Institut für Elektrische Energietechnik

Prof. Dr.-Ing. habil. Ingo Stadler

Why Cities will have the Key Role in 100% Renewable Power Systems

European Commission Project CELSIUS

The role of energy storage

Electricity vs. Heat

- The focus of our research is electricity supplies
  - with high shares of renewable energies
  - that ends in energy storage discussion

- CELSIUS concentrates very much on heat supplies
  - are we wrong here in this project?

- Transition from a fossil based era into a renewable based era comes along with…
  - … the change from consideration of single energy sectors
  - … towards consideration of inter-sectoral dependencies between electricity, heat and transport

  - … and that is what we try to make understand the conservative district heating industry

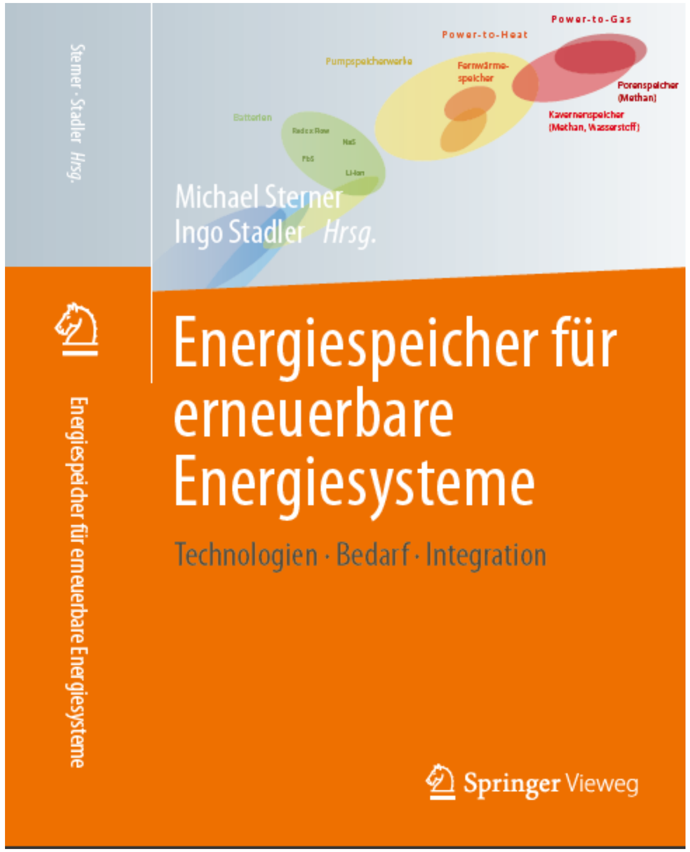
Not to talk about …

- … Energy storage need

Not to talk about …

- … Energy storage technologies

Commercial block

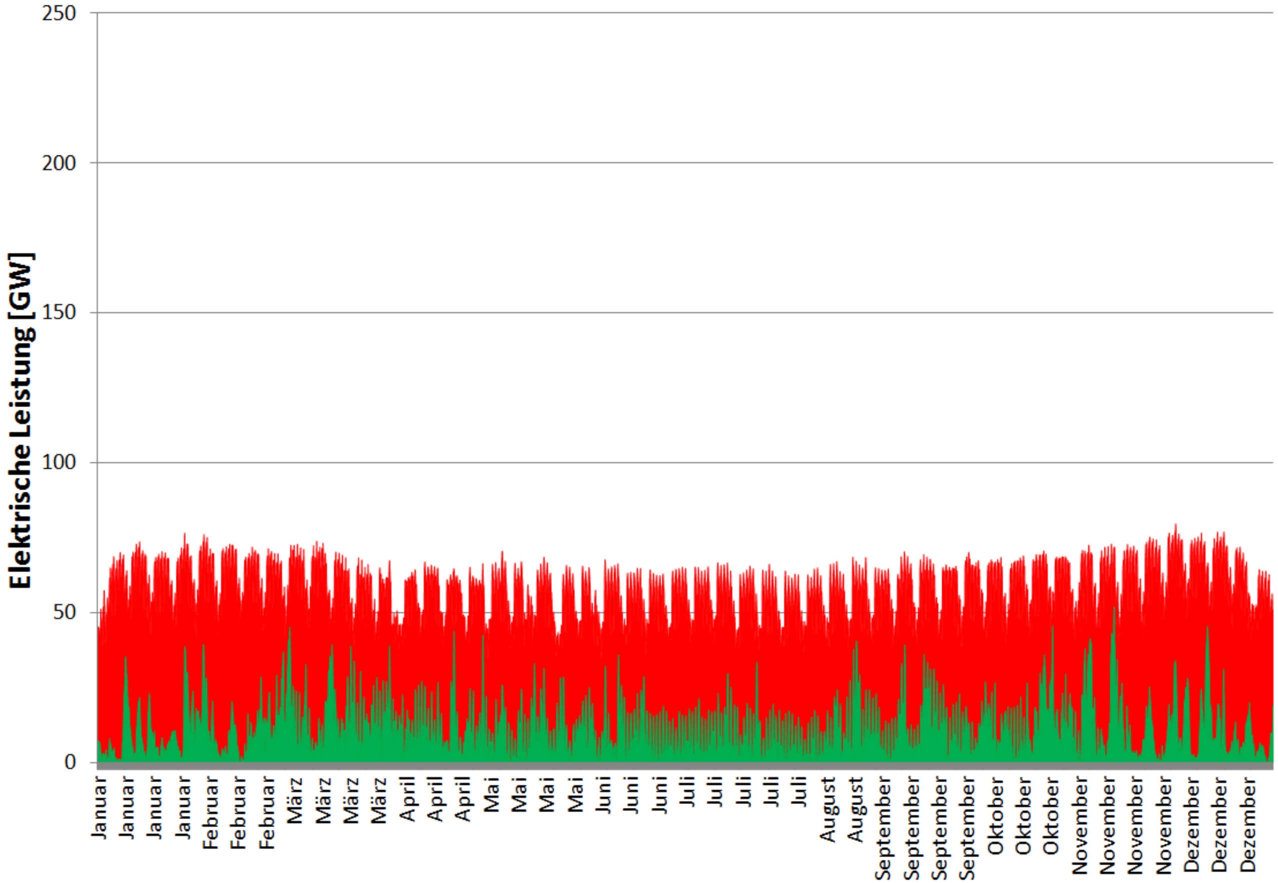


„Look: we do not have appropriate storage solutions!“

Content

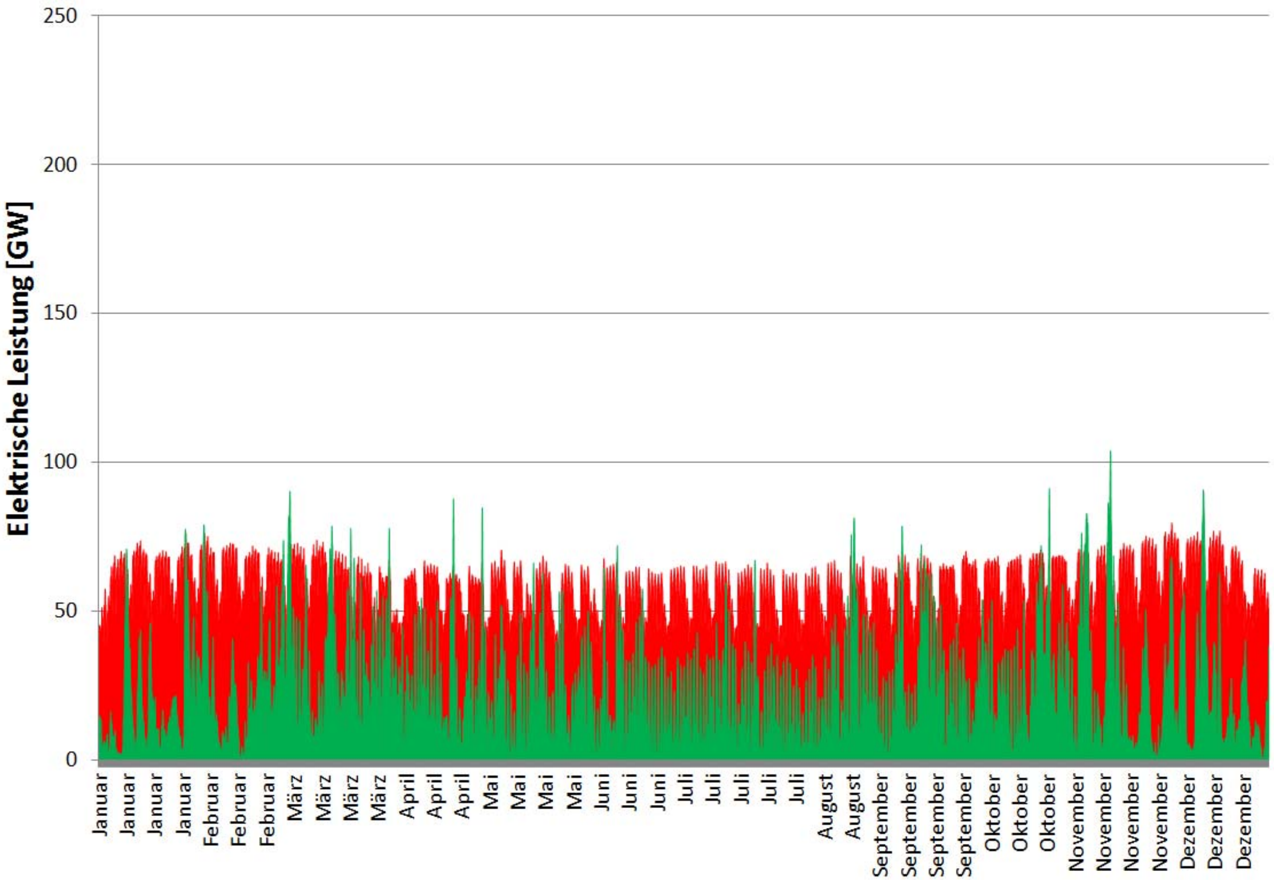
- Short Introduction on the need for energy storage
- Short Comparison of energy storage comparison
  - electricity – store in something – electricity back again
  - electricity – thermal storage – thermal heat usage
- inter-sectoral energy systems: CITIES are the solution
- show case: Study on Smart City Cologne

Storage Need? Renewable Generation (20%) and Consumption 2010



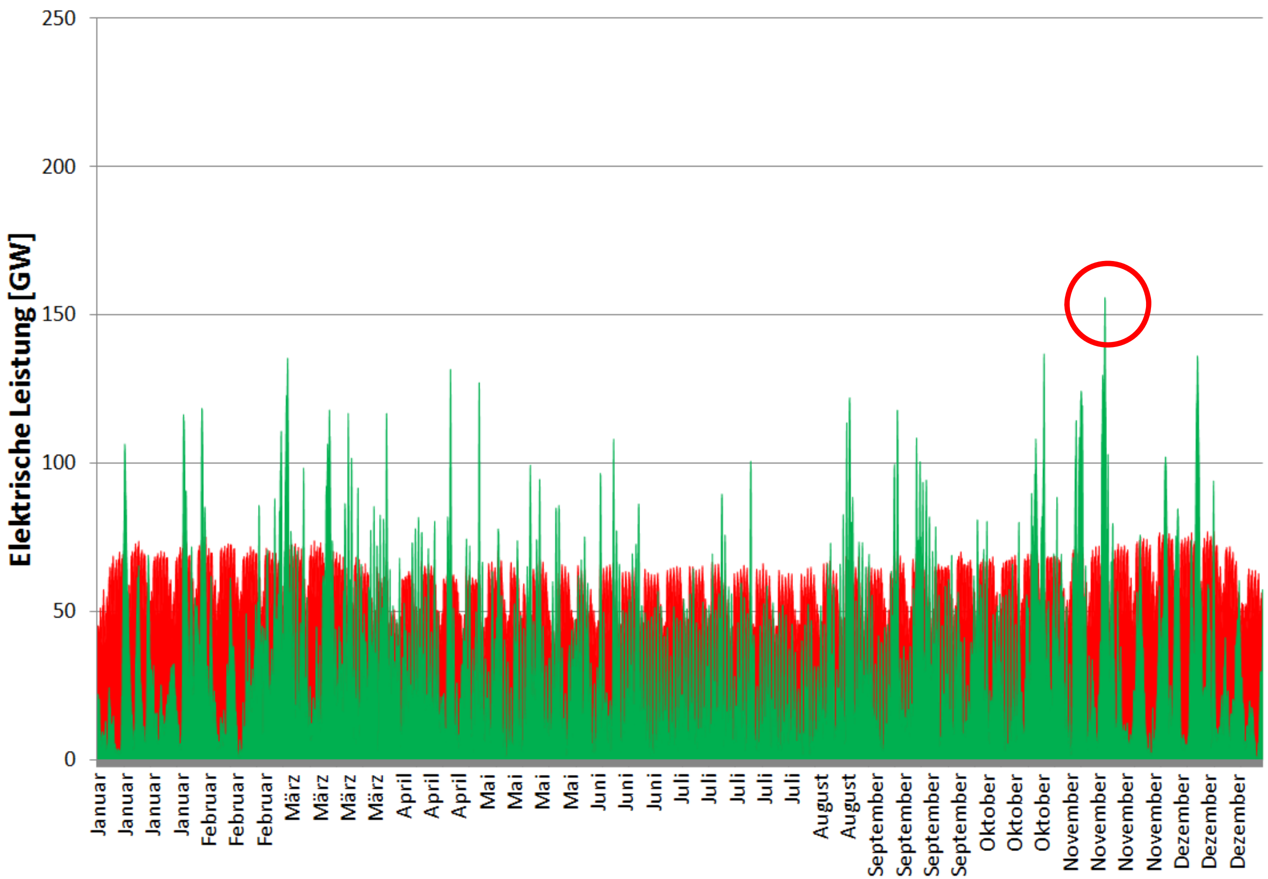
- Red:
  Load 2010
- Green:
  wind + solar 2010

Storage Need? Renewable Generation (40%)



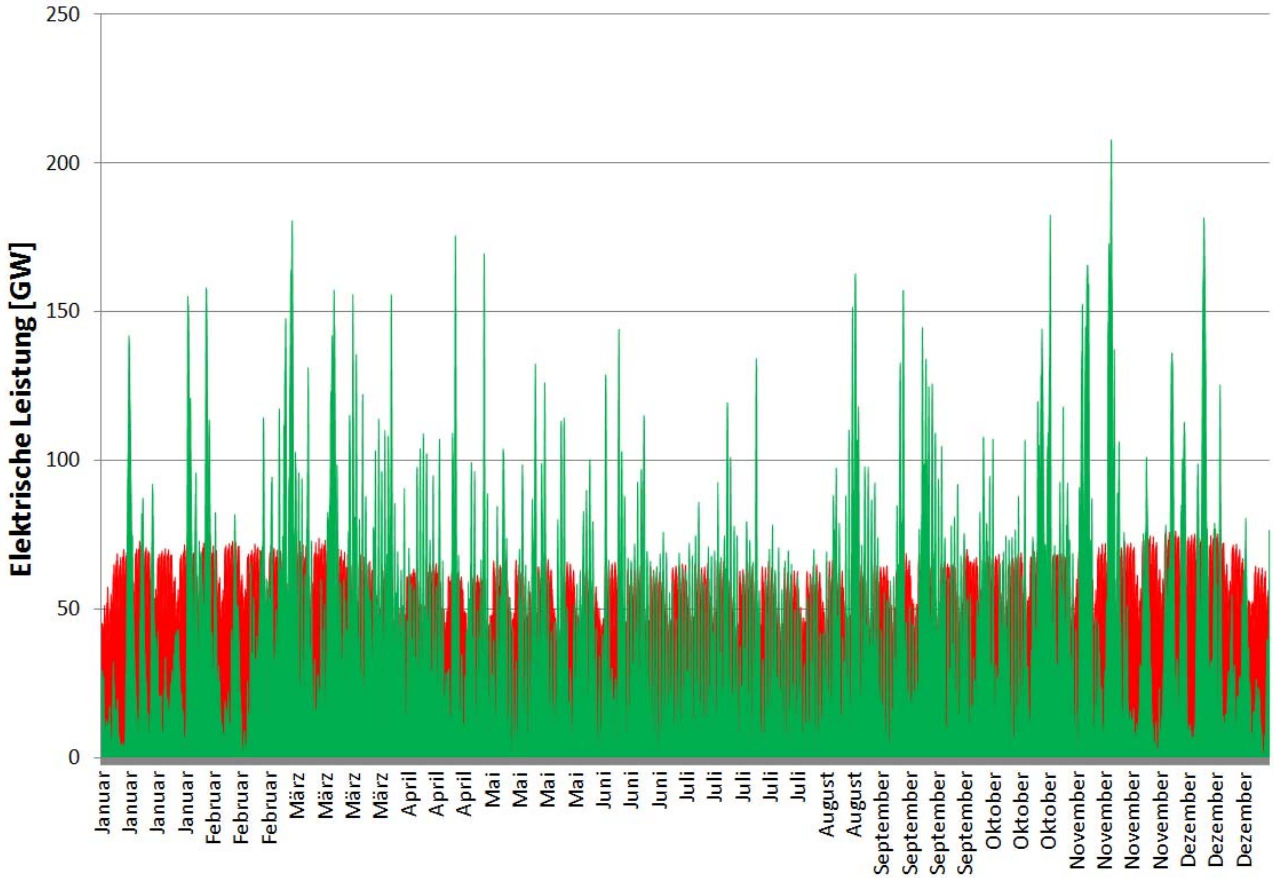
- Storage tolarable with 40% wind and solar?
- Rather no
- But inflexible existing power generation (lignite and nuclear) could cause an early start-up of energy storage

Storage Need? Renewable Generation (60%)



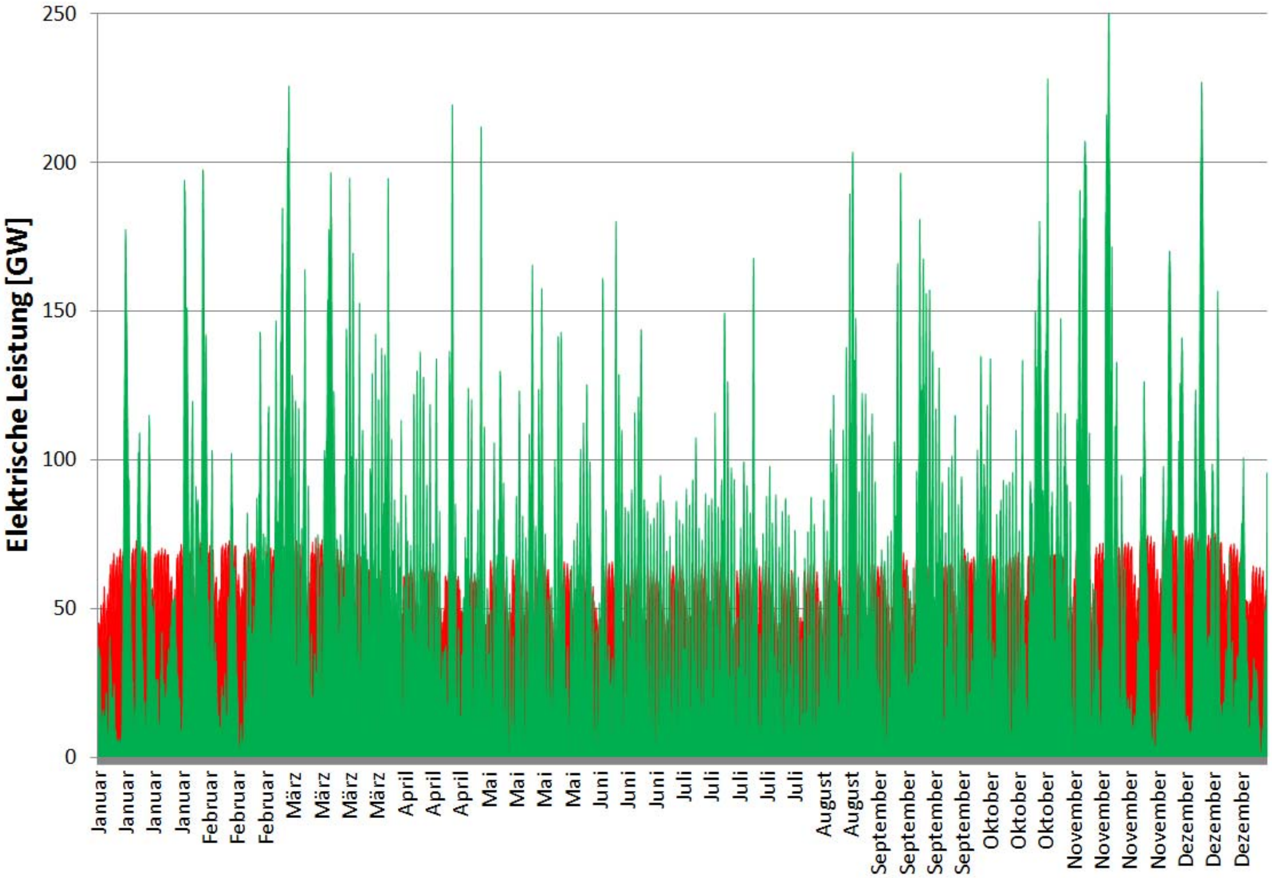
- With 60%?
- Maybe
- Or can power gaps be matched by fast reacting power stations?
- But not to use even the least kWh (dena II study caluclated with complete integration)

Storage Need? Renewable Generation (80%)

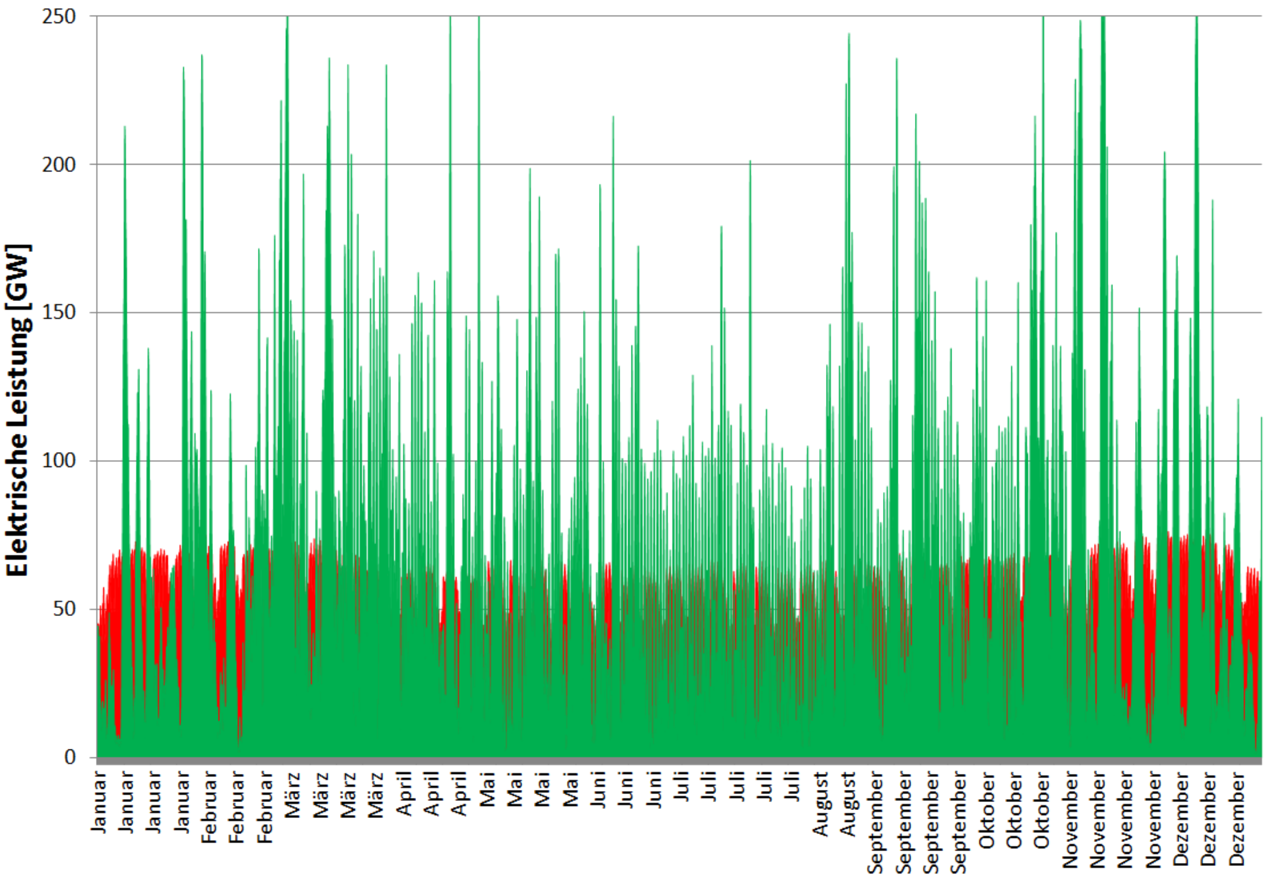


- With 80%?
- No doubt

Storage Need? Renewable Generation (100%)

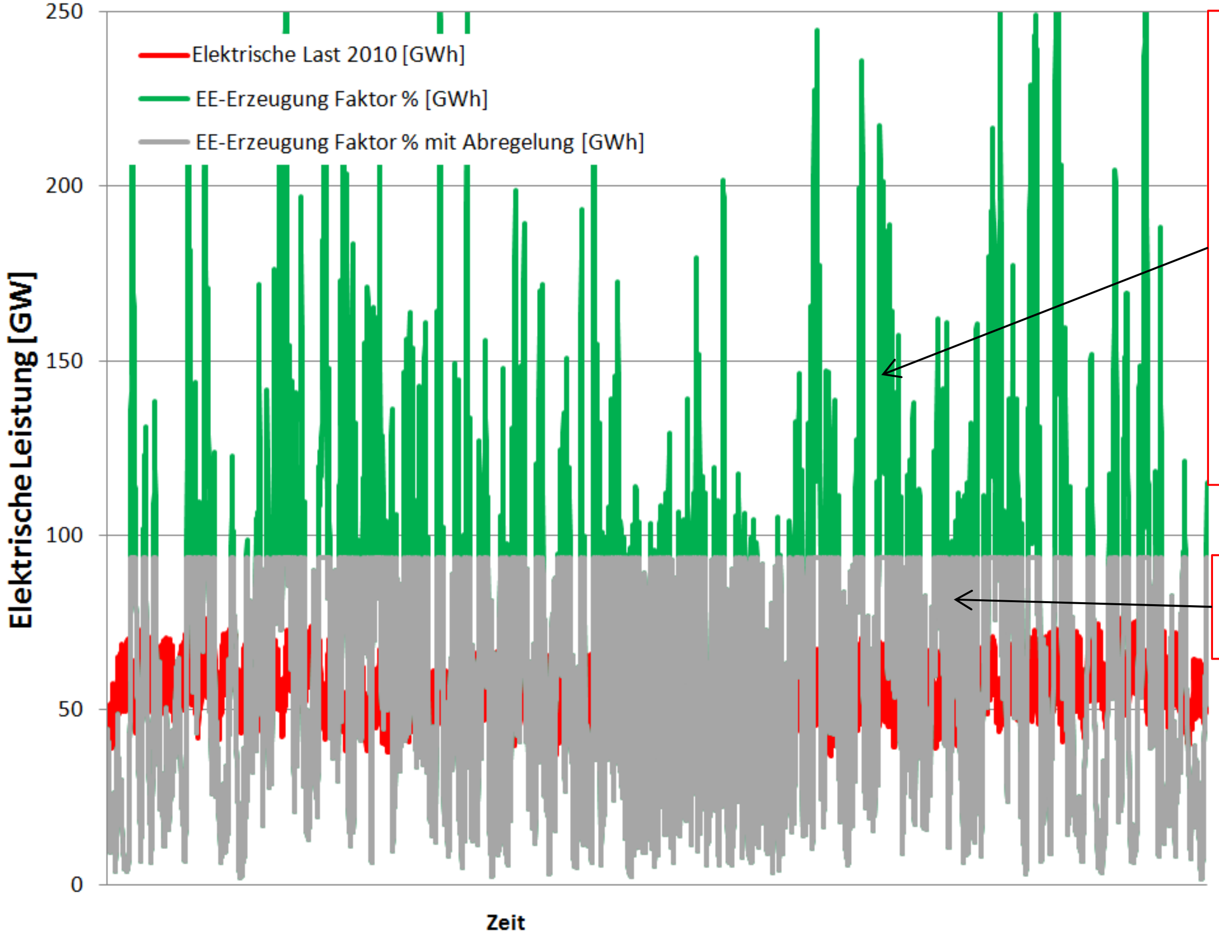


Storage Need? Renewable Generation (120%)



- Why120%?
- Pure renewable power supplies always have overproduction – due to economical reasons
- The cheaper renewable technologies become the more interesting overproduction will be

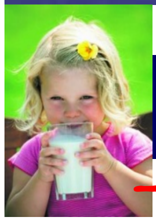
Renewable Generation (120%)



- Cut-off
- Strategic Electricity Reserves by methanisation
- Non-electric Consumption
  - Transport
  - Heat

- Any kind of Storage

Economics – Hot Water vs. Batteries



-calculation

Capacity costs:

ca. **250 €/kWh**

Costs per Cycle:

ca. **20 €ct/kWh**

Capacity co

ca. **2,7(**

ca. **38 €**

Costs per c

ca. **0,74**

Warum diese Produk

Brauch- Warmwasserspeicher 300 Liter mit 1 Wärmetauscher Trink-Brauchwasserspeicher 300 Liter mit 1 Wärmetauscher Das Schlangenrohr ist für die Sonnenkollektoren oder für den Heizkessel vorgesehen. Der ...	398,00 € 473,00 € mit Versand Heizung-Solar24
Pufferspeicher Warmwasserspeicher 300 L Liter Solar Speicher ... Finden Sie Pufferspeicher Warmwasserspeicher 300 L Liter Solar Speicher Heizung Heizsysteme bei eBay in der Kategorie Heimwerker>Installation ...	300,00 € 360,00 € mit Versand eBay
300 Liter TWL Solarspeicher, Warmwasserspeicher Typ So 300, isoliert	580 € bei 3 Anbietern Preise vergleichen
Vaillant VIH RW 300 Warmwasserspeicher Wärmepumpen-Speicher - 285 L rund	1.322 € bei mehr als 5 Anbietern Preise vergleichen
Zehnder Apart Warmwasserspeicher 300 Liter Herst-Nr.990102803 Warmwasserspeicher 300 Liter Zubehör für Zehnder ComfoBox Apart Kompaktenergiezentralen aus emaillierten Stahl, inkl. 2KW Heizflansch , speziellem ...	1.309,00 € Versand gratis wolf-online-shop.de 25 Erfahrungsberichte
Buderus Logalux SU300/1 V1 Warmwasserspeicher / Brauchwasserspeicher Technische Daten: Speicherinhalt300 Liter Abmessungen - Durchmesser: 672mm Höhe: 1465mm Füße: 15-25mm Gewicht145kg maximale Betriebstemperatur ...	885 € bei 3 Anbietern Preise vergleichen

Frame: i=5%; t_{bat}=10a;
t_{DSM}=25a; DOD=0,5; 1 cycle/d;
therm. St. 70kWh/m³;

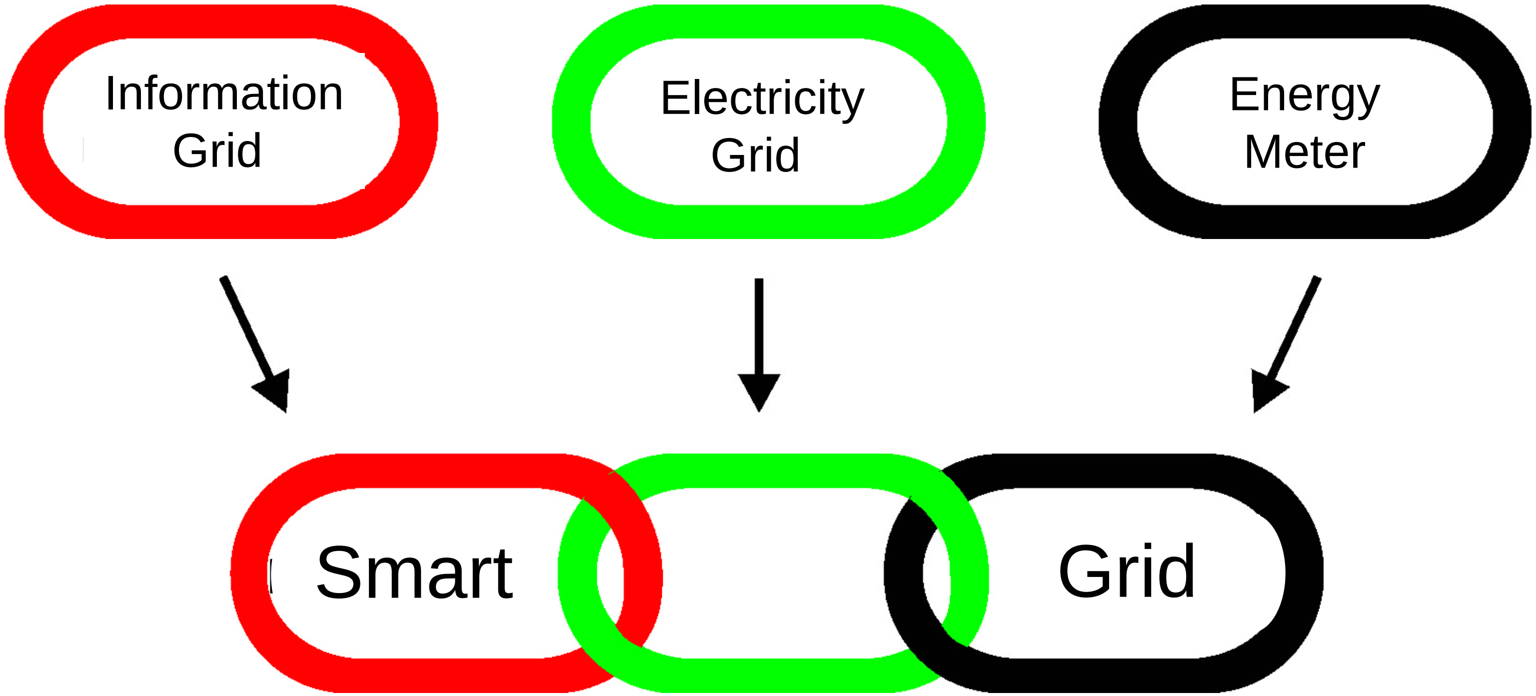
Pre-Conclusion

- Heat storage is economically more efficient to electricity storage by a factor of almost **1000**

- for a cost-effective transition of the energy (and not only electricity) system the combination of electricity, heat and transport is essential

- The future question will not be anymore whether we require heat storage for the district heating system.
- The driver will be that within district heating systems the storage task of future energy systems can be done more efficient than in any kind of batteries. Heat storages will be a market opportunity for district heating system operators in combination with CHP and heat pumps

Smart Grid

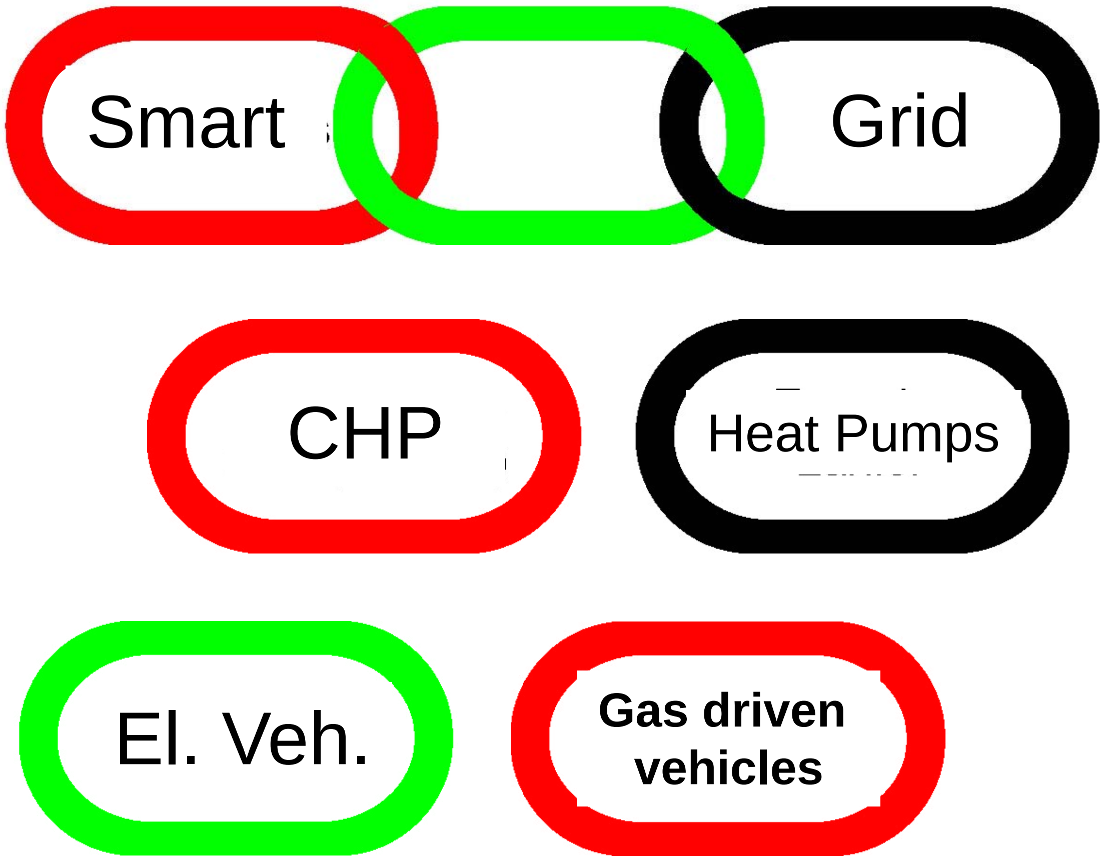

Information Grid
Electricity Grid
Energy Meter
Smart
Grid

Smart System

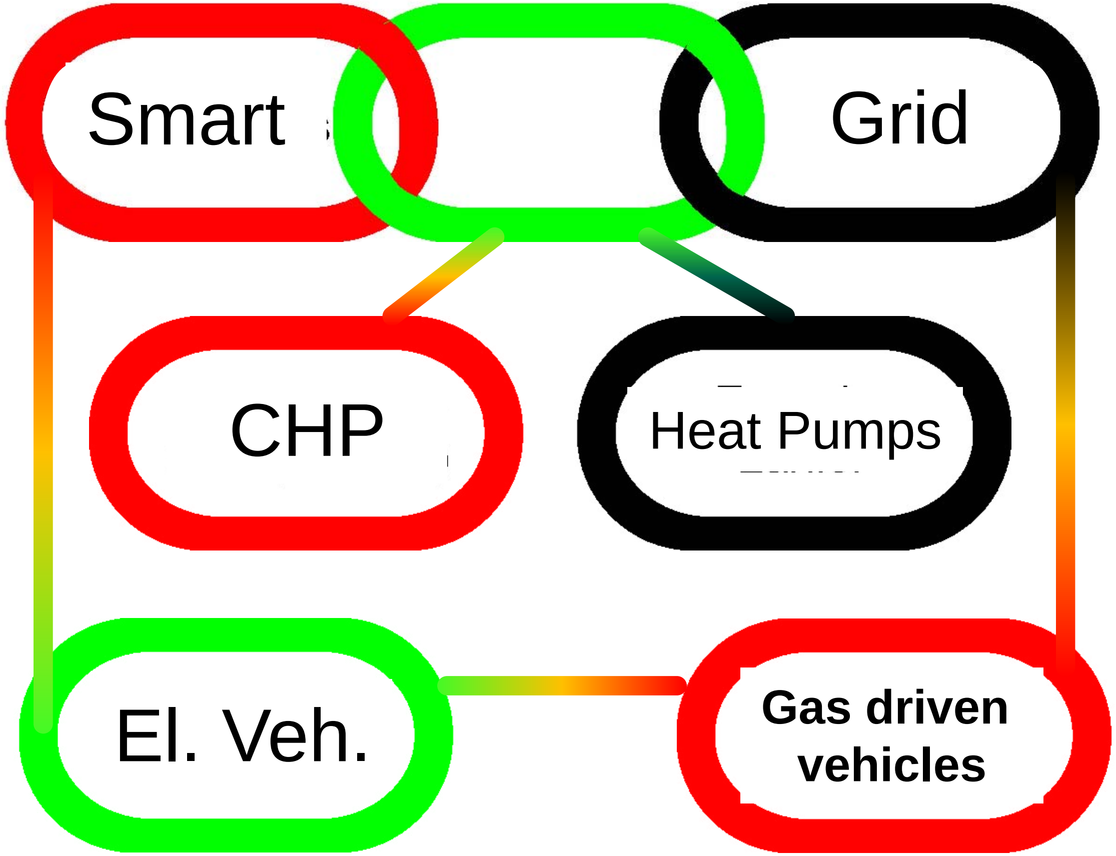
Electricity

Heating

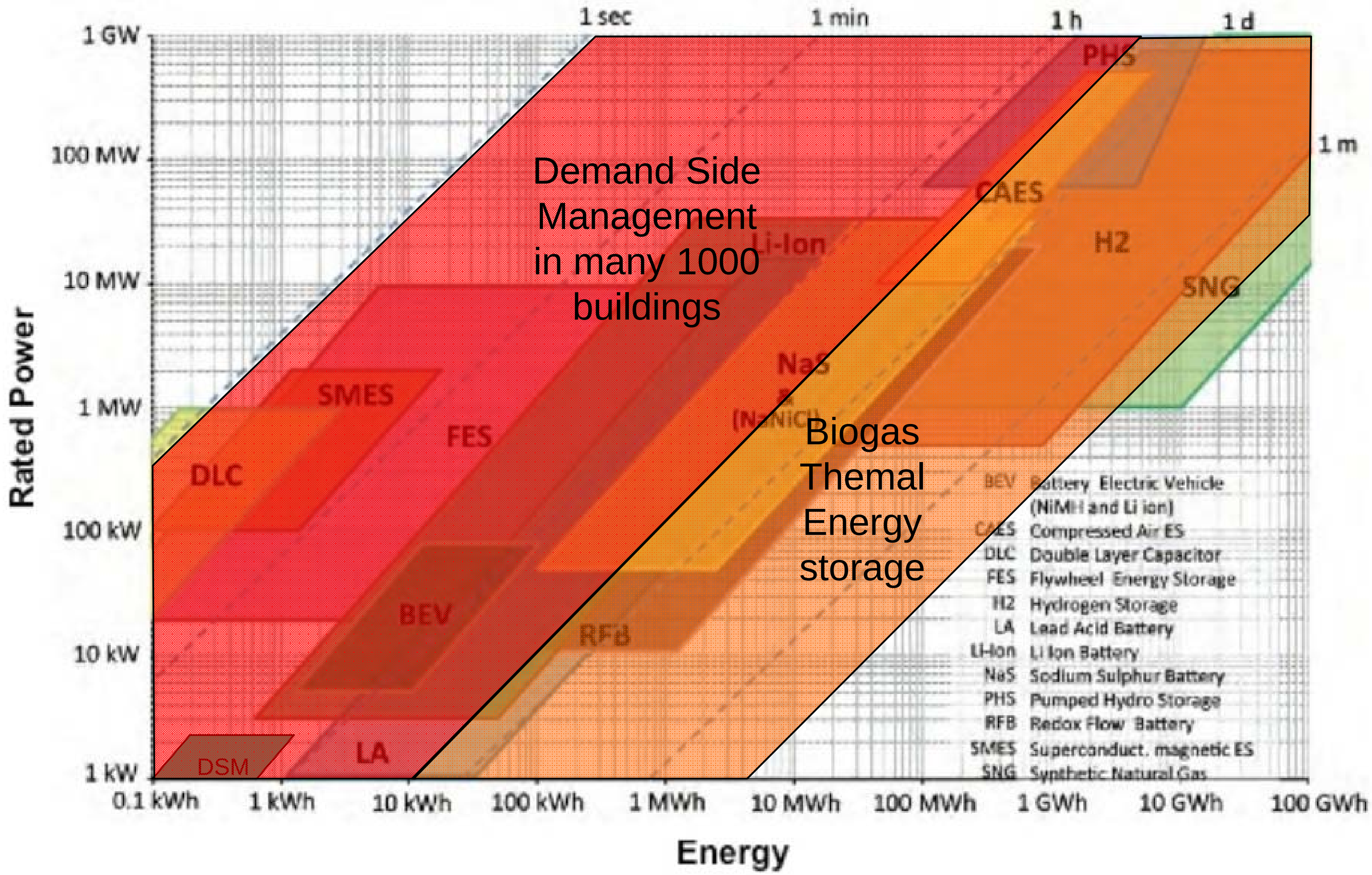
Transport



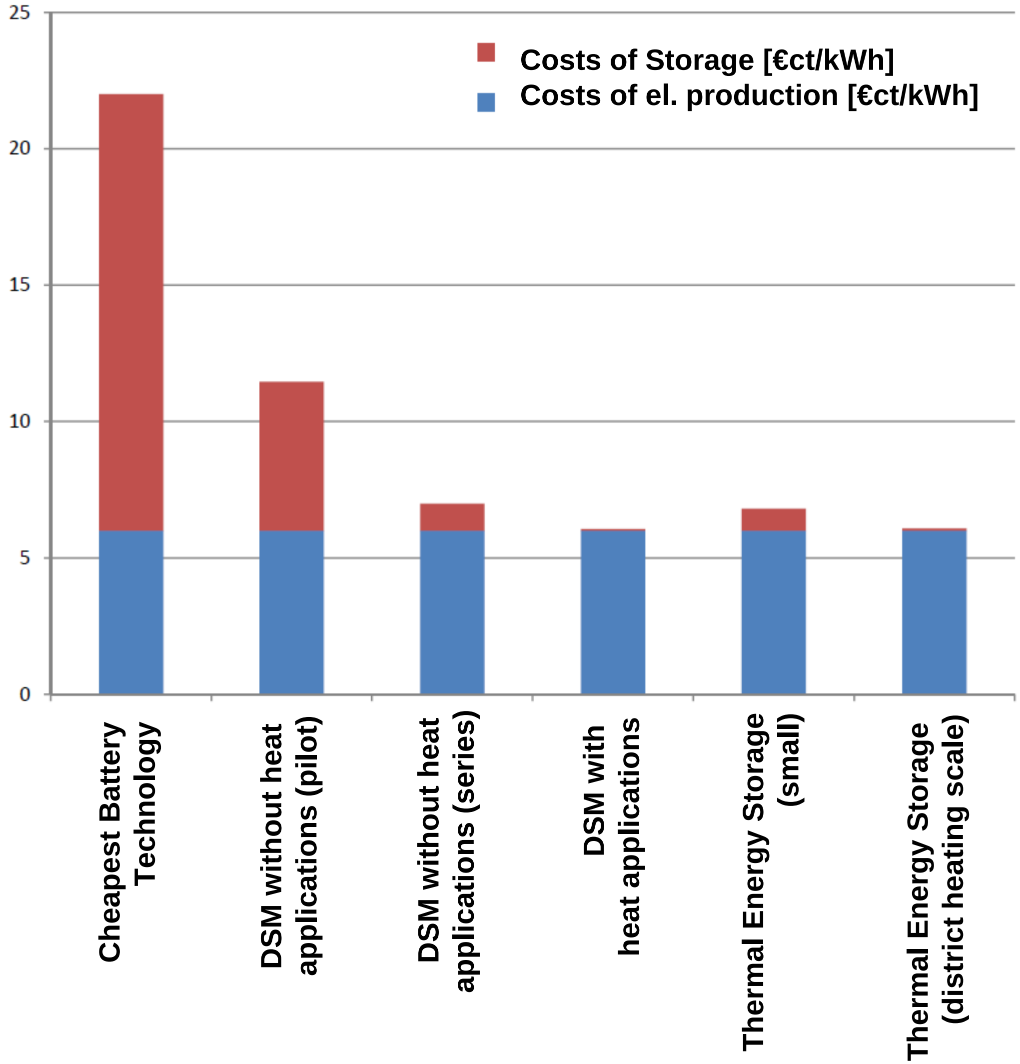
Smart System



(incomplete) Overviews on Energy Storage Technologies



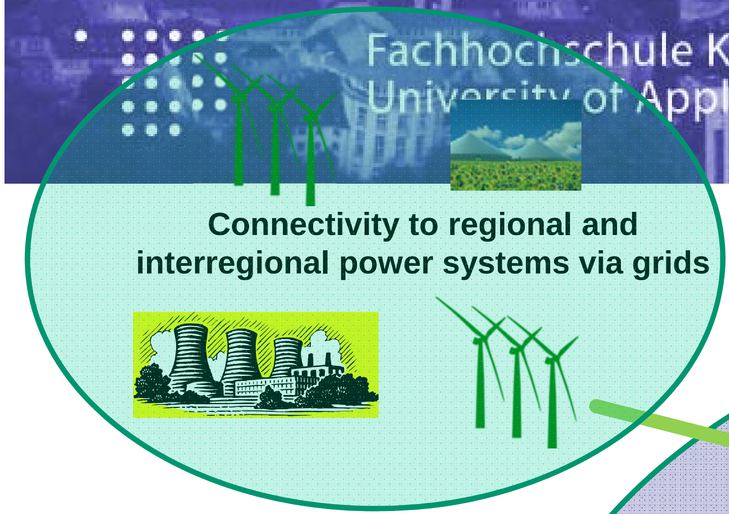
Source: IEC

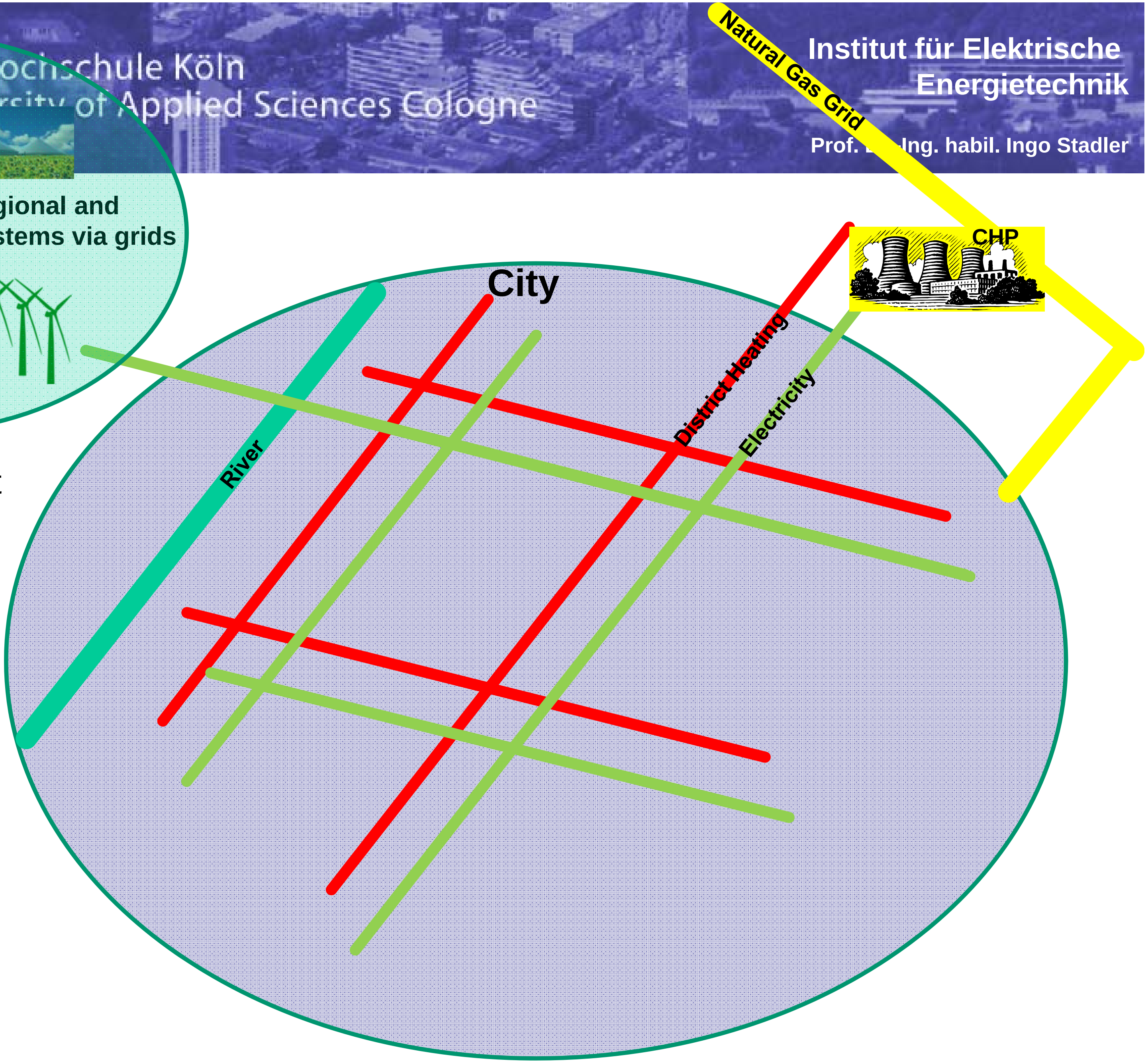


By coupling electricity and heat sector the „energy storage problem“ becomes marginal !

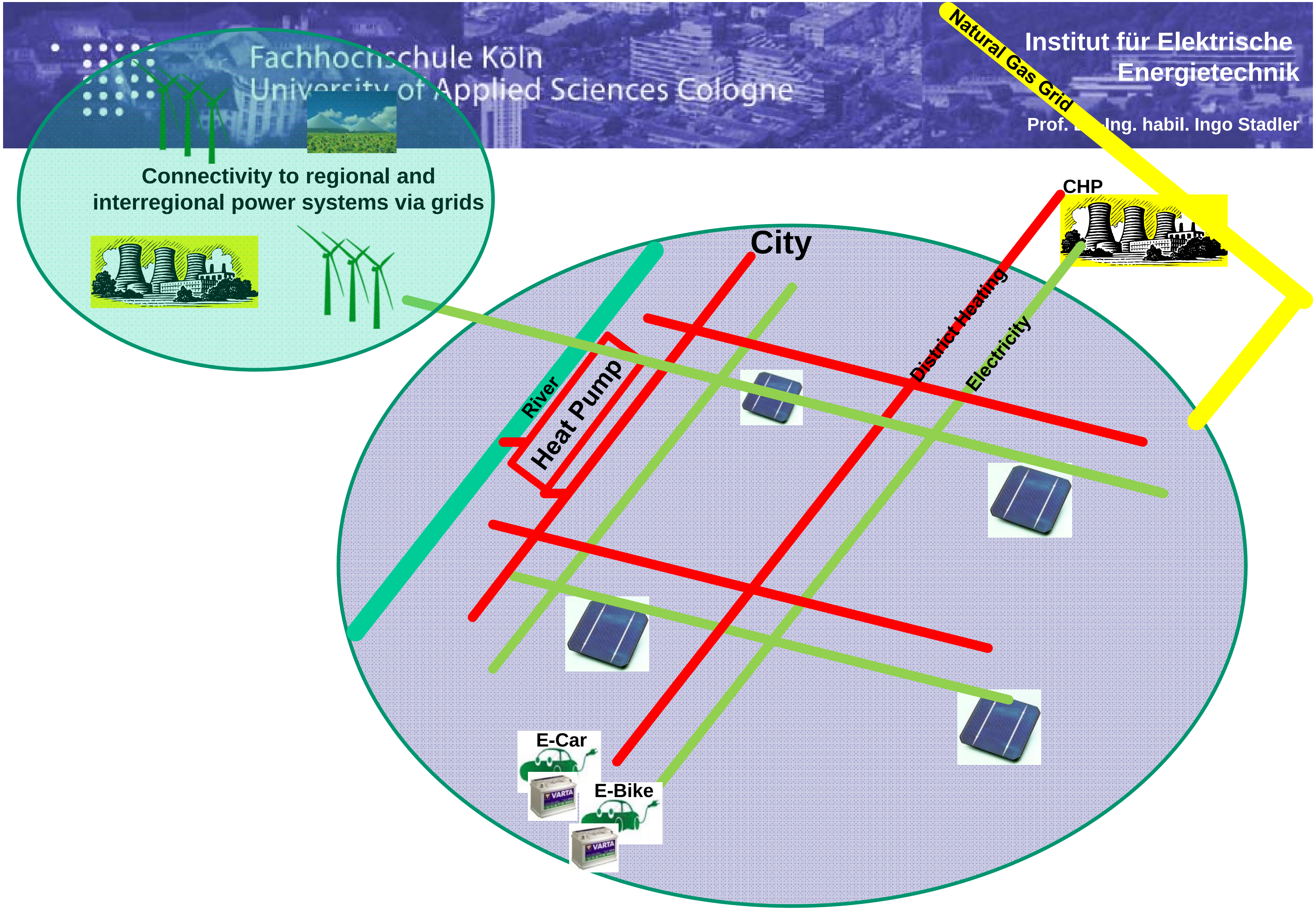
Now why cities?

- Energy transition has started on the countryside
  - Biogas installations on farms
  - Wind parks (for sure not in city centers;-)
  - Photovoltaic systems in residential areas, farms and on green land
- Cities have been more or less out of this development

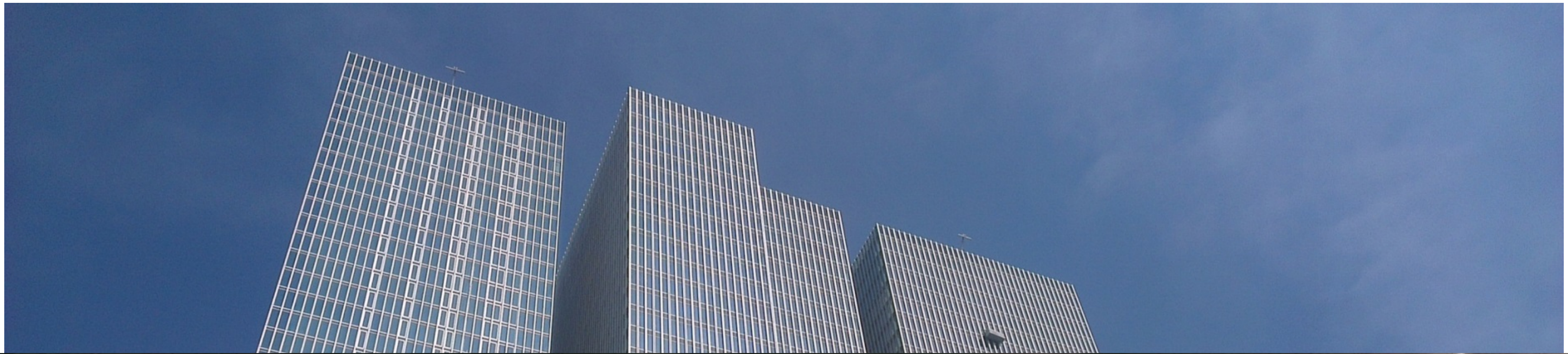


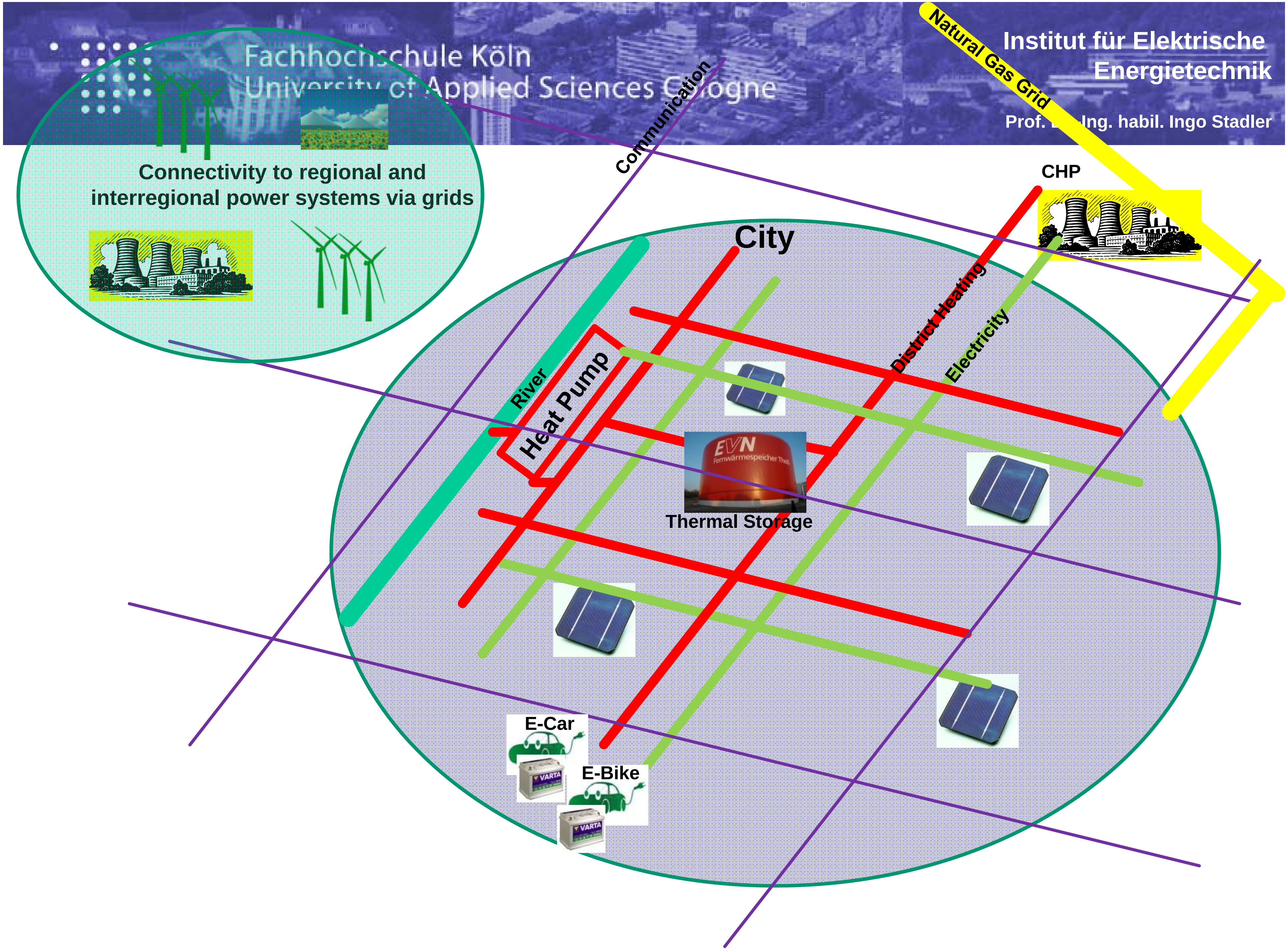


- Most cities are built at riversides
- but rivers are only used as heat sink of thermal power stations
- Cities have energy demand densities to allow efficient application of district heating


Connectivity to regional and interregional power systems via grids
Natural Gas Grid
CHP
City
District Heating
Electricity
River
Heat Pump
E-Car
E-Bike
VARTA
VARTA

CELSIUS: Rotterdam – Vertical City




Connectivity to regional and interregional power systems via grids
Communication
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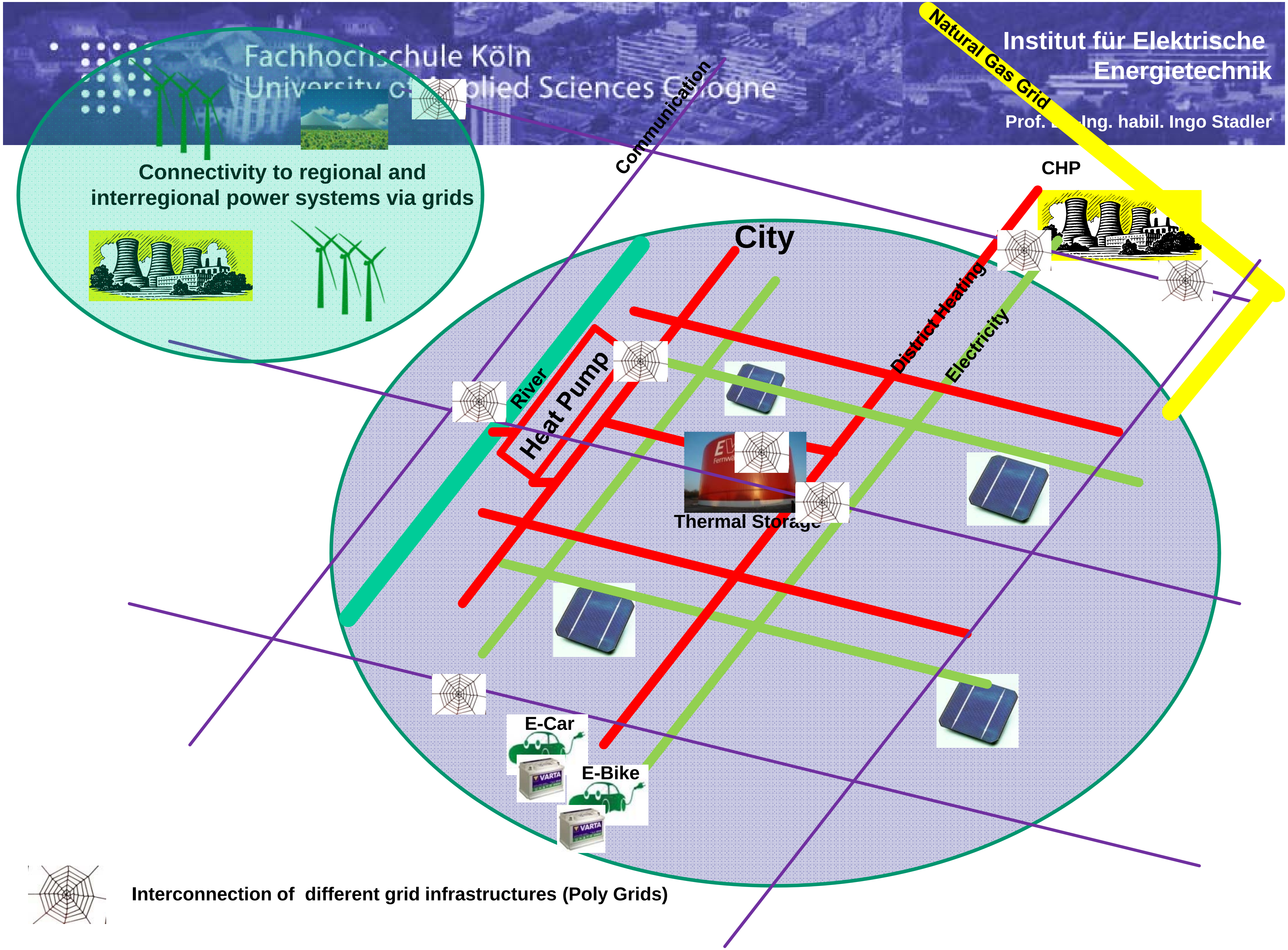
E-Car
E-Bike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Institut für Elektrische Energietechnik
Prof.
Ing. habil. Ingo Stadler
Connectivity to regional and interregional power systems via grids
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VARTA
Interconnection of different grid infrastructures (Poly Grids)

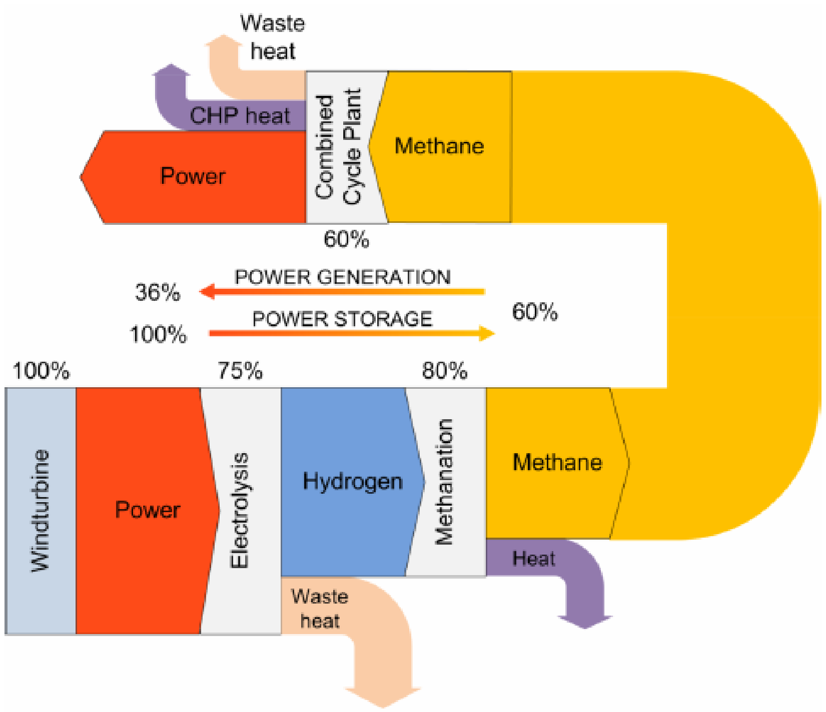
CELSIUS: Rotterdam – Heat Hub

A few words on LONG-term storage

- Bridging gaps of more than a week up to months …
  - all technologies fail
  - because of too low energy densities
- Only chemical energy carriers are capable to cover this gap
  - As far as is our knowledge today!
- Power-to-Gas
  - inefficient

„Renewable Methane“

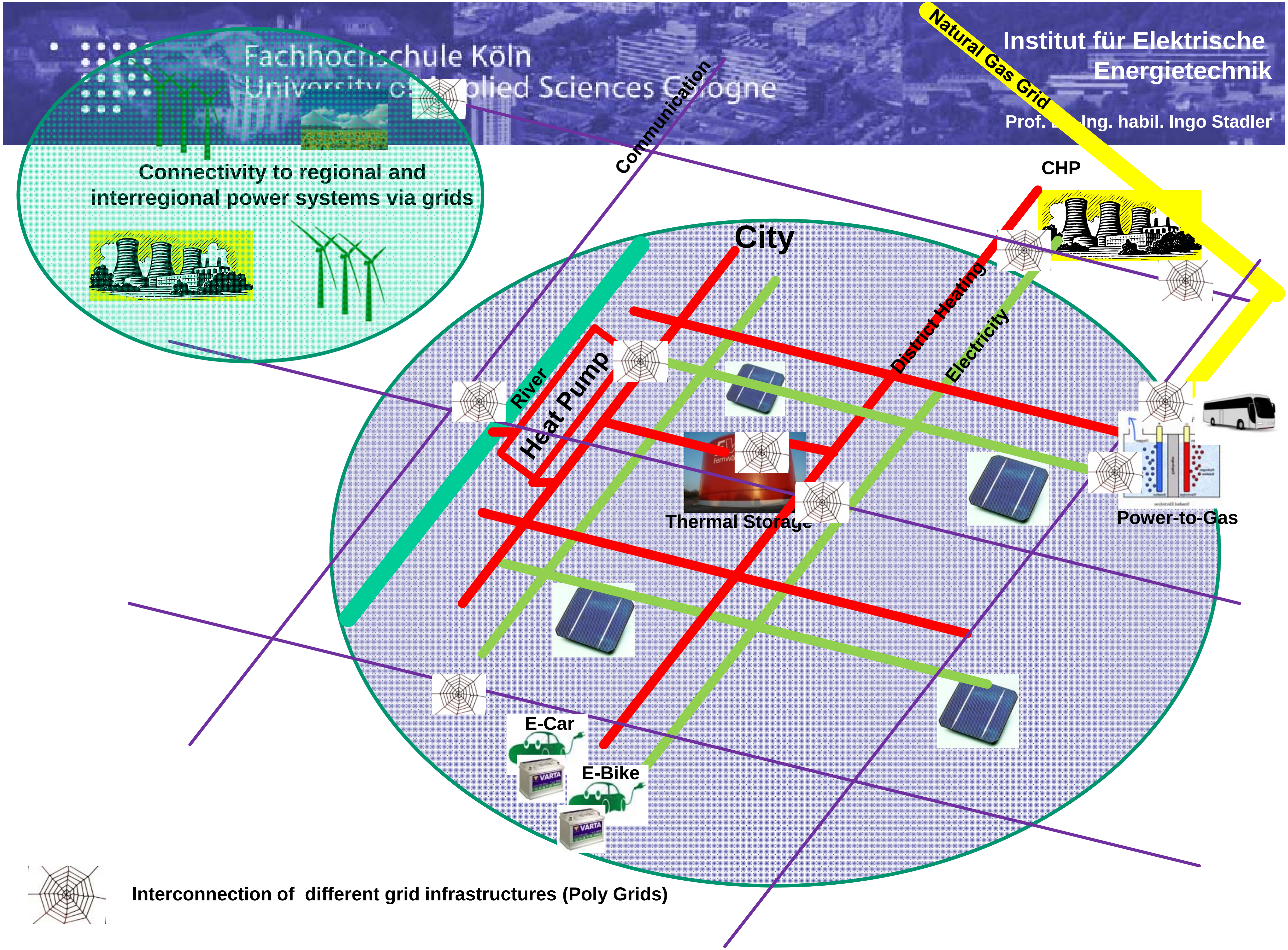
Renewable power (to) methane / SNG
Efficiency



60-65% SNG
35-40% Power
50-60% CHP
Vs. 0% due to power cut off

Source: Sterner, 2009

- Overall efficiency awful, even worse than hydrogen storage, but:
- **Use of waste heat when applied decentralized in a cites (temperatures >100°C)**
- Usage of existing natural gas infrastructure



Interconnection of different grid infrastructures (Poly Grids)

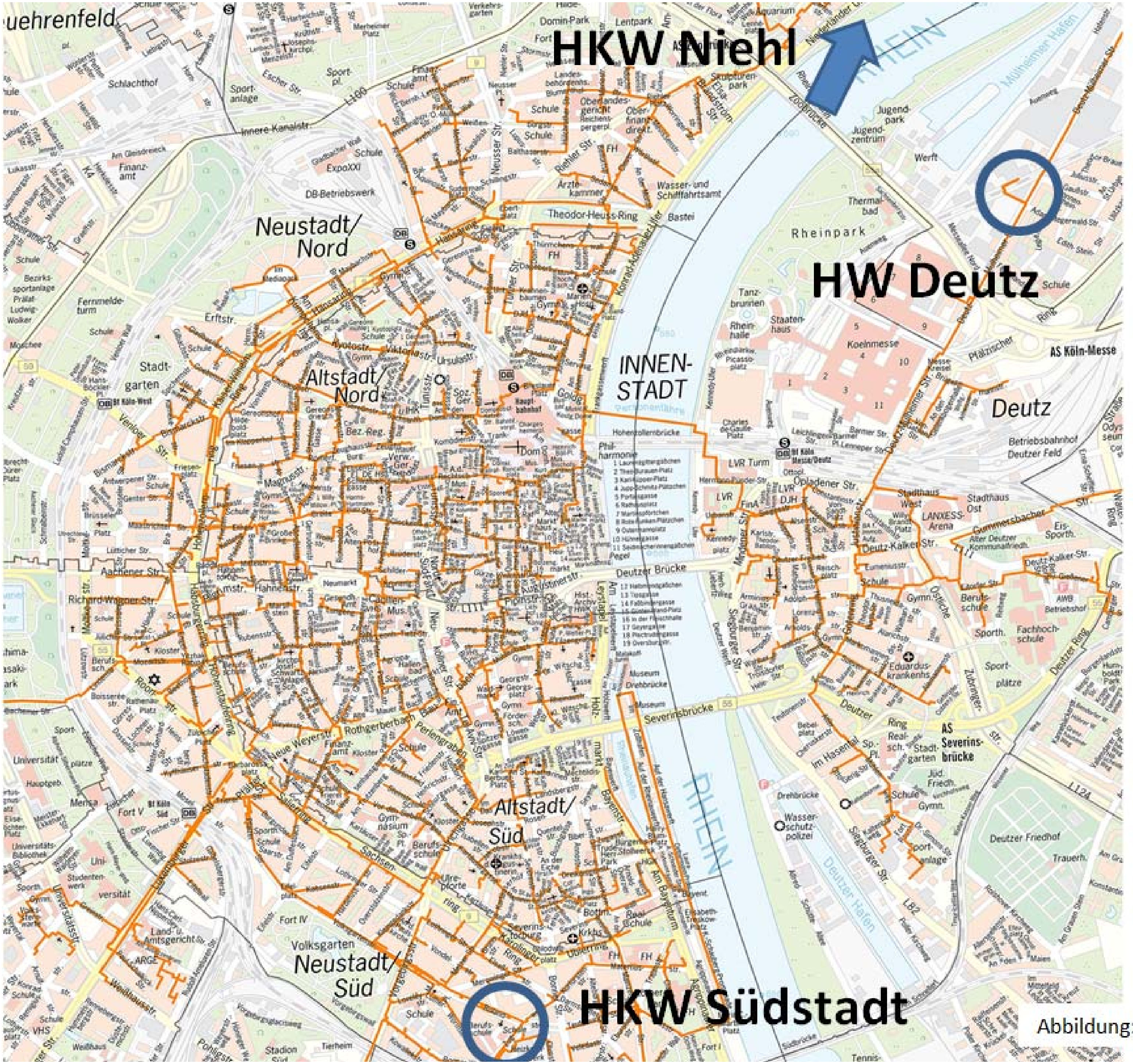
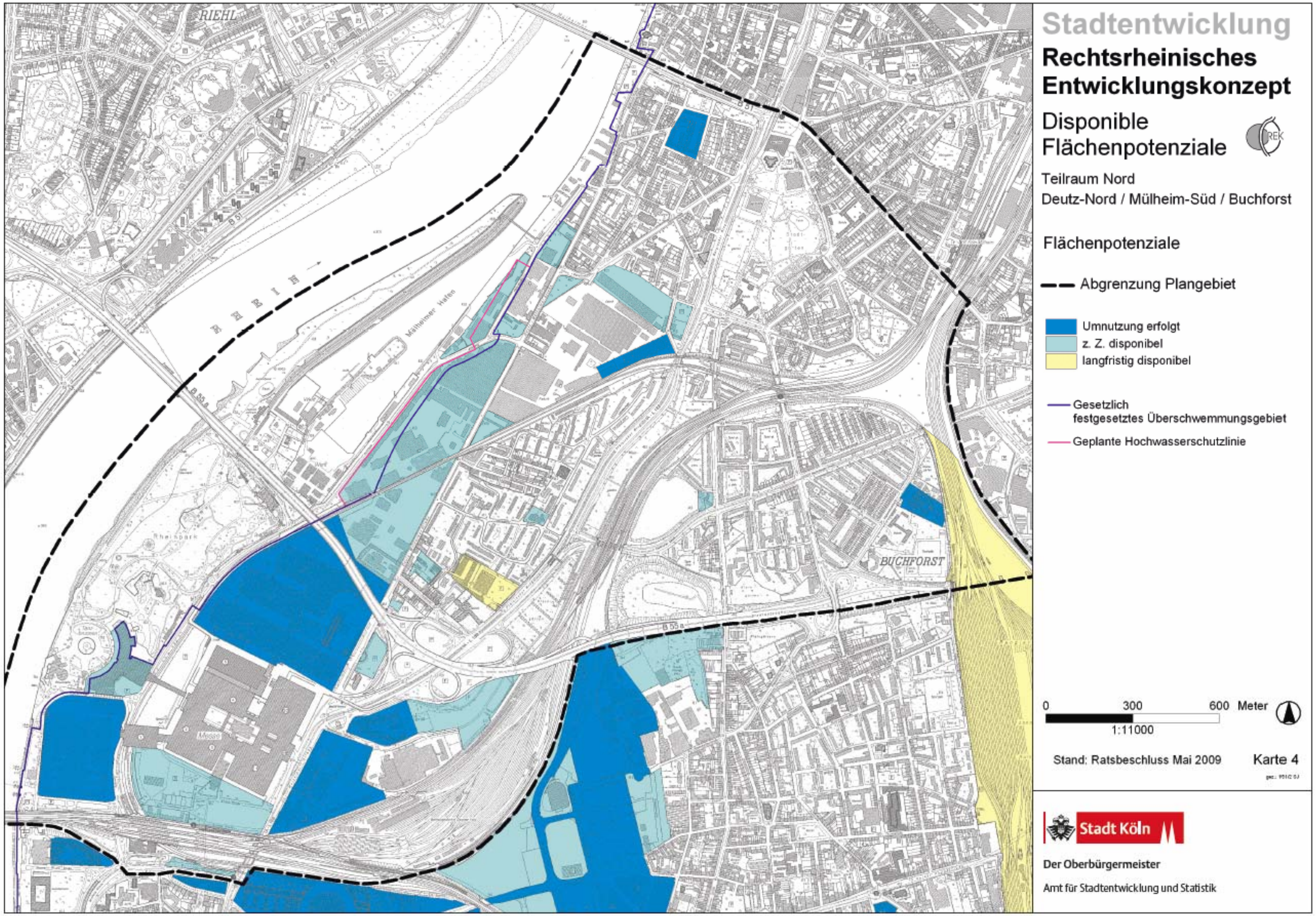


Abbildung: RheinEnergie AG


RIEHL
RHEIN
Mülheimer Hafen
Rheinpark
BUCHFORST
Stadtentwicklung
Rechtsrheinisches Entwicklungskonzept
Disponible Flächenpotenziale
Teilraum Nord
Deutz-Nord / Mülheim-Süd / Buchforst
Flächenpotenziale
Abgrenzung Plangebiet
Umnutzung erfolgt
z. Z. disponibel
langfristig disponibel
Gesetzlich festgesetztes Überschwemmungsgebiet
Geplante Hochwasserschutzlinie
0
300
600
Meter
1:11000
Stand: Ratsbeschluss Mai 2009
Karte 4
Stadt Köln
Der Oberbürgermeister
Amt für Stadtentwicklung und Statistik

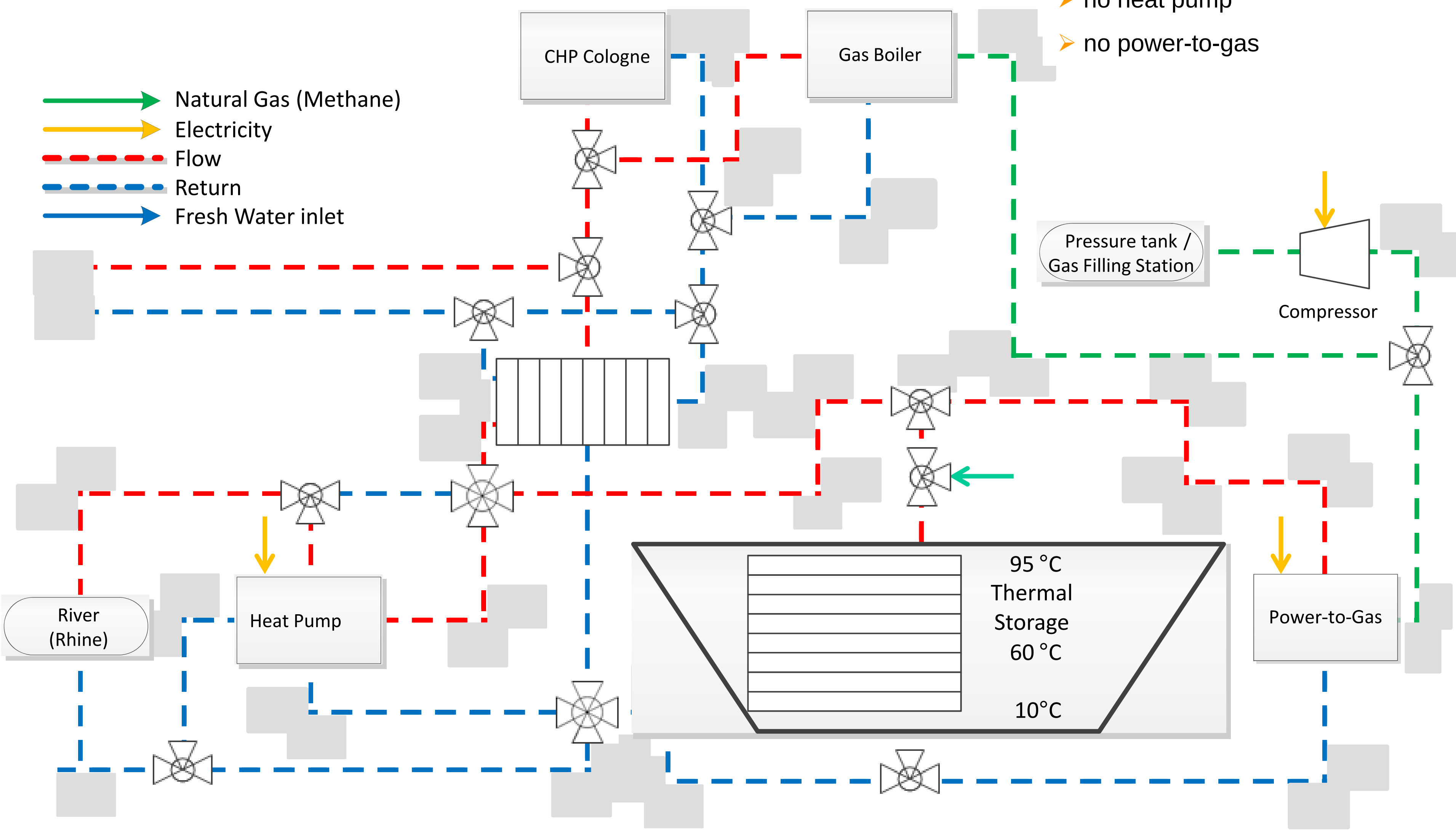
SmartCITY Cologne Mülheim

Masterseminar 13/14

Patrick Beuel, Benjamin Lehmann, Daniel Vehlow

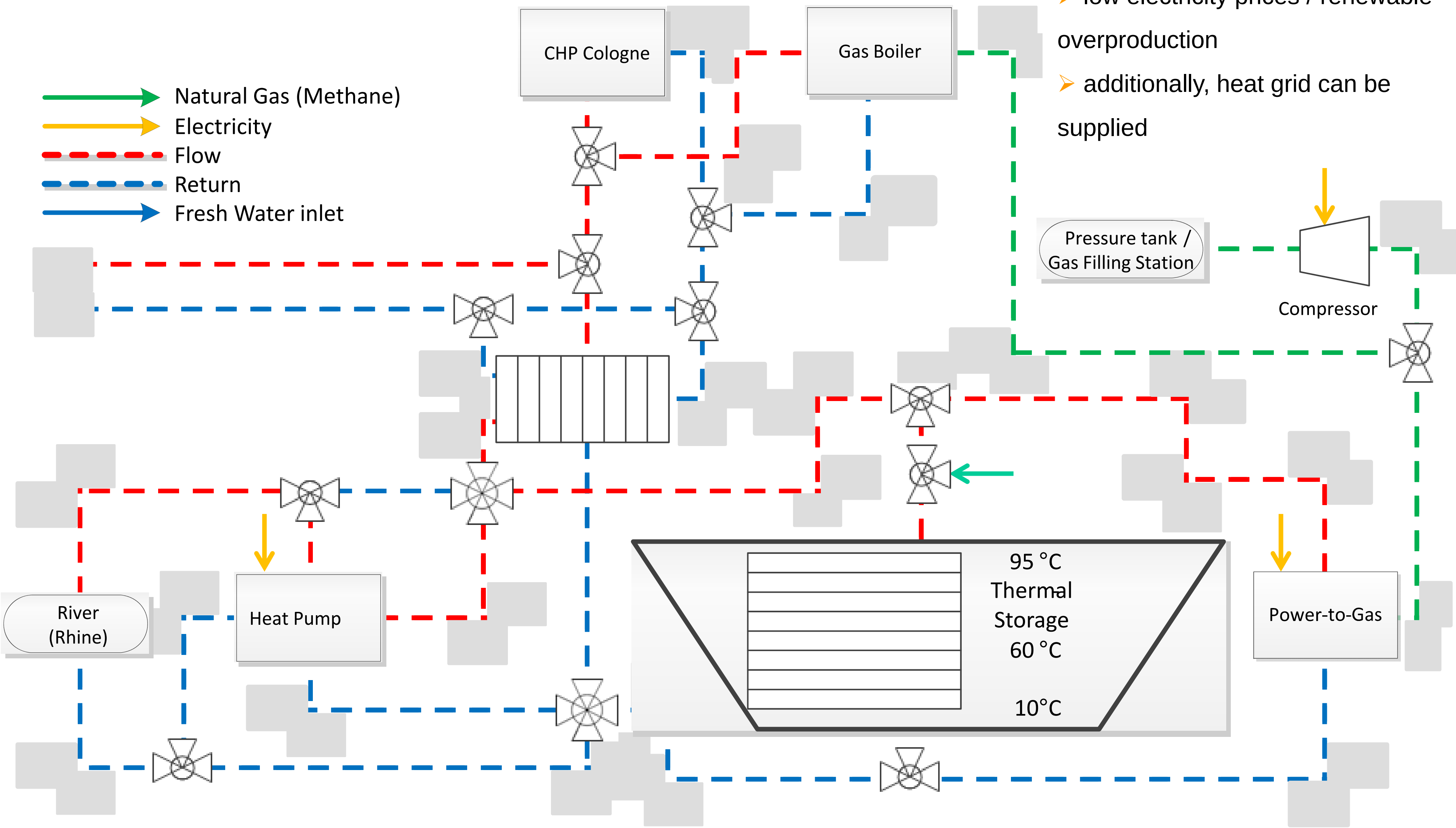
Today‘s system with CHP and District Heating only

- no storage
- no heat pump
- no power-to-gas



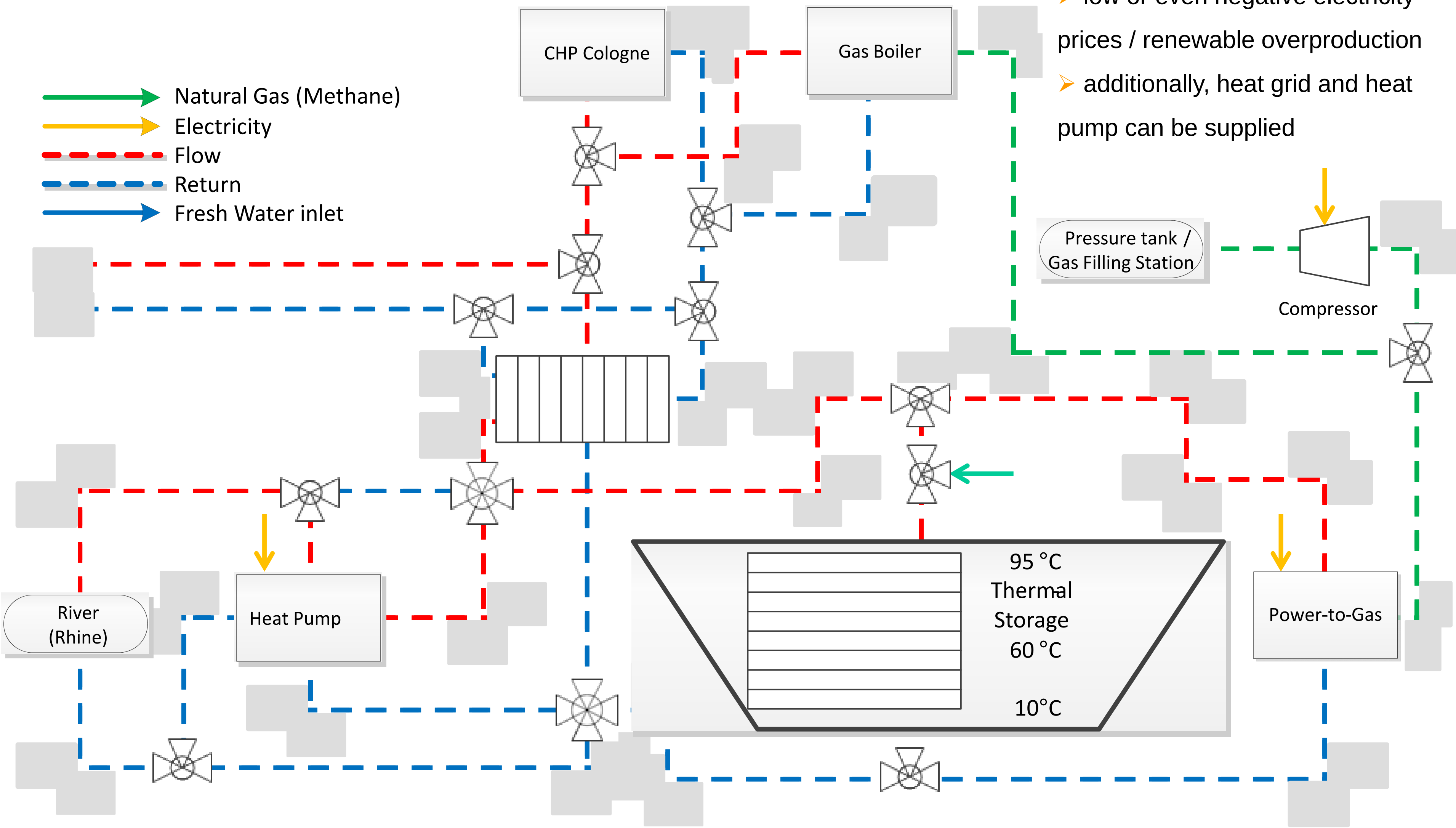
Charging Thermal Storage by: Heat Pump

- low heat demand
- low electricity prices / renewable overproduction
- additionally, heat grid can be supplied



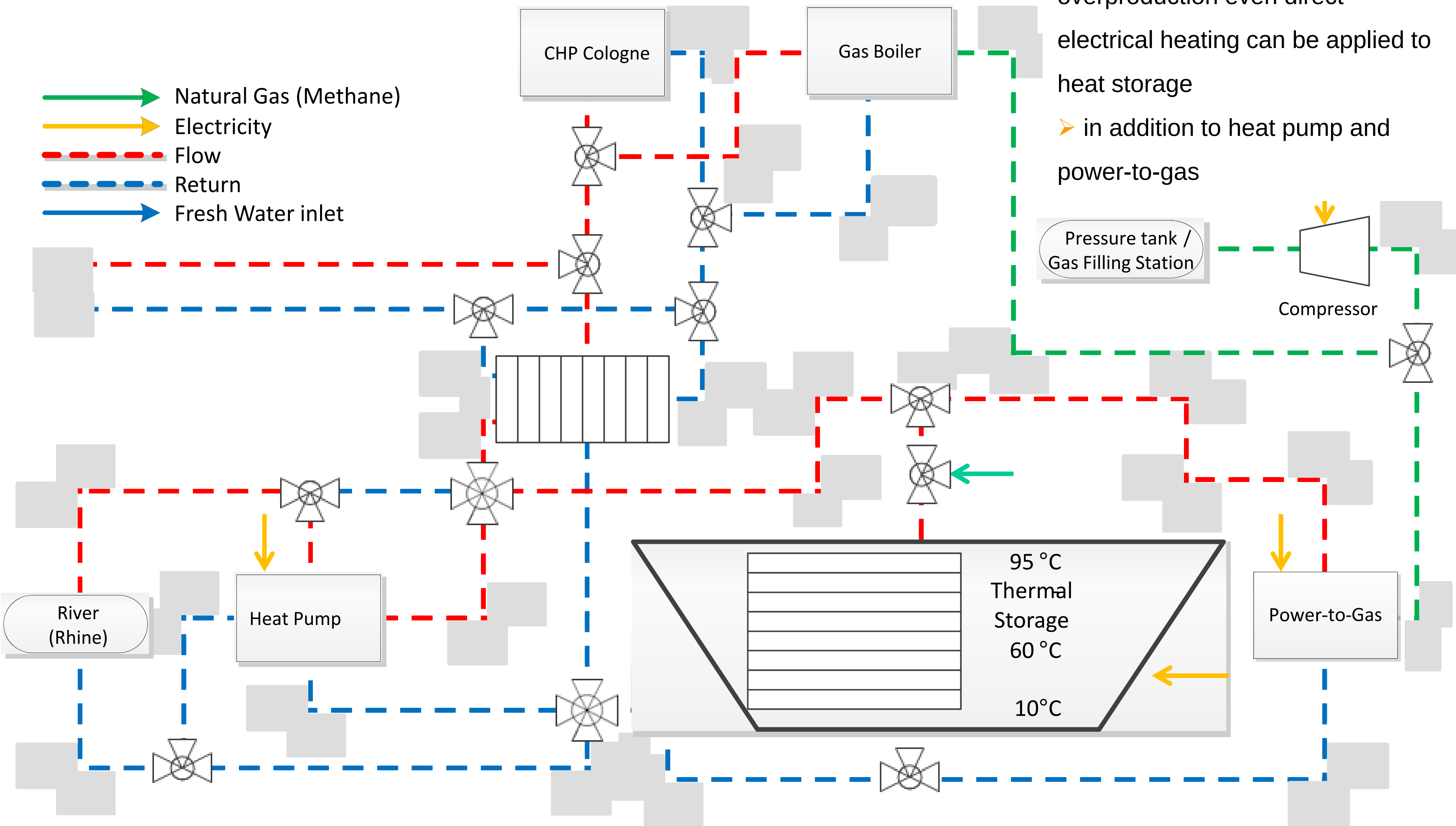
Charging Methane Storage by: Electrolysis and Methanisation

- low heat demand
- low or even negative electricity prices / renewable overproduction
- additionally, heat grid and heat pump can be supplied



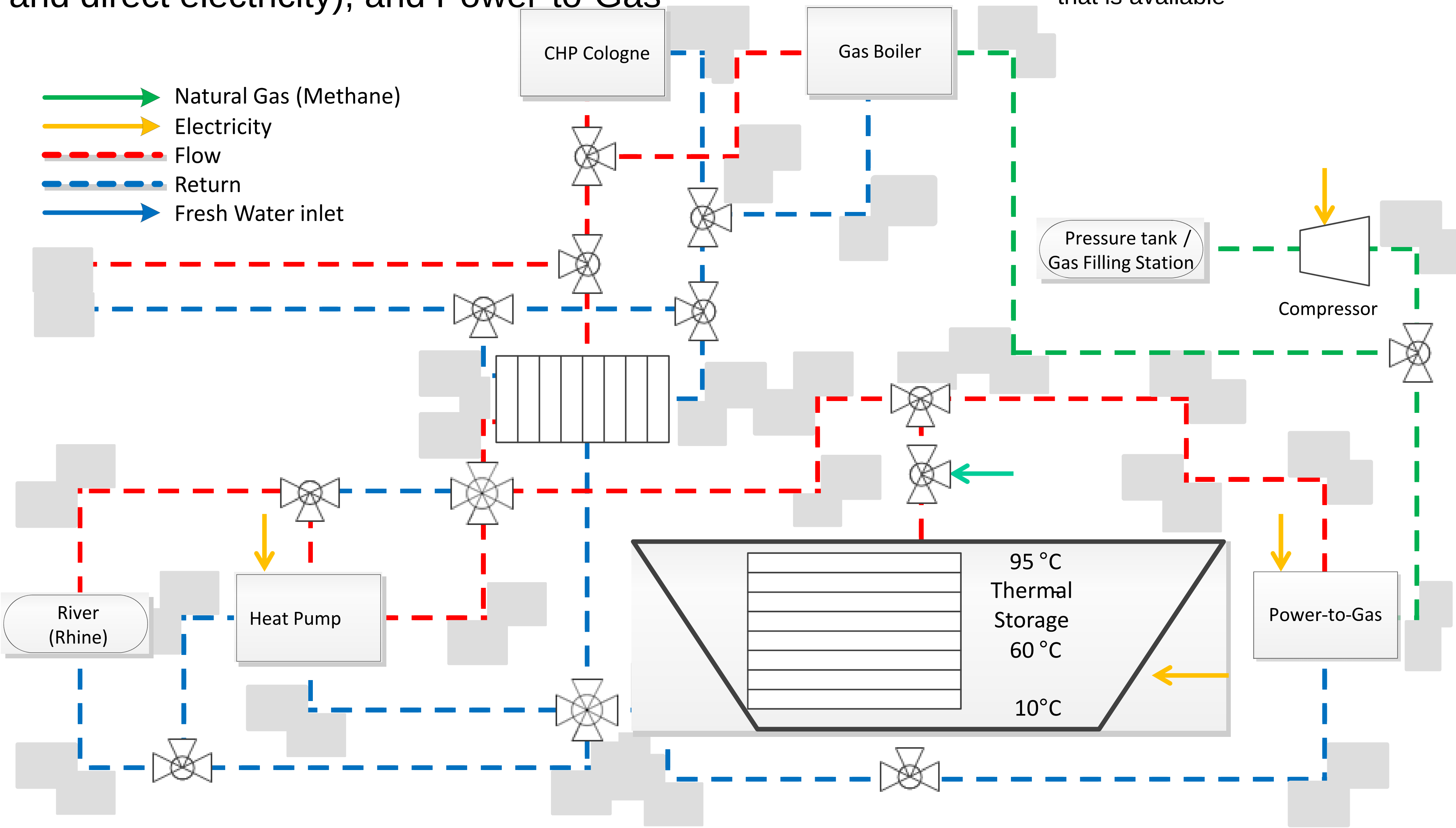
Charging Thermal Storage by: Electricity Overproduction

- in times of extreme overproduction even direct electrical heating can be applied to heat storage
- in addition to heat pump and power-to-gas



Charging Process by all means: Power-to-Heat (heat pump and direct electricity), and Power-to-Gas

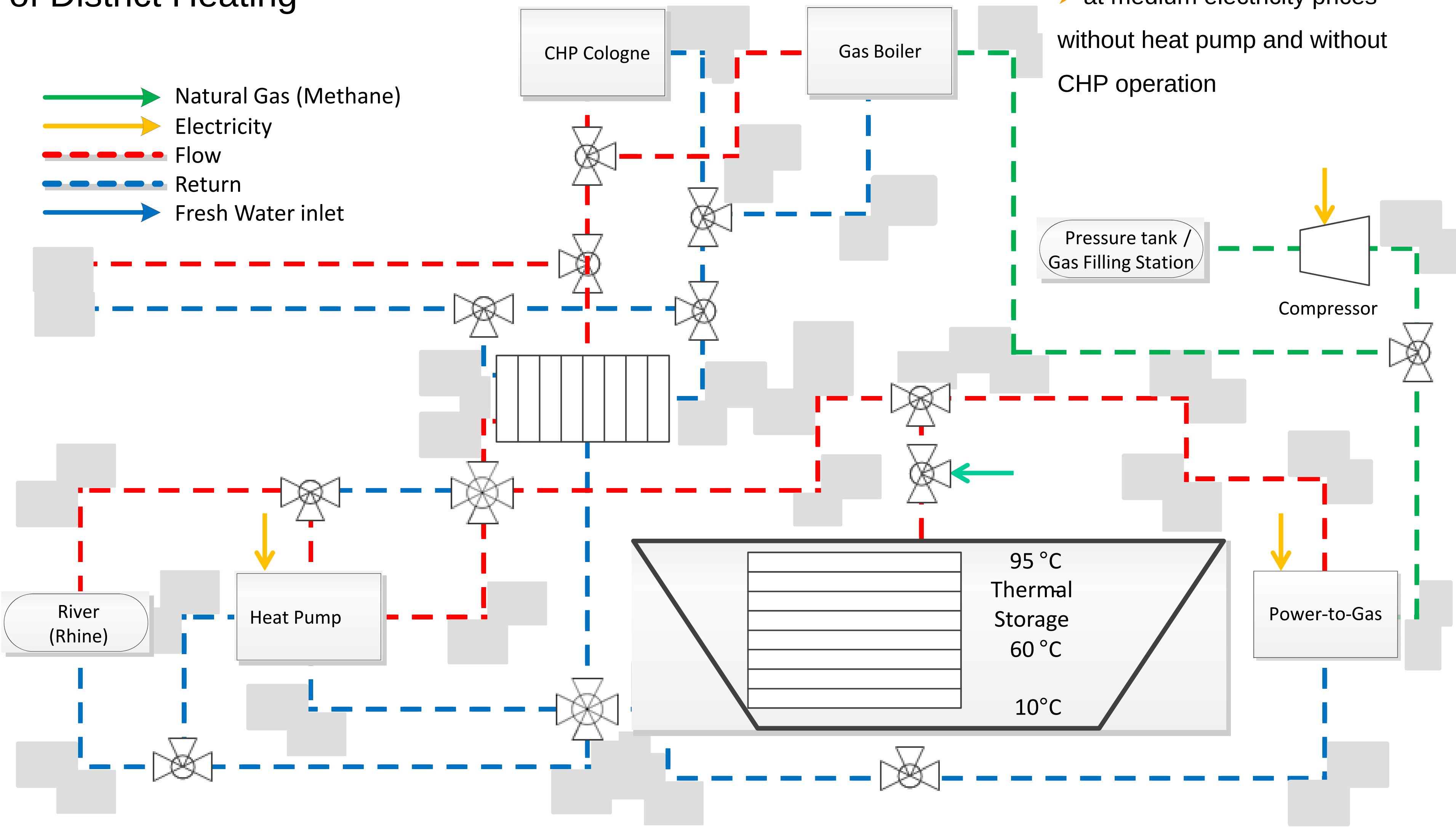
- charging thermal store with all that is available



Discharging Thermal Storage: Insertion of Heat into the Flow of District Heating

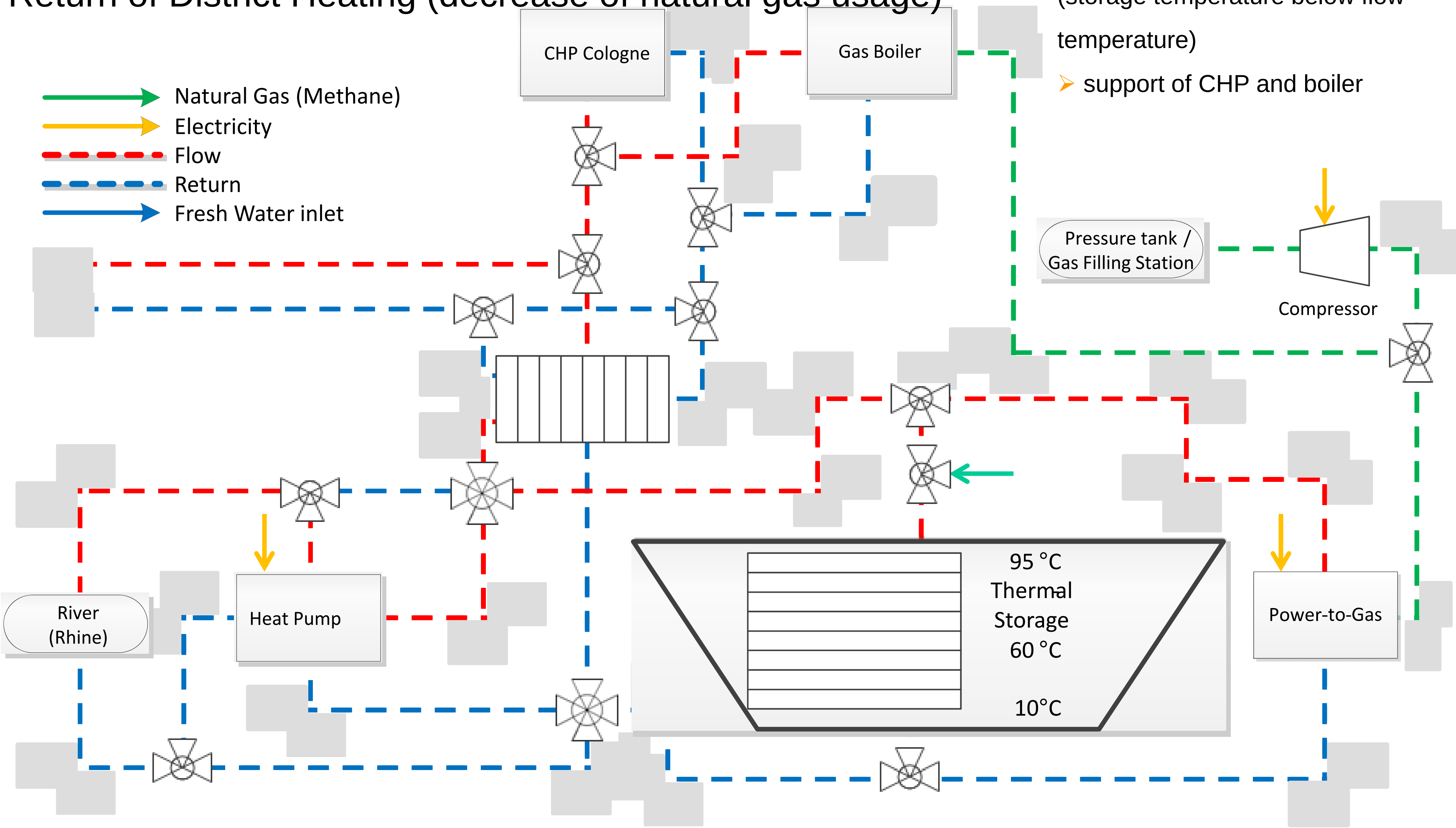
- at medium ambient temperatures
- at medium electricity prices

without heat pump and without CHP operation



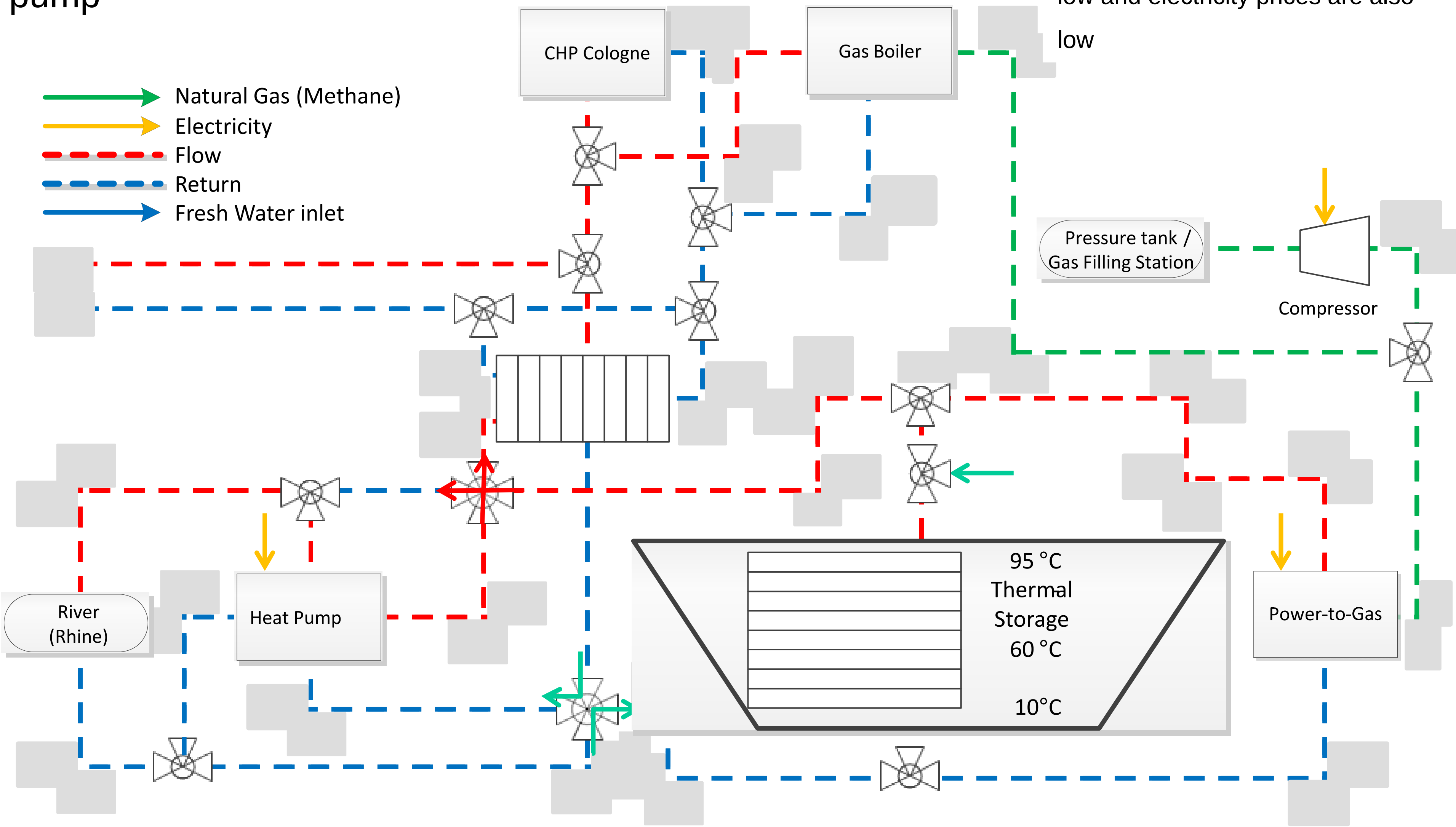
Discharging Thermal Storage: Insertion of Heat into the Return of District Heating (decrease of natural gas usage)

- with cold ambient temperatures (storage temperature below flow temperature)
- support of CHP and boiler



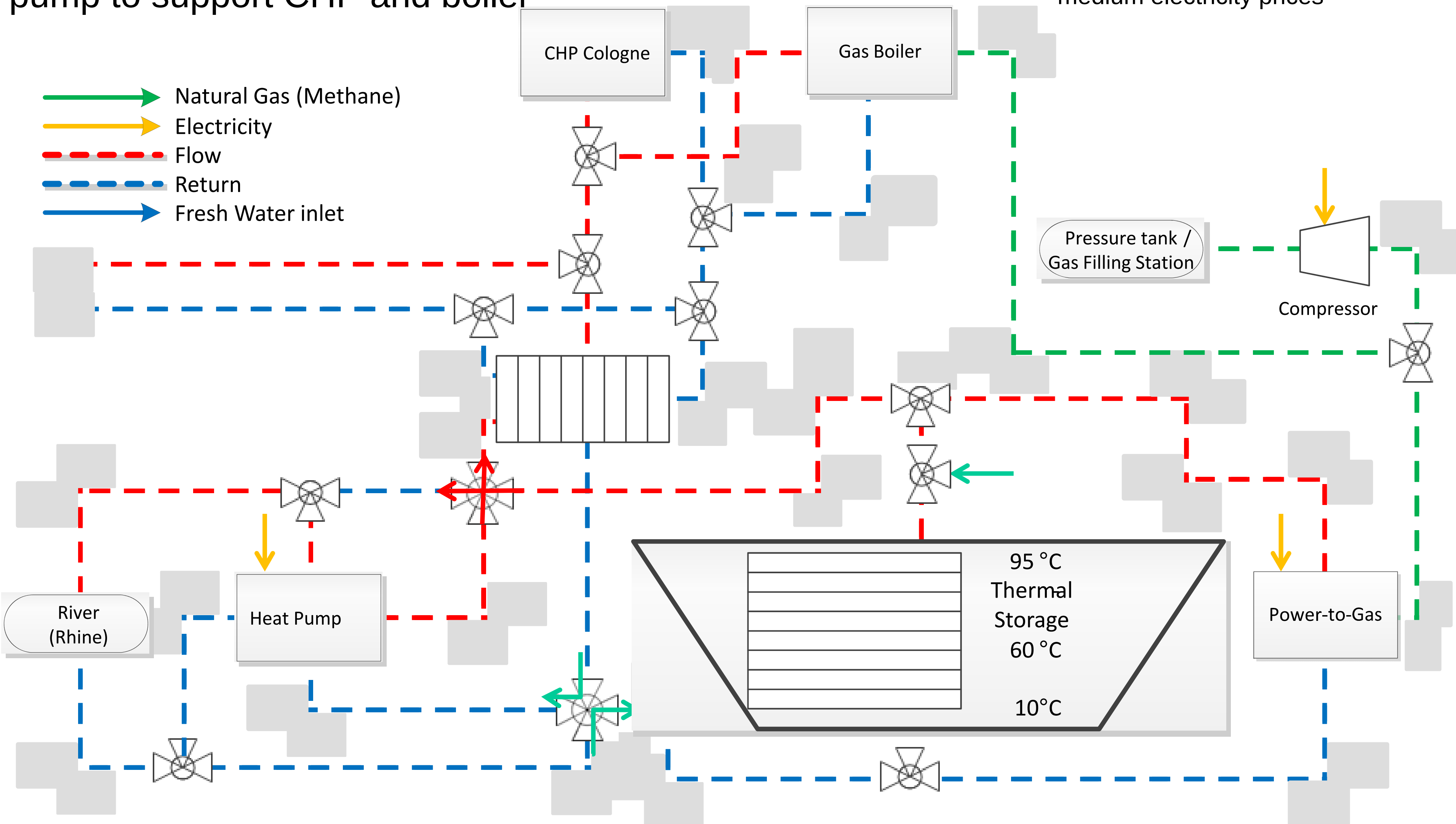
Heating: Discharging Thermal Storage as source for the heat pump

- When storage temperature is too low and electricity prices are also low



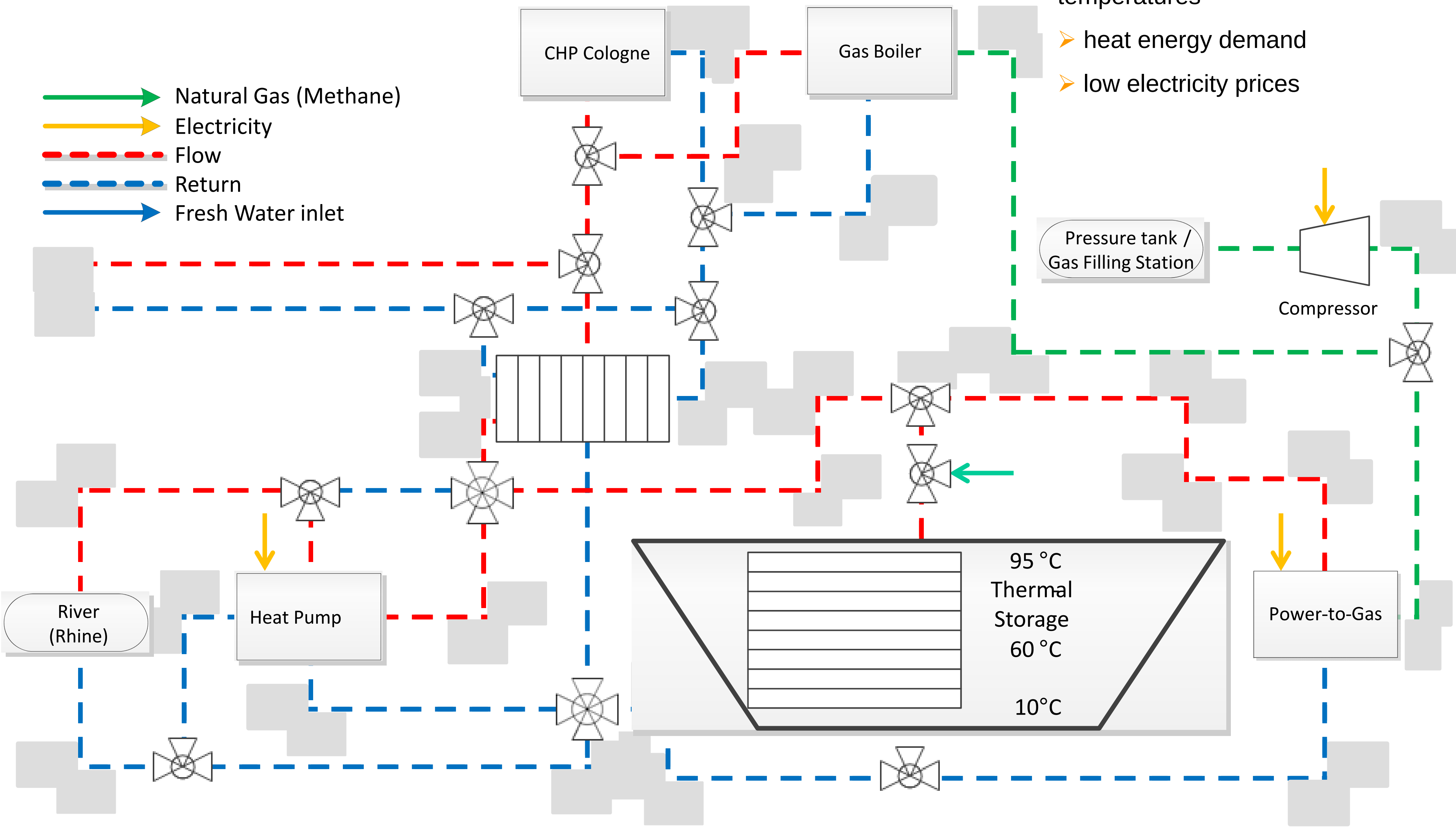
Heating: Discharging Thermal Storage as source for the heat pump to support CHP and boiler

- At low ambient temperatures, medium electricity prices



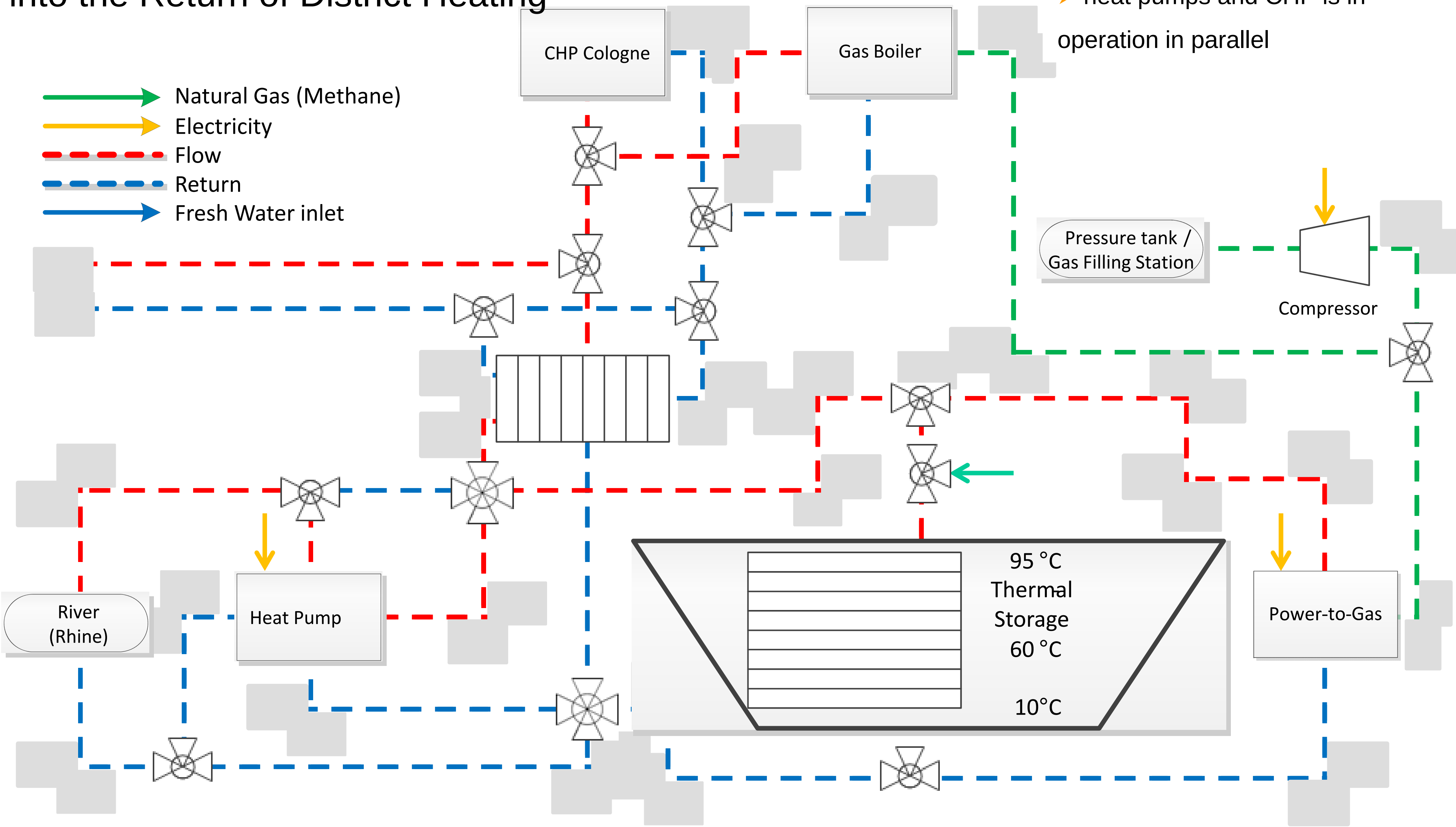
Heating: Heat pump into the Flow of District Heating

- with higher ambient temperatures
- heat energy demand
- low electricity prices



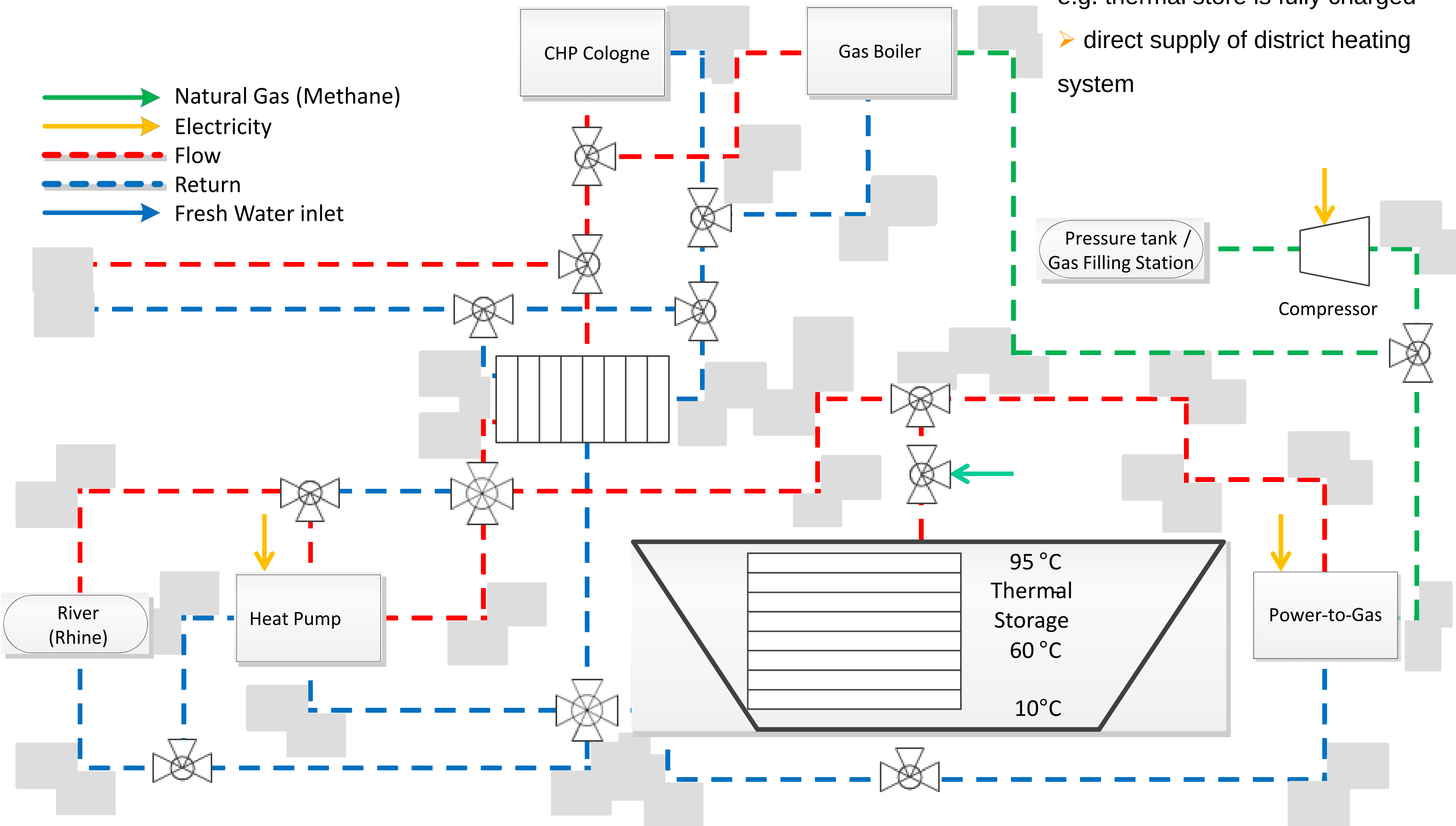
Heating: Insertion of Heat from heat pump into the Return of District Heating

- average electricity prices
- heat pumps and CHP is in operation in parallel

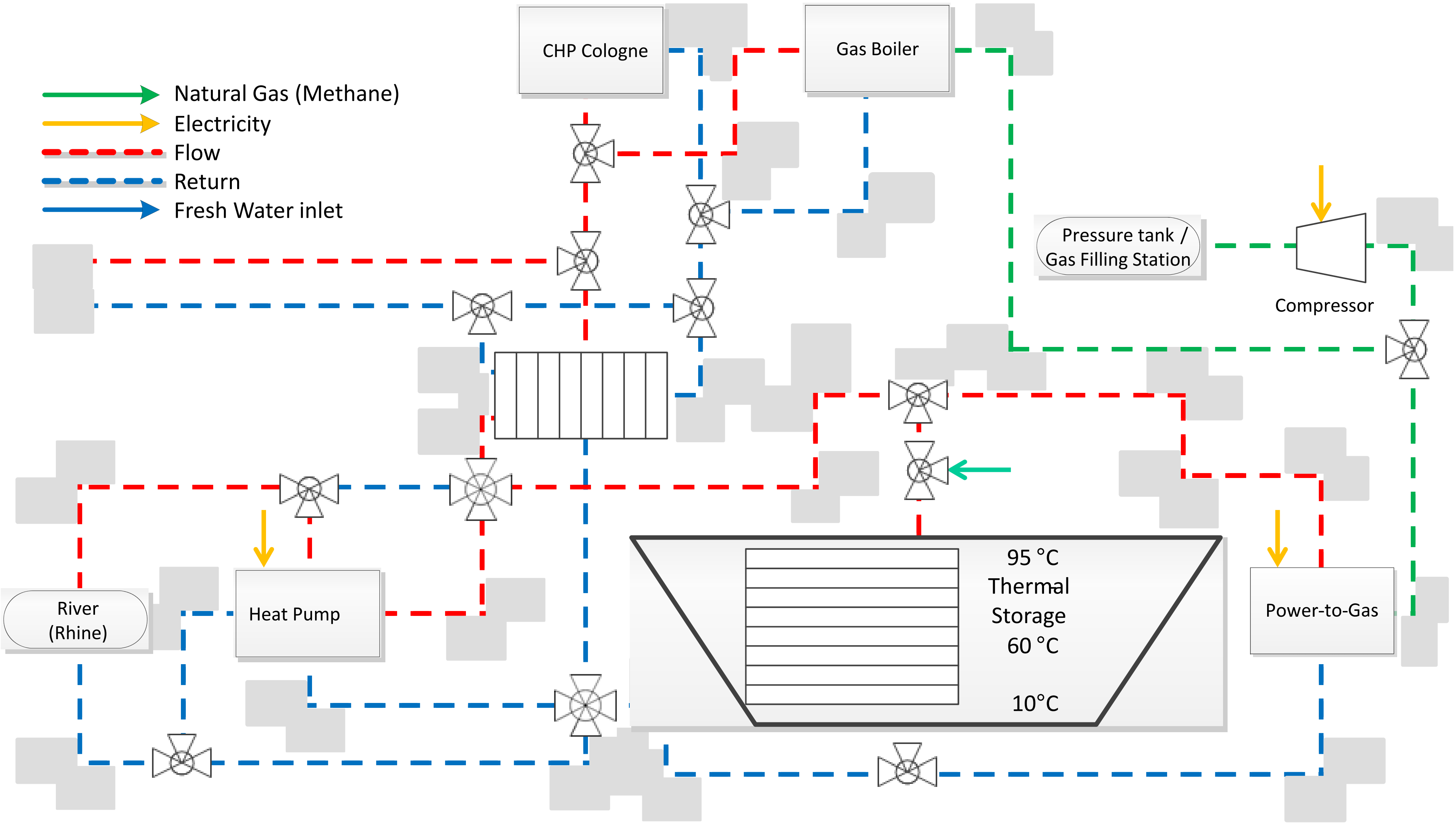


Heating: Using Methane from the Power-to-Gas Process

- filling up long term storage when e.g. thermal store is fully charged
- direct supply of district heating system

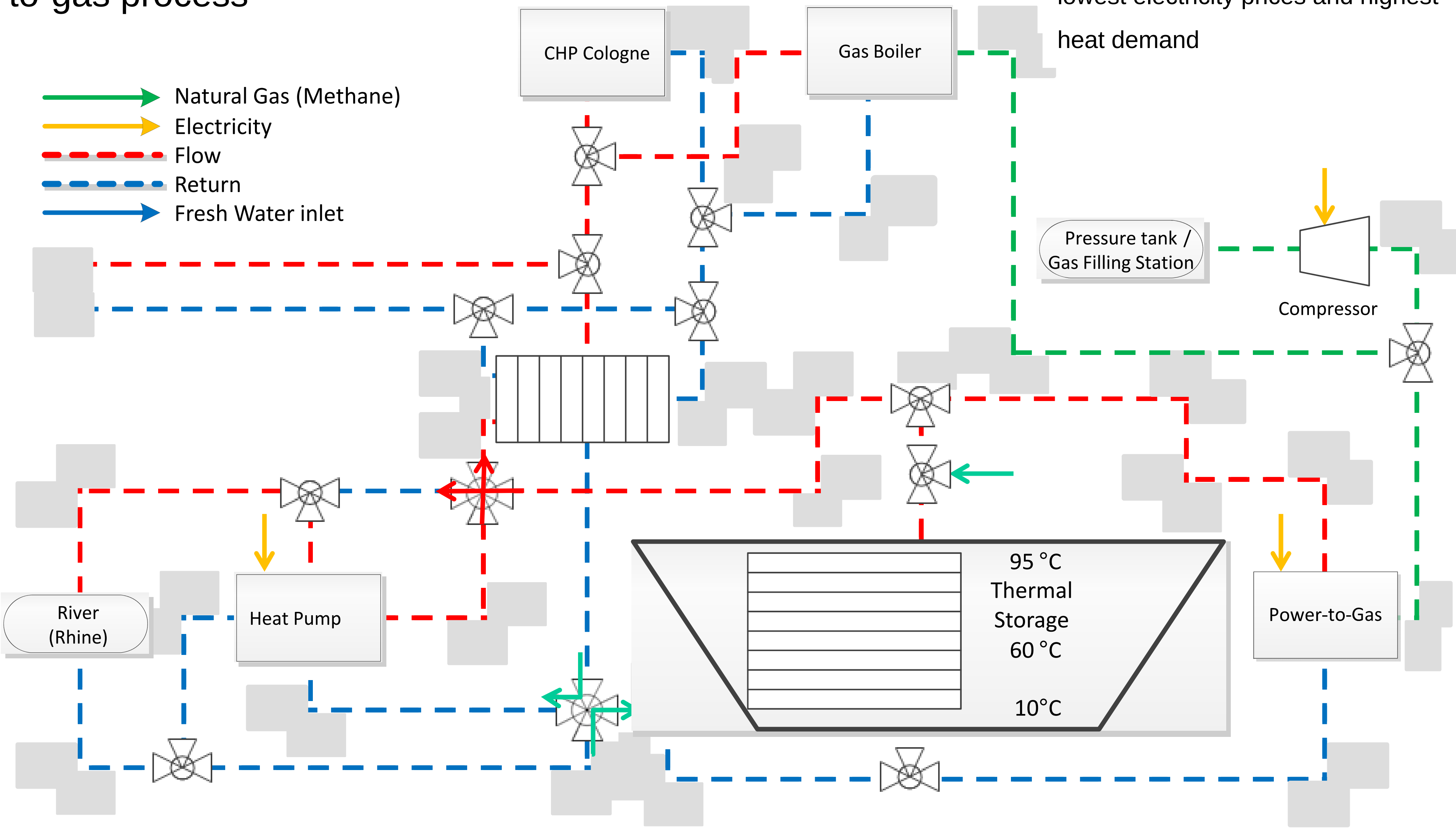


Heating: Combining heat pump and power-to-gas process



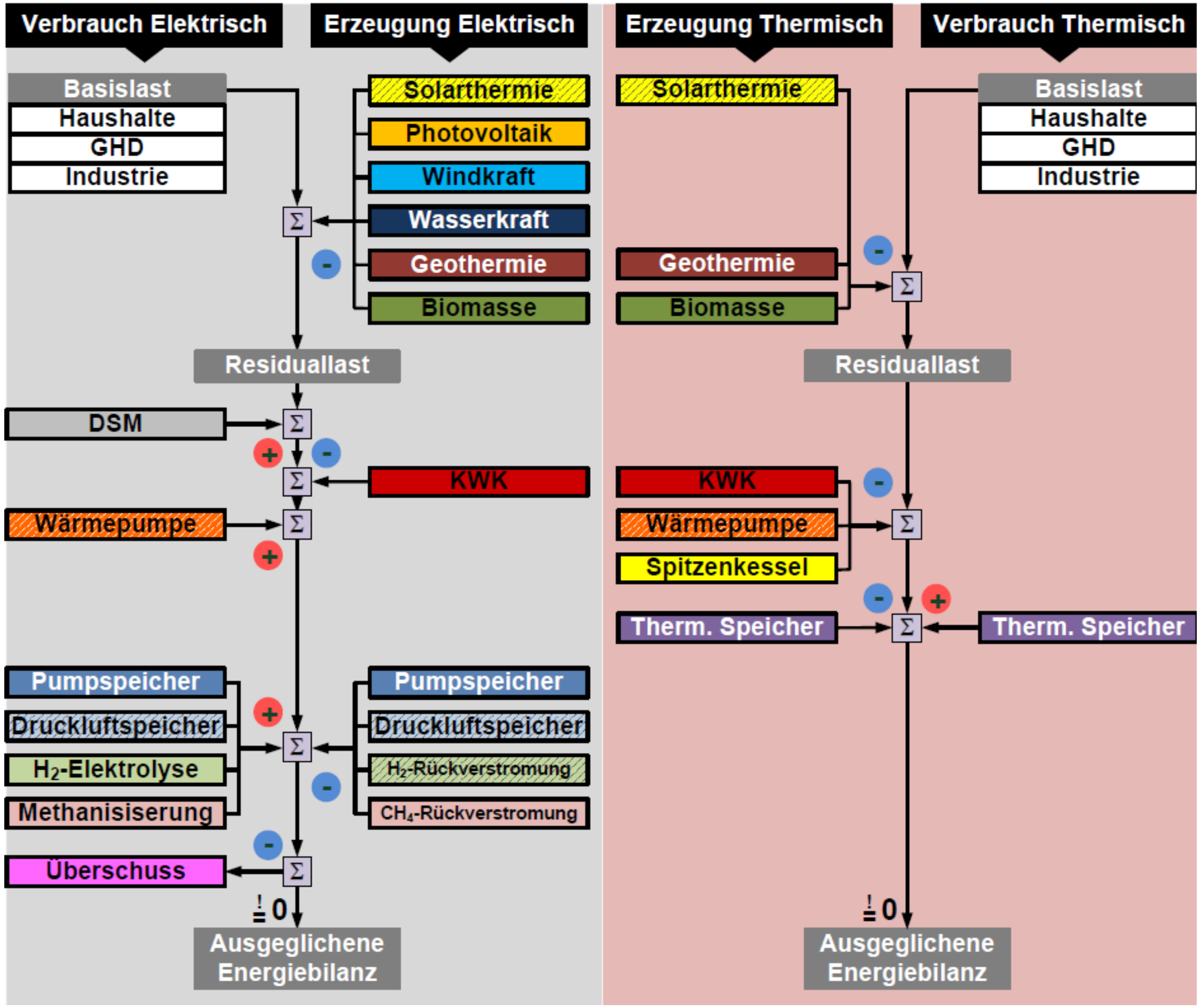
Heating: Combining heat pump, thermal storage and power-to-gas process

- discharging the thermal store at lowest electricity prices and highest heat demand



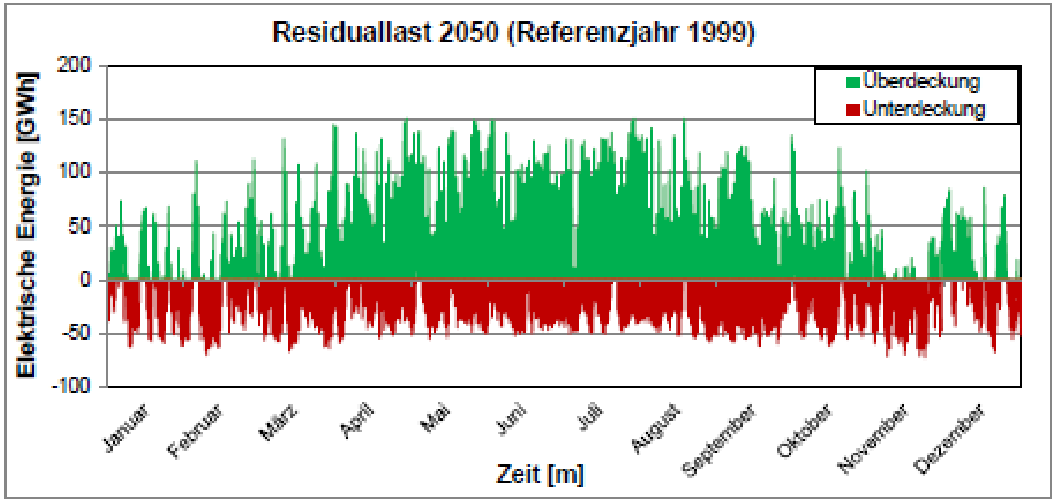
There is something more left!

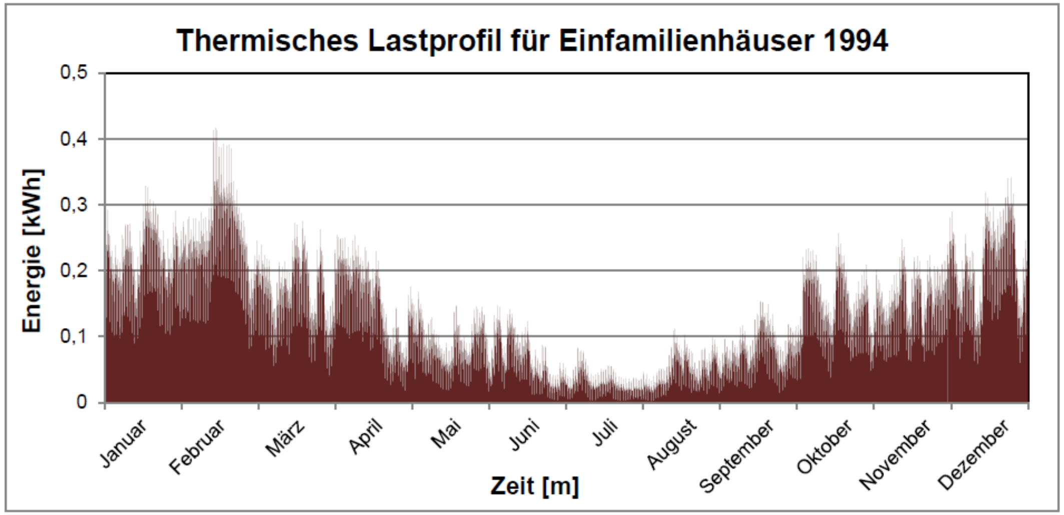
Only nice thoughts?



- … but doesn't not work in the real system?

Residual load left over





Results after energy system optimization

Stromkennzahlen	SK01_1996	SK01_2003	SK02_1996	SK02_2003	SK03_1996	SK03_2003	SK04_1996	SK04_2003	SK05_1996	SK05_2003	SK06_1996	SK06_2003
Speicherbare Tages-maximallasten [GWh]	Elektrische Unterdeckung nach KWK-Einsatz [GWh]											
0	128.701	-	105.737	-	84.841	-	65.834	-	50.491	-	38.899	-
2	122.580	105.875	94.068	77.902	68.545	54.155	45.849	35.776	28.827	22.680	17.624	14.283
4	121.172	-	91.425	-	64.994	-	41.677	-	24.642	-	13.984	-
6	120.247	103.096	89.961	73.236	62.508	47.207	39.491	27.452	22.536	14.475	12.213	7.389
8	119.839	-	89.009	-	61.268	-	38.149	-	21.378	-	11.489	-
10	119.339	101.492	88.379	70.356	60.452	43.518	37.286	23.278	20.686	11.206	11.277	5.838
	Durchschnittlich geleistete Volllaststunden der KWK-Anlagen [h]											
	3.338	-	3.231	-	3.133	-	2.984	-	2.815	-	2.617	-
	4.111	3.809	3.977	3.649	3.832	3.428	3.616	3.166	3.354	2.885	3.056	2.620
	4.286	-	4.141	-	3.981	-	3.747	-	3.458	-	3.125	-
	4.379	4.118	4.228	3.941	4.044	3.683	3.811	3.376	3.503	3.034	3.144	2.663
	4.443	-	4.282	-	4.091	-	3.847	-	3.527	-	3.151	-
10	4.482	4.280	4.318	4.088	4.121	3.807	3.869	3.454	3.538	3.050	3.149	2.641
	Verhältnis von KWK- zu Kesseleinsatz [%]											
0	0,41	-	0,39	-	0,38	-	0,36	-	0,34	-	0,32	-
2	0,50	0,50	0,48	0,48	0,46	0,45	0,44	0,41	0,41	0,37	0,37	0,34
4	0,52	-	0,50	-	0,48	-	0,45	-	0,42	-	0,38	-
6	0,53	0,53	0,51	0,50	0,49	0,47	0,46	0,44	0,42	0,39	0,38	0,35
8	0,53	-	0,51	-	0,49	-	0,46	-	0,43	-	0,38	-
10	0,53	0,54	0,51	0,51	0,49	0,48	0,46	0,44	0,43	0,40	0,38	0,35
	Bedarf an installierter Methanspeicherkapazität [GWh]											
0	429.817	-	306.005	-	193.463	-	91.292	-	17.988	-	7.829	-
2	397.572	335.009	245.024	195.666	108.906	77.370	19.091	10.732	9.132	3.198	4.427	1.937
4	389.809	-	230.377	-	89.331	-	17.030	-	8.528	-	3.955	-
6	384.618	319.892	222.042	170.267	75.845	39.940	15.994	5.676	8.159	2.588	3.831	1.279
8	382.274	-	216.690	-	68.933	-	15.563	-	8.112	-	3.808	-
10	379.514	311.024	213.182	154.439	64.426	22.086	15.317	5.463	8.075	2.387	3.802	1.179

Thermal storage given in hours of maximum heat load

CHP power to heat ratio

Electricity demand not covered by CHP and renewables

Full load hours

CHP coverage rate

Required Methane storage capacity

1996:
bad wind year
bad solar year

2003:
Excellent wind year
average solar year

Conclusion

- By combining different energy sectors energy supplies can be converted towards renewables without the usage of electricity storage
- That means only by
  - Demand Side Management,
  - Heat Storage in combination with CHP and heat pumps, and
  - Power-to-Gas technology
- Therefore, the "energy storage problem" becomes marginal

- But life is different from science

- Together with lobbyist pressure our government started to subsidize the most expensive way of energy storage: batteries

THANK YOU FOR YOUR ATTENTION