CO_2 capture combined with utilization

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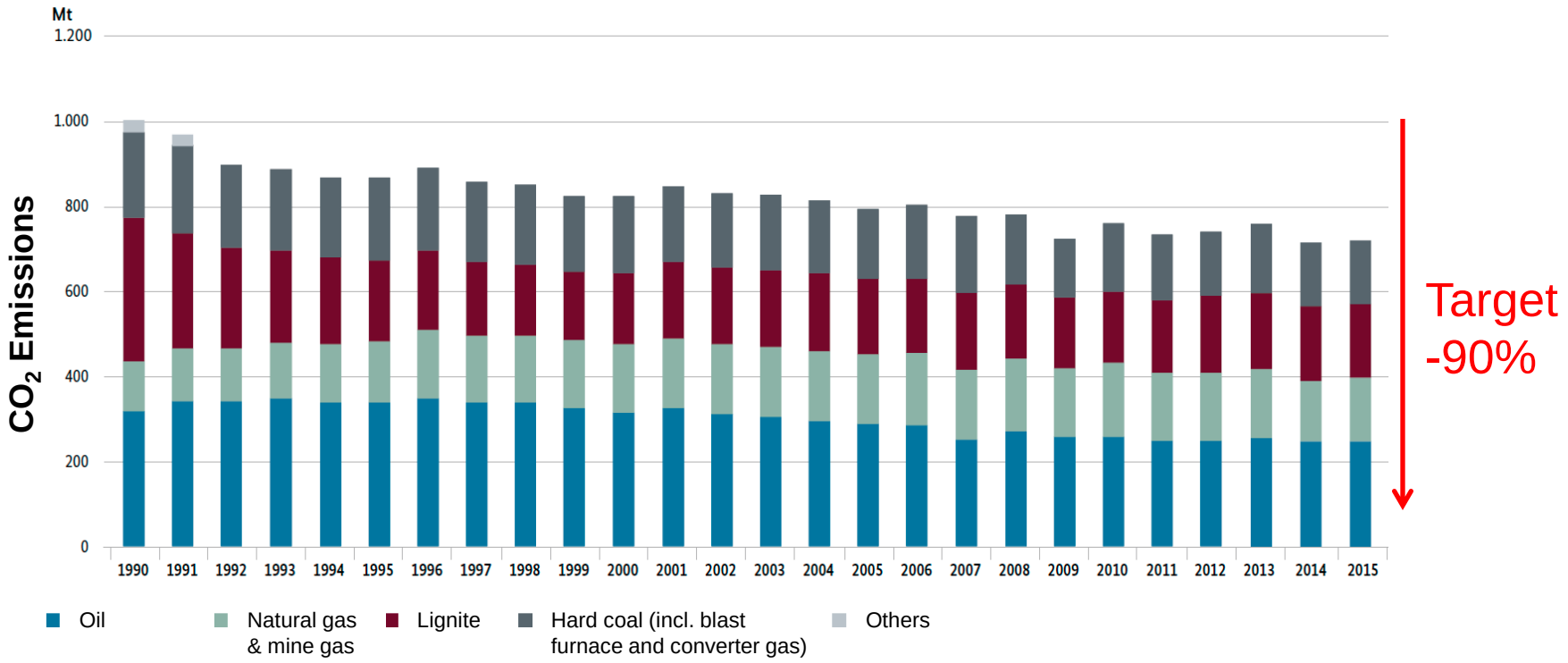
POWERING. RELIABLE. FUTURE.

RWE

Energy-related CO_2 Emissions in Germany:
Oil > Lignite ≈ Hard coal ≈ Natural gas



Source: Arbeitsgemeinschaft Energiebilanzen (AGEB), Umweltbundesamt (UBA)

To meet the German climate protection targets (80-95% less CO_2 emissions compared to 1990 until 2050) all economic sectors have to contribute: power generation, transport, industry, households

Same Options for Reduction of CO_2 Emissions for fossil-based Power Plants and Industries

CO_2 Mitigation → **CO_2 Capture and Utilisation** → **CO_2 Storage**

- Continuous efficiency enhancement

- Research focus at RWE Power

- Missing public acceptance and regulatory framework are blocking CCS in several countries

- The source of CO_2 is irrelevant for the utilisation and climate protection, as long as less CO_2 is emitted and fossil fuels can be substituted
- The CCU product becomes more “green“ the more renewable energy is used in the process

CO_2 Capture – Solid Knowledge Base
RWE: Several PCC projects using real flue gas

European Union
R&D projects
CASTOR/CESAR
Dong power plant
(hard coal)
Esbjerg, DK
Commissioning 2005

BASF's OASE® blue
Engineering form Linde
RWE power plant
(lignite)
Niederaussem
Germany
Commissioning 2009

PCC pilot plant at Niederaussem
>60.000 operating hours

OASE® blue: 2.5 GJ/t_{CO2}, <300 $g_{solvent}$/t_{CO2}

2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

Alstom's
Chilled Ammonia
We Energies
P4 power plant
(hard coal)
USA
Commissioning
2008

Alstom's
Chilled Ammonia
AEP power plant
(hard coal)
Mountaineer
USA
Commissioning
2009

Shell's Cansolv
RWE power plant
(hard coal)
Aberthaw
UK
Commissioning
2013

- PCC is ready for large-scale application and CCU
- High purity of the CO_2 captured by PCC is ideal for CCU, no complex treatment necessary
- PCC is the only option to realise a significant reduction of CO_2 emissions in existing large-scale industrial plants and power plants using fossil fuels
- Retrofit ability and adaptability to specific feed gas properties (avoidance of aerosols)

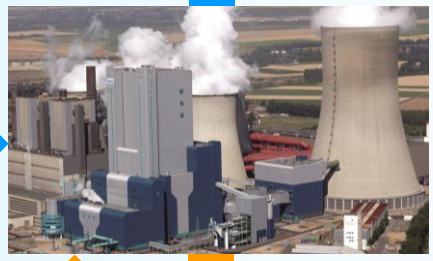
Coal Innovation Centre at Niederaussem

Interconnected pilot plants and flue gas pre-treatment

Lignite combustion

Lignite

Power plant



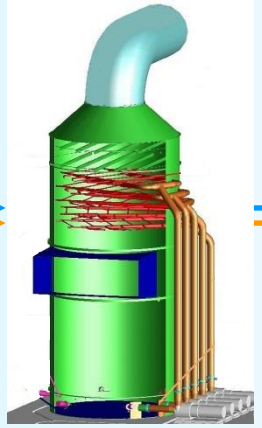
Flue gas, raw lignite

Flue gas, dry lignite

Pre-drying WTA®

Flue gas pre-treatment

Conventional FGD



Dust dosing

SO_2/SO_3 dosing

FGDplus

Wet ESP

Post combustion capture

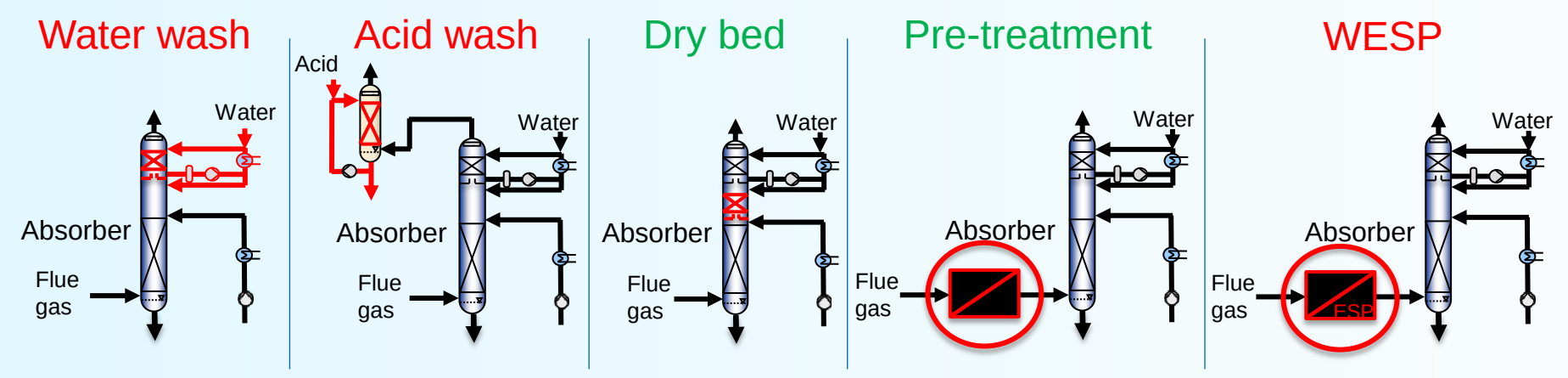
CO_2-lean flue gas

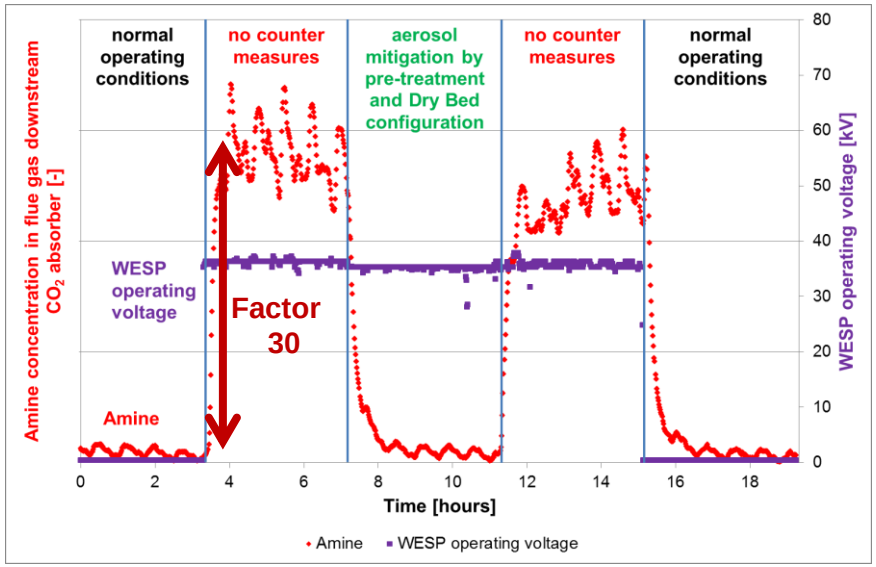
CO_2

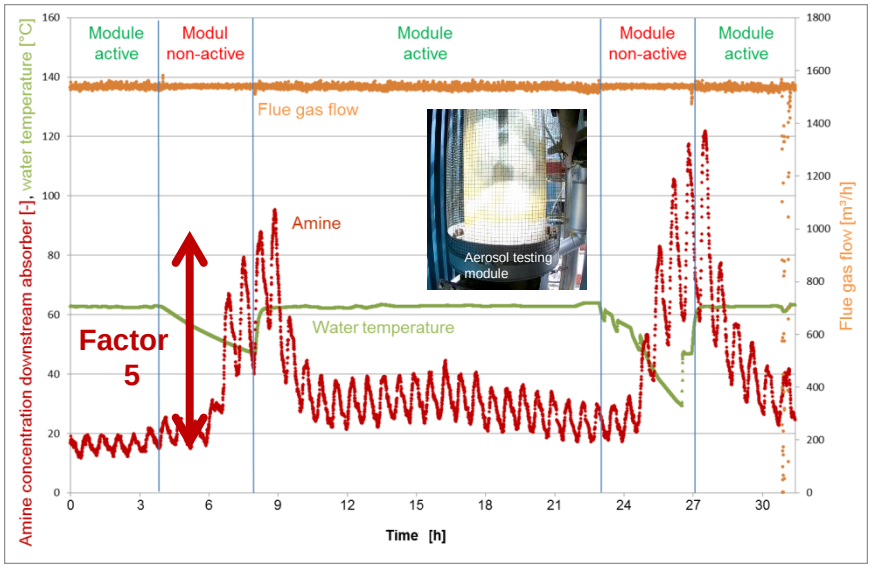
Capture Plant

Effective Aerosol Mitigation Measures are available

Validated by long-term testing with real flue gas







RWE was and is involved in several CCU Projects

Focussing on the full CCU chain

Power plant

Post combustion capture

CO_2 compression liquefaction

CO_2

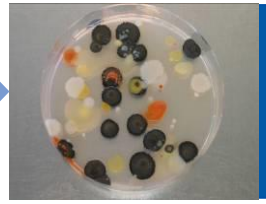
Flue gas

Flue gas

Direct Utilisation
Waste water treatment

Chemistry
Polyurethane synthesis

Chem. Energy Storage
Power to methane/methanol



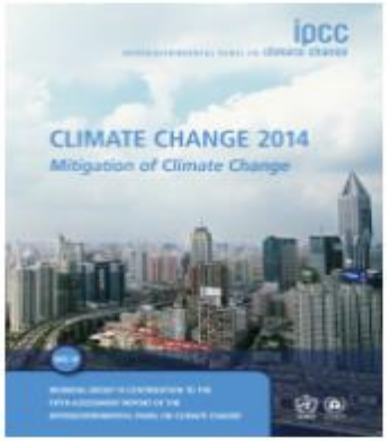
Biotechnology
Bacteria, BRAIN AG

Biology
Algae pilot plant

Before CCU/CCS will be implemented in large-scale some barriers must be broken down

- Although CCU/CCS is needed as cost-effective climate protection measure, public acceptance is missing in several European countries

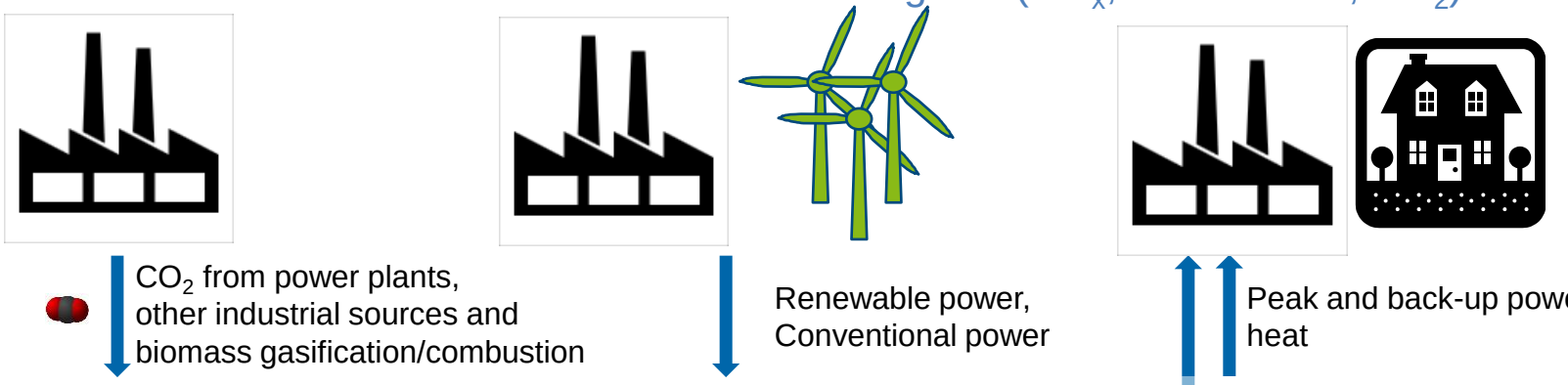
- Main reasons are:
  - Lack of demonstration of the full CCU/CCS chain hinders an objective discussion due to missing knowledge in the public
  - Competition with alternative climate protection measures
  - Lack of an appropriate regulatory framework



- CCU offers more socio-economic benefits by sector coupling than ”only” providing climate protection
- Further development and demonstration of the full CCU chain and its benefits is needed together with regulatory frameworks that allocate the benefits of CCU

Demonstration of CCU and Sector Coupling:

CCU, chemical long-term energy storage, fuel for peak power generation and transport sector
Co-benefit: DME lowers emissions of Diesel engines (NO_x, Particulates, CO_2)



Demonstration Plant


Electrolyser


Peak power generation

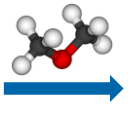

CO_2 PCC


CO_2 tank

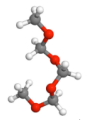
H_2

CO_2


DME synthesis




DME tank


OME

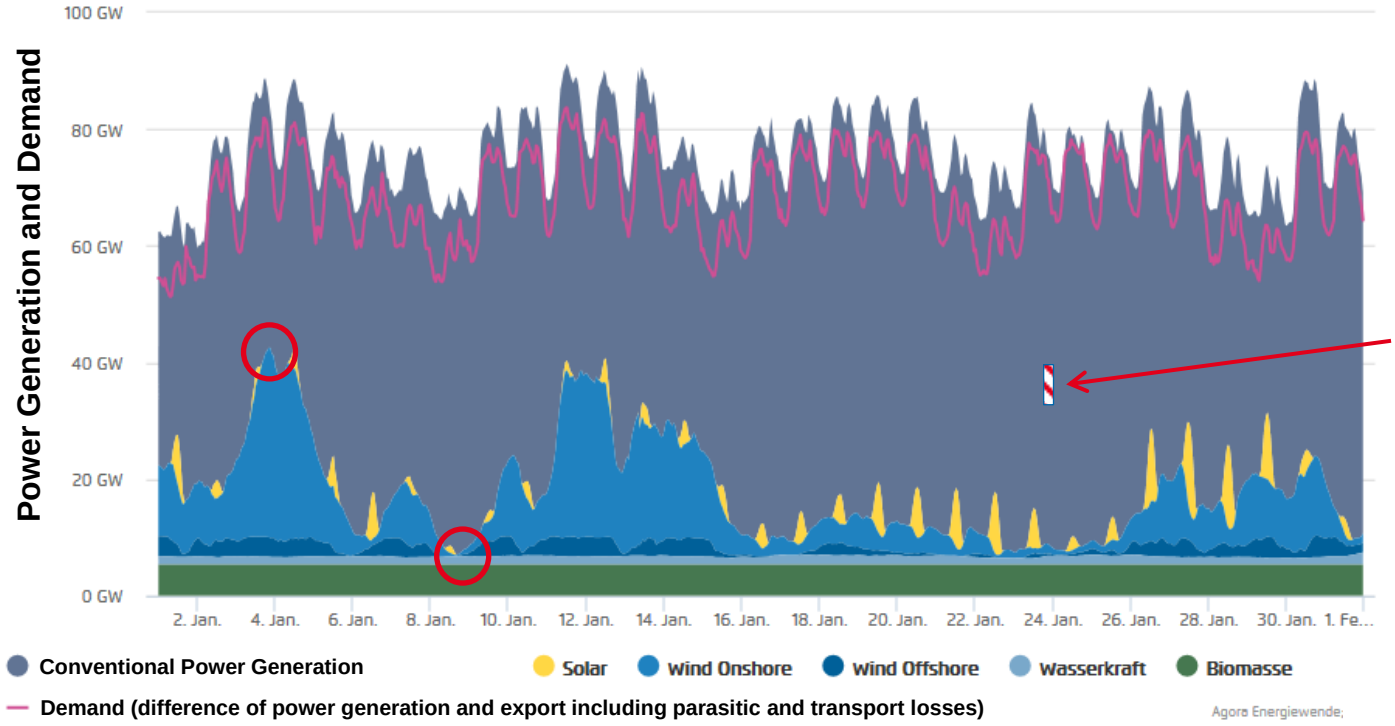
Transport

CCU and Sector Coupling offer more than climate protection by CO_2 reduction: grid stability, security of supply, substitution of fossil fuels, emission reduction

Fluctuating Renewable Energies - Challenge for Grid Stability

Germany January 2017 –
Wind turbines & Photovoltaic produced together between 0.3 and 35.7 GW

Installed Wind and PV capacity 91 GW: 27,720 Wind turbines onshore 45,911 MW*); 947 Wind turbines offshore 4,108 MW*); 1,500,000 PV 41,000 MW)**



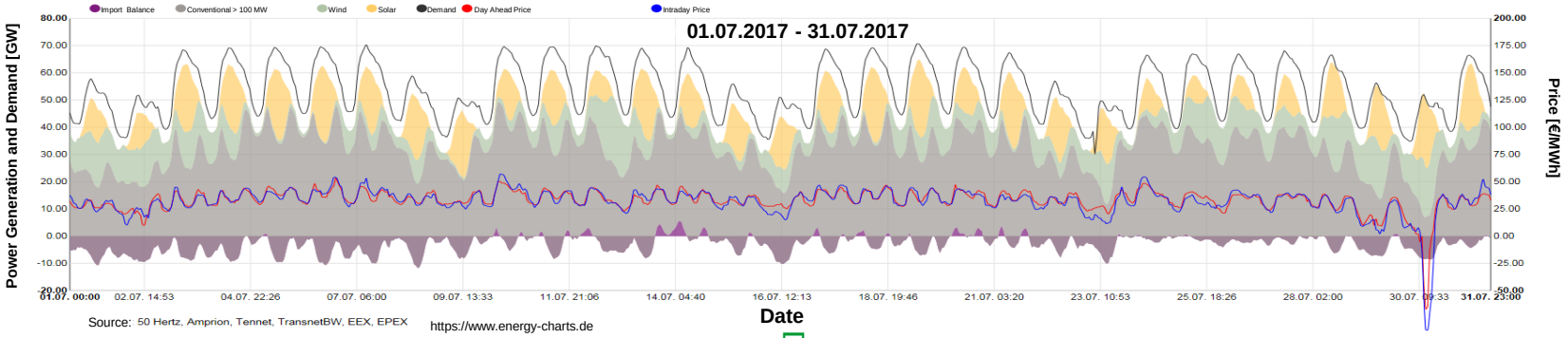
Energy storage capacity of all German pumped hydro storages

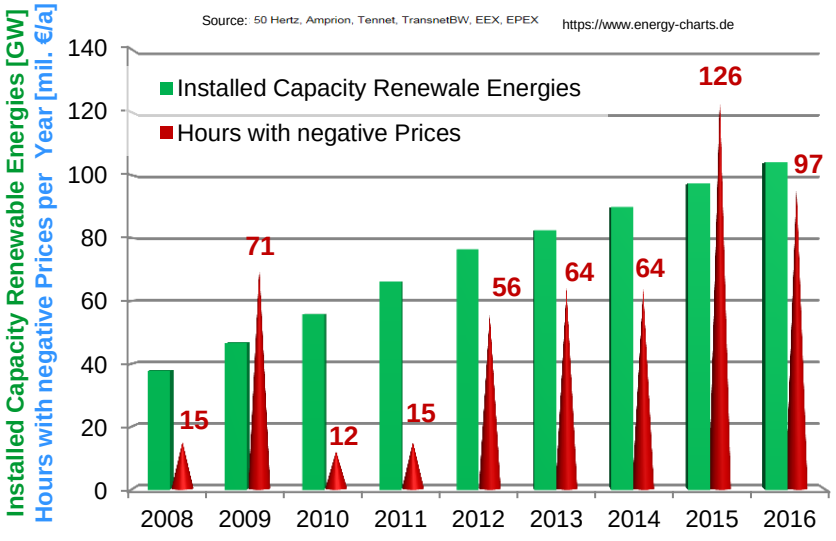
- Conventional power plants will be needed for decades before sufficient energy storage capacity is operational
- CCU can help to reduce the CO_2 emissions and to store energy

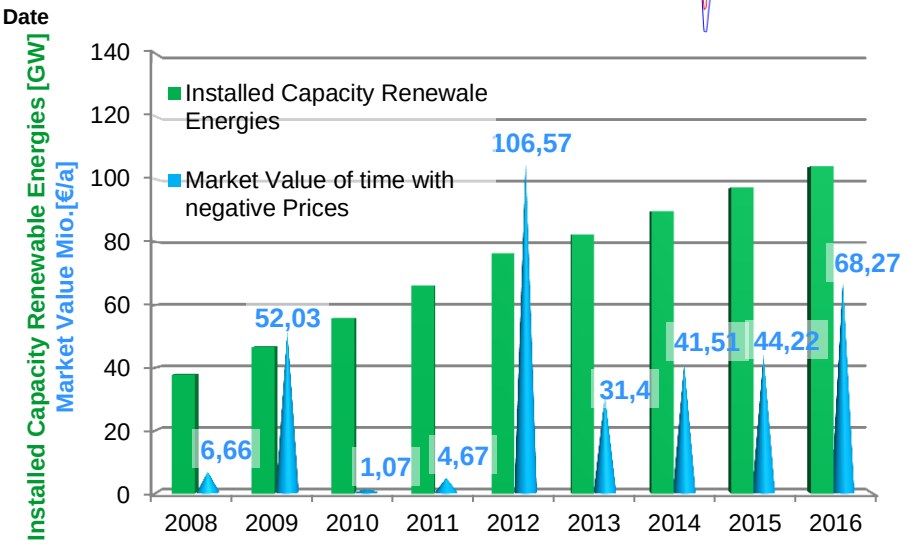
*) Deutsche WindGuard „Status des Offshore-Windenergieausbaus in Deutschland, 2016
**) Fraunhofer ISE „Aktuelle Fakten zur Photovoltaik in Deutschland".2017

Renewable Excess Power and negative Power Prices as Drivers for CCU?

Germany 2008 - 2016: Negative electricity prices remain rare events, even with increased renewable generation capacity & renewable power generation does not exceed the demand







- To facilitate the business case of CCU the value in a sector coupling regime must be allocated and reimbursed
- Climate protection, emission reduction and security of supply are not for free

Conclusion

- PCC/CCU has the potential to become an important pillar of global climate protection
- Increase of public acceptance by further benefits of CCU in addition to climate protection: Security of supply and low-emission fuels not based on crude oil
- The more excess power from renewable energies is used, the more “green” becomes CO_2 recycling products independent from the CO_2 source
- Demonstration of the full CCU chain and utilisation of CCU products in the power and transport sector are necessary to identify and achieve cost reduction potentials by innovations
- Appropriate regulatory frameworks are needed for CCU