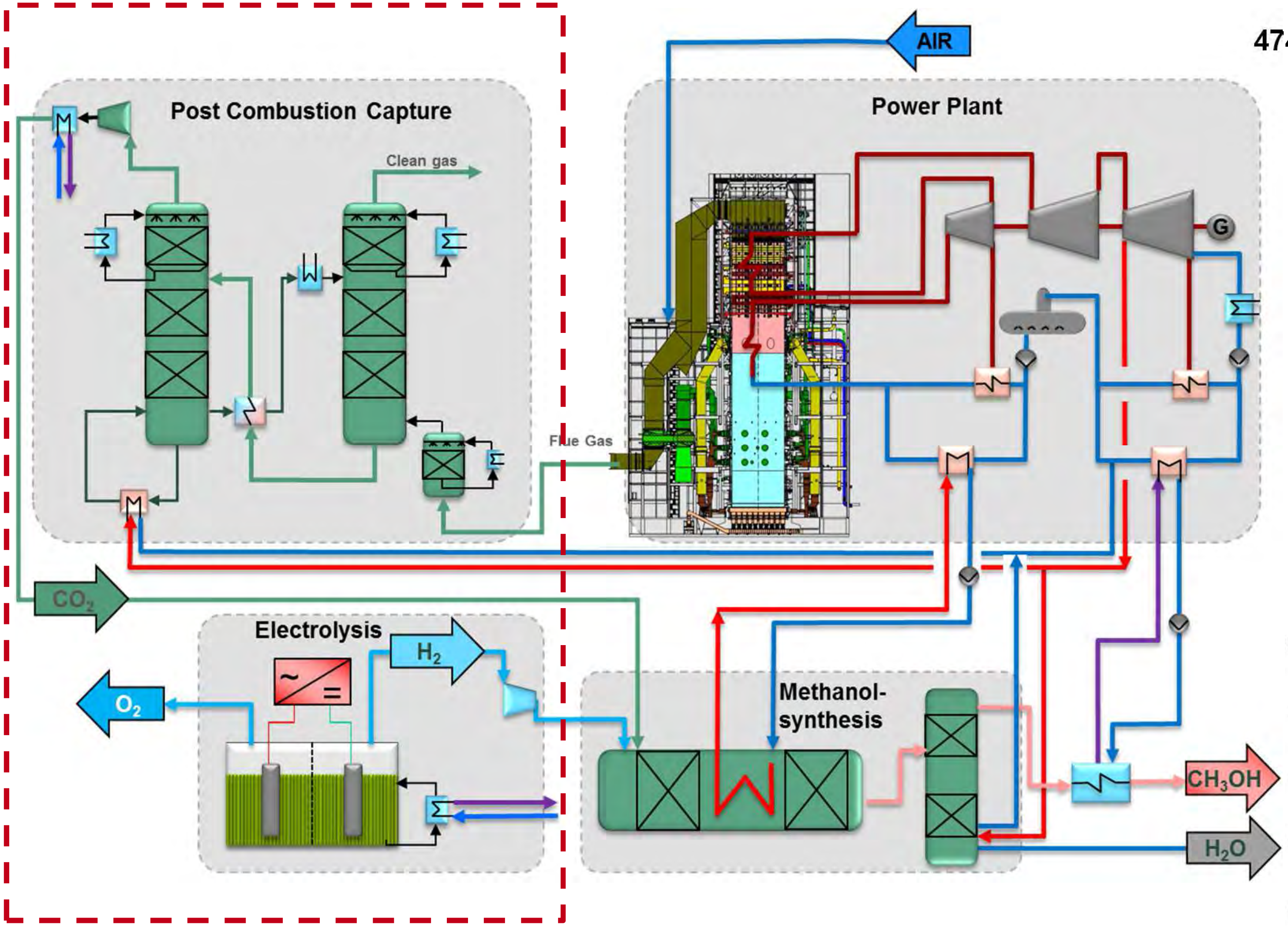
PtF is a cross sector energy storing technology, which is producing methanol and its following derivatives as olefins, gasoline, DME and other chemicals or transportation fuels. It is processing from electrical energy hydrogen and oxygen. The produced hydrogen is together with captured CO_2 processed to methanol with an exothermal process. The heat is used in the water steam cycle of an power plant for efficiency gain of the process.

The efficiencies of the technology are u**p to 67%** without the use of the oxygen in other processes. Using the oxygen this efficiency rises **up to 72%**, if it is used close to other industries using oxygen as one of its educts

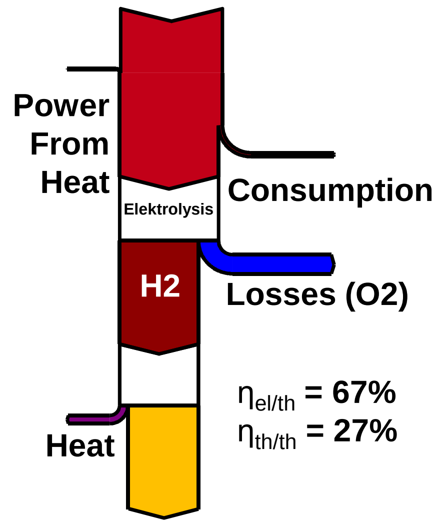
Carbon Recycling International



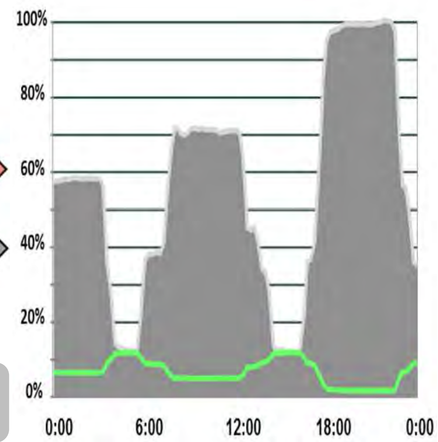
Power to Fuel in a Power Plant (Lignite)
A flexibility option with a Market for its Products



474 MW_{th} Coal Consumption
191 MW_{el} at 30% Load

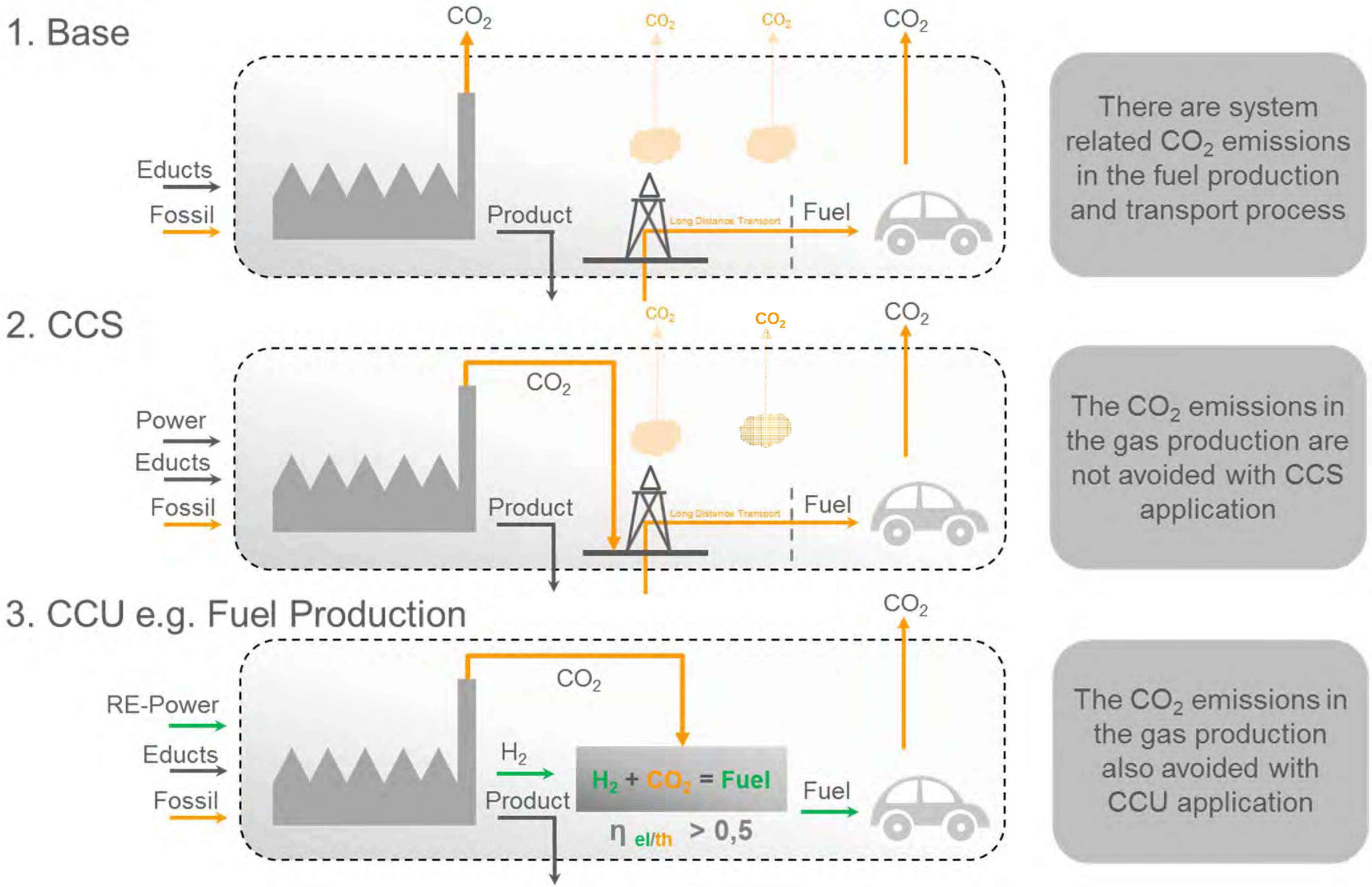


128 MW Methanol

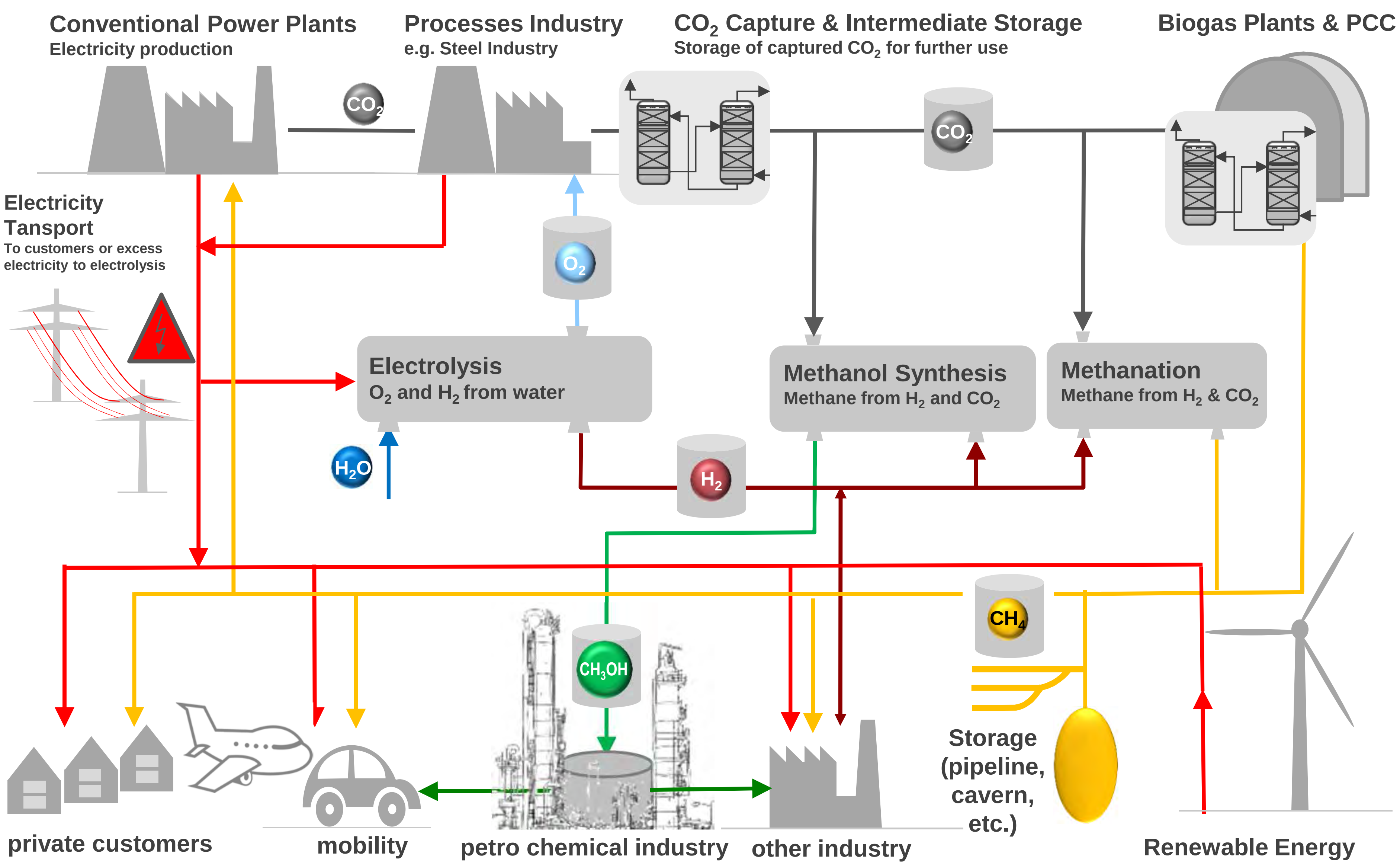


Keeps power plants in the business due to combined production !!!

Power to Fuel and Carbon Management



The Future is an Integrated Industry System (ISS)



Thank you for your attention

MITSUBISHI HITACHI POWER SYSTEMS EUROPE