The cost-effectiveness of natural gas combined cycle power plants with CO_2 capture and storage in a climate change mitigation strategy

Machteld van den Broek, U. Utrecht
Niels Berghout, U. Utrecht
Ed Rubin, Carnegie Mellon University

Presented to the Global CCS Institute
Webinar
March 18, 2014

Background

- Target : stabilising GHG emissions at 450 ppm(v) CO_2 equivalent
- Low-carbon electricity generation portfolio's
- What is role of NGCC-CCS in low-carbon portfolio
  - providing baseload power
  - providing backup services

Research questions

- Cost-effectiveness of NGCC-CCS
  - in baseload role compared to
    - offshore wind
    - concentrated solar power (CSP)
    - photovoltaic systems (PV)
  - as backup service compared to
    - pumped hydro storage (PHS)
    - Compressed air energy storage (CAES)
    - Li-ion battery
    - ZiBr battery (Zinc-bromine)
    - Zebra battery (Sodium-Nickel-Chloride, NaNiCl)
- What are the potential cost reductions over time due to learning?

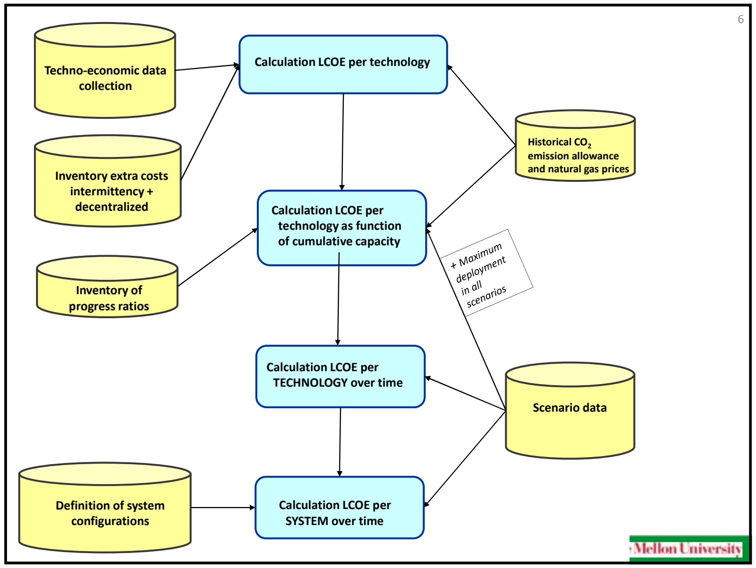
Methodology – starting points

- Scope: costs for Europe
- Technological learning – experience curve method
  - Progress ratio (PR): fraction of original cost after each **doubling** of cumulative installed capacity
  - Learning rate = 1 – progress ratio.
  - Global learning
- Levelised costs of electricity including extra costs for intermittent technologies
  - Balancing
  - Transmission
  - Backup services

Levelised cost of electricity - LCOE

- Capital cost (CAPEX) and fixed operating and maintenance cost (FOM)
  - capacity factor is crucial parameter
- Variable operating and maintenance cost (VOC)
- Fuel cost
- CO_2 emission cost
- Extra balancing and transmission costs
- CO_2 transport and storage costs

- (costs for backup services included in system cost)



Techno-economic data collection

Inventory extra costs intermittency + decentralized

Inventory of progress ratios

Calculation LCOE per technology

Calculation LCOE per technology as function of cumulative capacity

Historical CO_2 emission allowance and natural gas prices

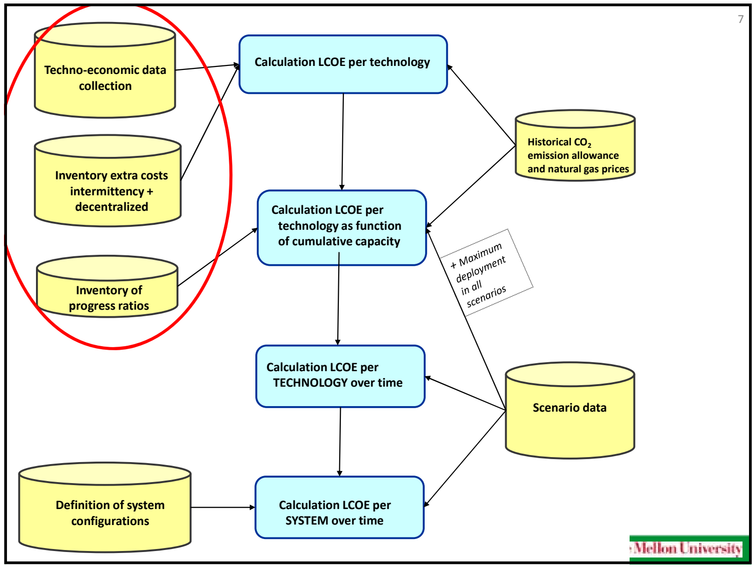
+ Maximum deployment in all scenarios

Calculation LCOE per TECHNOLOGY over time

Scenario data

Definition of system configurations

Calculation LCOE per SYSTEM over time



Techno-economic data collection

Inventory extra costs intermittency + decentralized

Inventory of progress ratios

Calculation LCOE per technology

Calculation LCOE per technology as function of cumulative capacity

Historical CO_2 emission allowance and natural gas prices

+ Maximum deployment in all scenarios

Calculation LCOE per TECHNOLOGY over time

Scenario data

Definition of system configurations

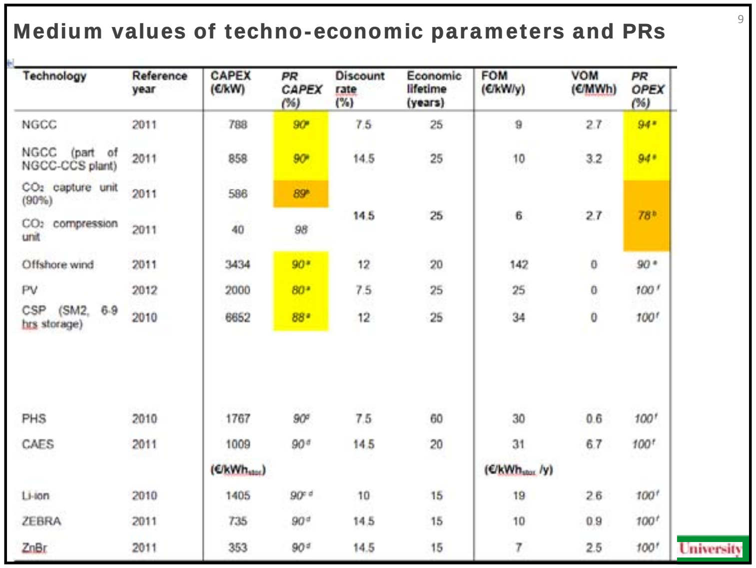
Calculation LCOE per SYSTEM over time

Inventory of techno-economic data

- Medium values
  - Averages of the input data found in the literature.
  - can be considered as most representative values for Europe.

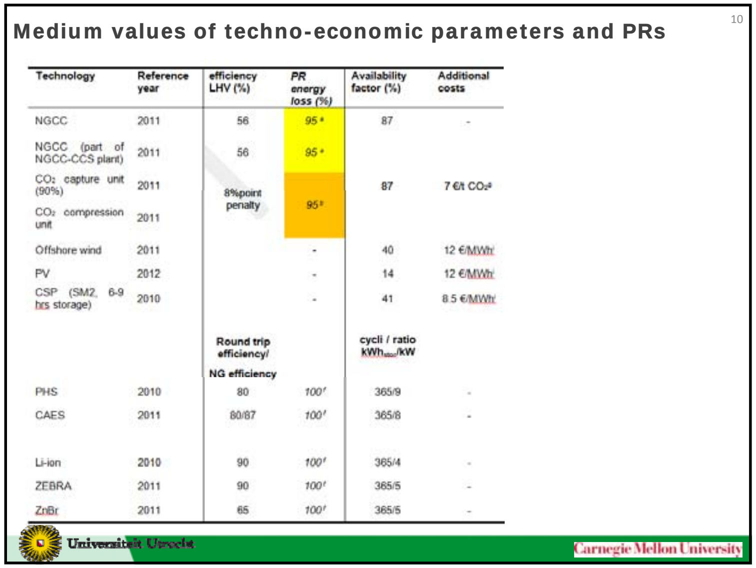
- Full ranges between optimistic and pessimistic values

- Values can be lower or higher in particular regions in Europe



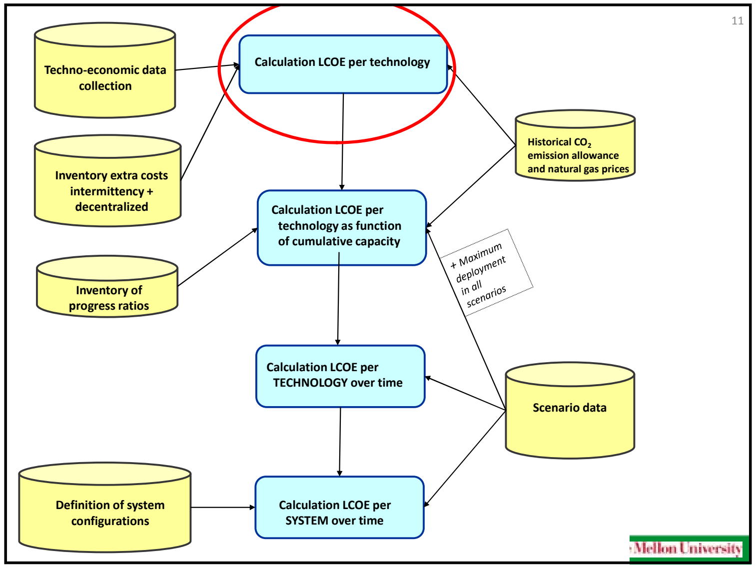
Medium values of techno-economic parameters and PRs

Technology	Reference year	CAPEX (€/kW)	*PR CAPEX (%)*	Discount rate (%)	Economic lifetime (years)	FOM (€/kW/y)	VOM (€/MWh)	*PR OPEX (%)*
NGCC	2011	788	*90*[a]	7.5	25	9	2.7	*94*[a]
NGCC (part of NGCC-CCS plant)	2011	858	*90*[a]	14.5	25	10	3.2	*94*[a]
CO_2 capture unit (90%)	2011	586	*89*[b]	14.5	25	6	2.7	*78*[b]
CO_2 compression unit	2011	40	*98*					
Offshore wind	2011	3434	*90*[a]	12	20	142	0	*90*[a]
PV	2012	2000	*80*[a]	7.5	25	25	0	*100*[f]
CSP (SM2, 6-9 hrs storage)	2010	6652	*88*[a]	12	25	34	0	*100*[f]
PHS	2010	1767	*90*[c]	7.5	60	30	0.6	*100*[f]
CAES	2011	1009	*90*[d]	14.5	20	31	6.7	*100*[f]
		(€/kWh$_{stor}$)				(€/kWh$_{stor}$ /y)		
Li-ion	2010	1405	*90*[c d]	10	15	19	2.6	*100*[f]
ZEBRA	2011	735	*90*[d]	14.5	15	10	0.9	*100*[f]
ZnBr	2011	353	*90*[d]	14.5	15	7	2.5	*100*[f]



Medium values of techno-economic parameters and PRs

Technology	Reference year	efficiency LHV (%)	*PR energy loss (%)*	Availability factor (%)	Additional costs
NGCC	2011	56	*95*[a]	87	-
NGCC (part of NGCC-CCS plant)	2011	56	*95*[a]		
CO_2 capture unit (90%)	2011	8%point penalty	*95*[b]	87	7 €/t CO_2[a]
CO_2 compression unit	2011				
Offshore wind	2011		-	40	12 €/MWh[i]
PV	2012		-	14	12 €/MWh[i]
CSP (SM2, 6-9 hrs storage)	2010		-	41	8.5 €/MWh[i]
		Round trip efficiency/ NG efficiency		**cycli / ratio kWh$_{stor}$/kW**	
PHS	2010	80	*100*[f]	365/9	-
CAES	2011	80/87	*100*[f]	365/8	-
Li-ion	2010	90	*100*[f]	365/4	-
ZEBRA	2011	90	*100*[f]	365/5	-
ZnBr	2011	65	*100*[f]	365/5	-



Techno-economic data collection

Inventory extra costs intermittency + decentralized

Inventory of progress ratios

Definition of system configurations

Calculation LCOE per technology

Calculation LCOE per technology as function of cumulative capacity

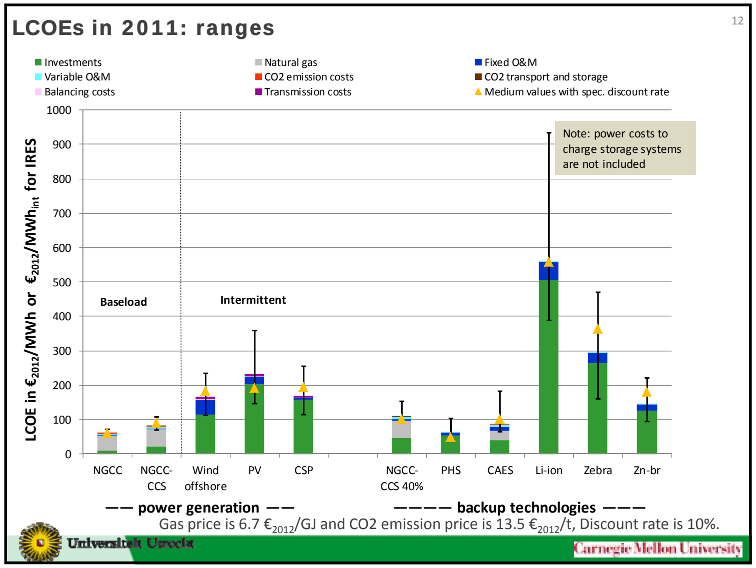
Calculation LCOE per TECHNOLOGY over time

Calculation LCOE per SYSTEM over time

Historical CO_2 emission allowance and natural gas prices

Scenario data

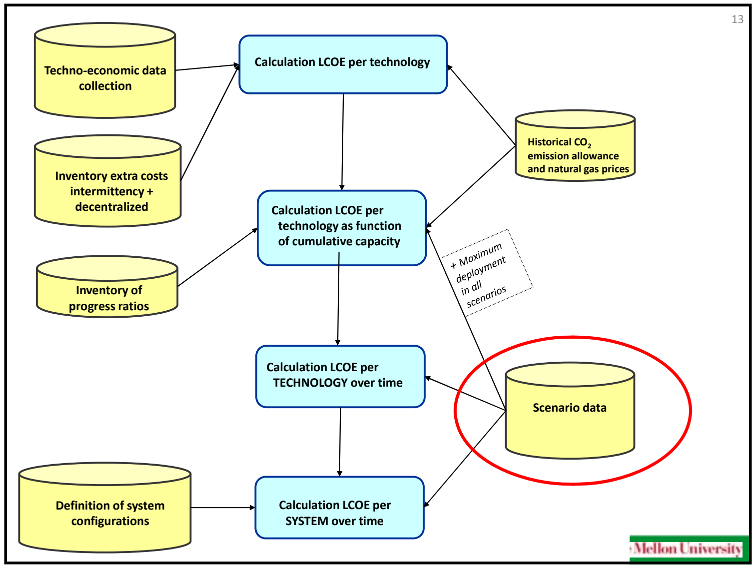
+ Maximum deployment in all scenarios



LCOEs in 2011: ranges

Note: power costs to charge storage systems are not included

Gas price is 6.7 €$_{2012}$/GJ and CO2 emission price is 13.5 €$_{2012}$/t, Discount rate is 10%.



Techno-economic data collection

Inventory extra costs intermittency + decentralized

Inventory of progress ratios

Definition of system configurations

Calculation LCOE per technology

Calculation LCOE per technology as function of cumulative capacity

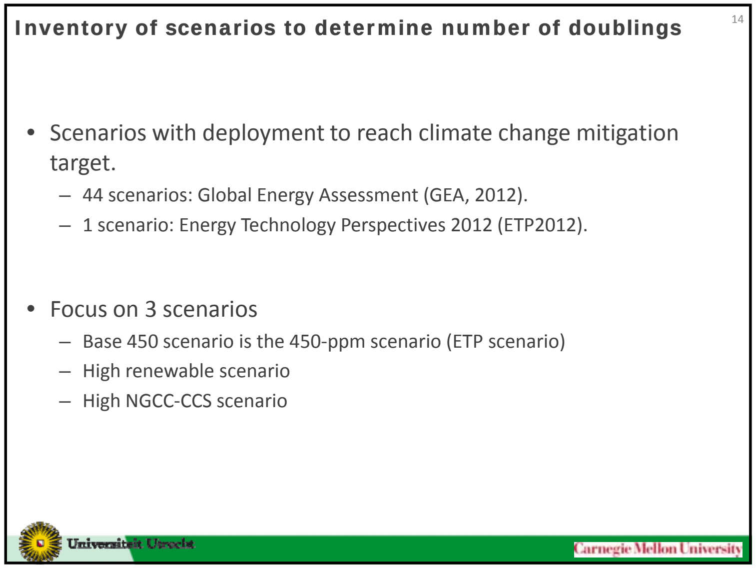
Calculation LCOE per TECHNOLOGY over time

Calculation LCOE per SYSTEM over time

Historical CO_2 emission allowance and natural gas prices

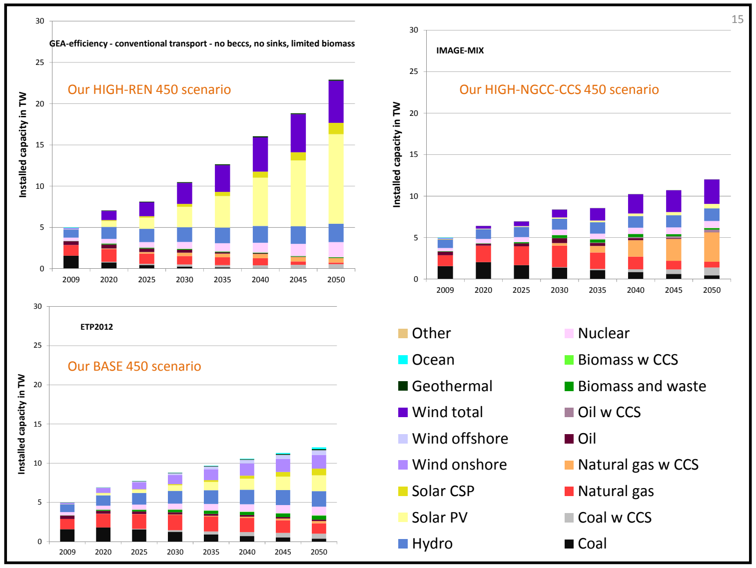
+ Maximum deployment in all scenarios

Scenario data



Inventory of scenarios to determine number of doublings

- Scenarios with deployment to reach climate change mitigation target.
  - 44 scenarios: Global Energy Assessment (GEA, 2012).
  - 1 scenario: Energy Technology Perspectives 2012 (ETP2012).
- Focus on 3 scenarios
  - Base 450 scenario is the 450-ppm scenario (ETP scenario)
  - High renewable scenario
  - High NGCC-CCS scenario



GEA-efficiency - conventional transport - no beccs, no sinks, limited biomass

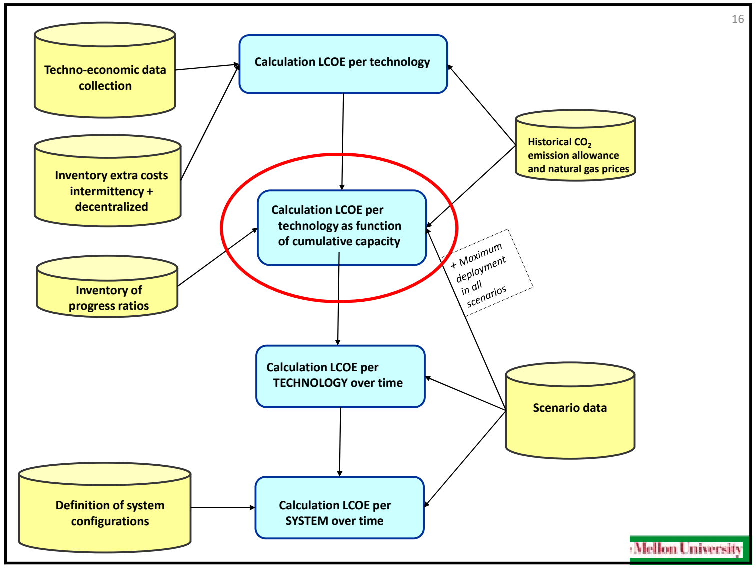
Our HIGH-REN 450 scenario

IMAGE-MIX

Our HIGH-NGCC-CCS 450 scenario

ETP2012

Our BASE 450 scenario



Techno-economic data collection

Inventory extra costs intermittency + decentralized

Inventory of progress ratios

Definition of system configurations

Calculation LCOE per technology

Calculation LCOE per technology as function of cumulative capacity

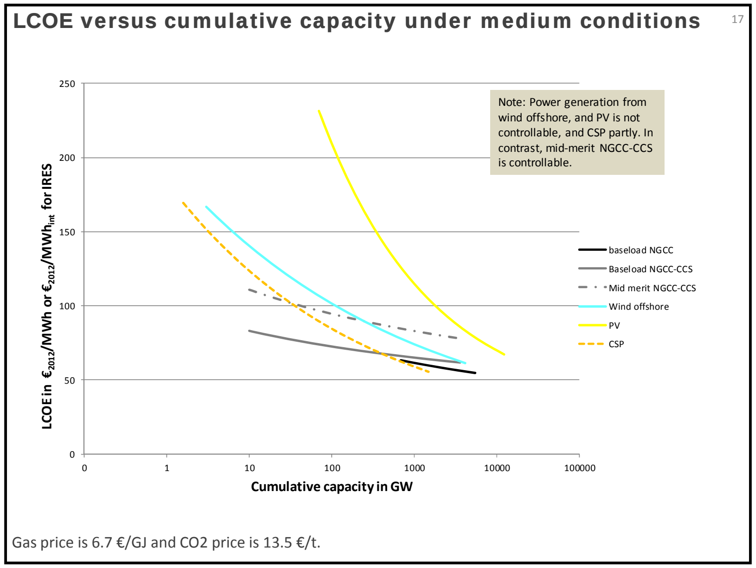
Calculation LCOE per TECHNOLOGY over time

Calculation LCOE per SYSTEM over time

Historical CO_2 emission allowance and natural gas prices

+ Maximum deployment in all scenarios

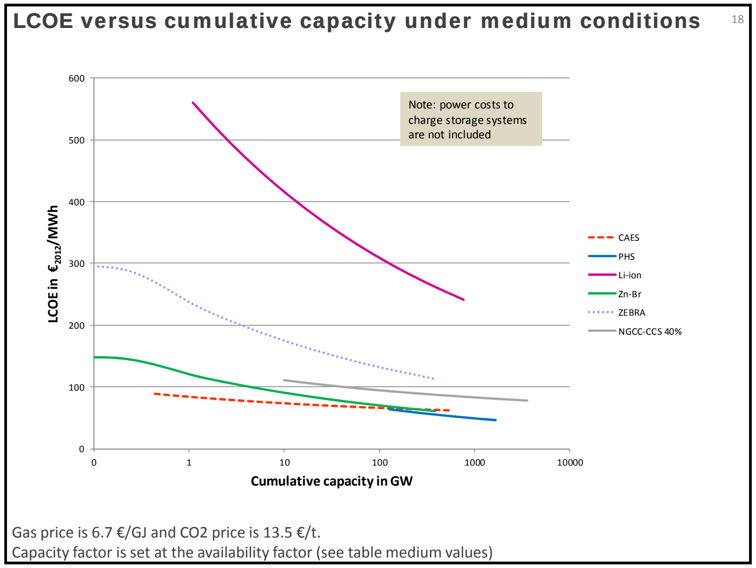
Scenario data



LCOE versus cumulative capacity under medium conditions

Note: Power generation from wind offshore, and PV is not controllable, and CSP partly. In contrast, mid-merit NGCC-CCS is controllable.

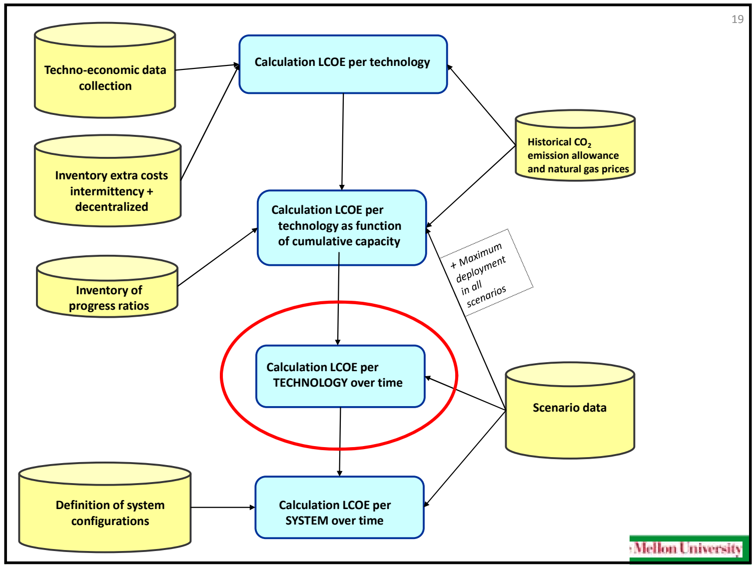
Gas price is 6.7 €/GJ and CO2 price is 13.5 €/t.



LCOE versus cumulative capacity under medium conditions

Note: power costs to charge storage systems are not included

Gas price is 6.7 €/GJ and CO2 price is 13.5 €/t.
Capacity factor is set at the availability factor (see table medium values)



Techno-economic data collection

Inventory extra costs intermittency + decentralized

Inventory of progress ratios

Definition of system configurations

Calculation LCOE per technology

Calculation LCOE per technology as function of cumulative capacity

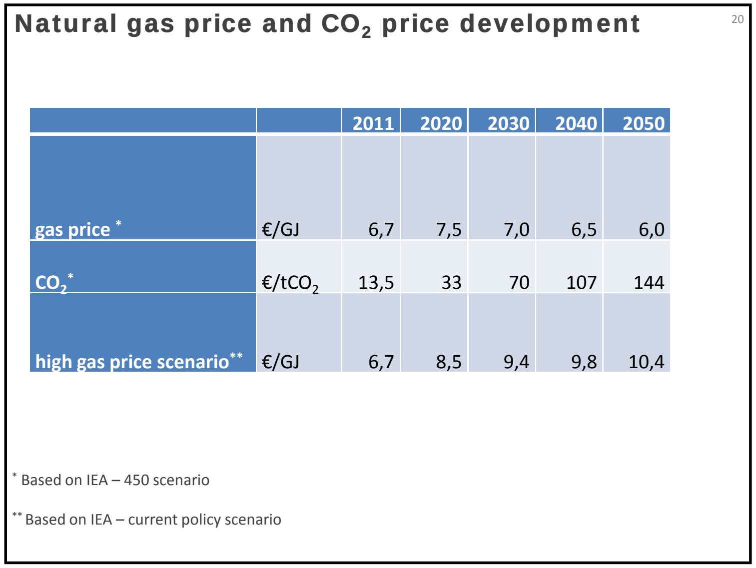
Calculation LCOE per TECHNOLOGY over time

Calculation LCOE per SYSTEM over time

Historical CO_2 emission allowance and natural gas prices

+ Maximum deployment in all scenarios

Scenario data



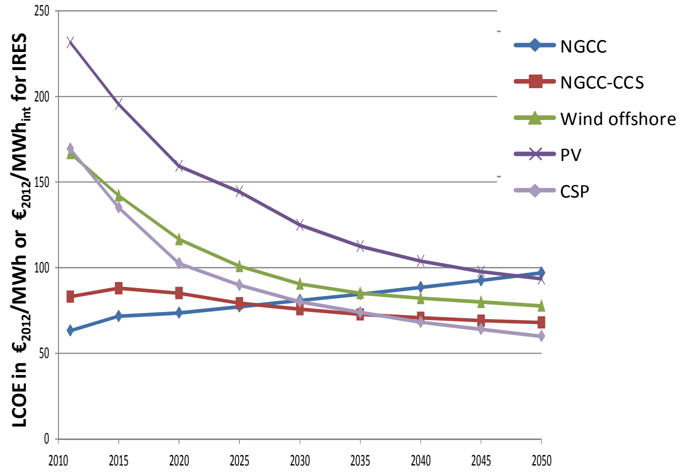
Natural gas price and CO_2 price development

		2011	2020	2030	2040	2050
gas price *	€/GJ	6,7	7,5	7,0	6,5	6,0
CO_2 *	€/tCO_2	13,5	33	70	107	144
high gas price scenario**	€/GJ	6,7	8,5	9,4	9,8	10,4

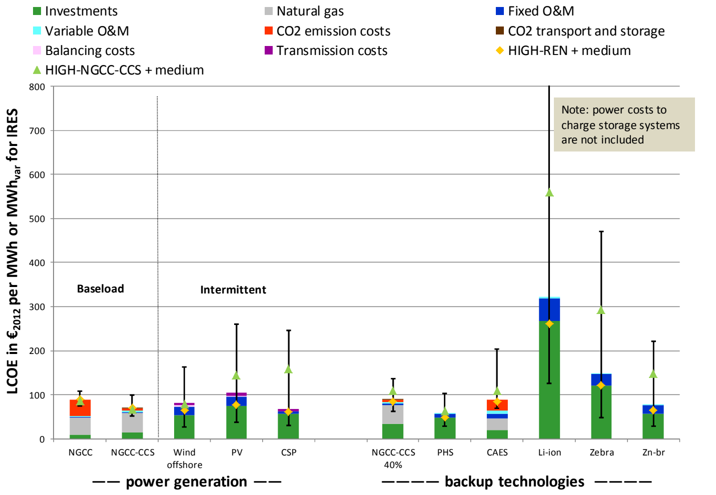
[*] Based on IEA – 450 scenario

[**] Based on IEA – current policy scenario

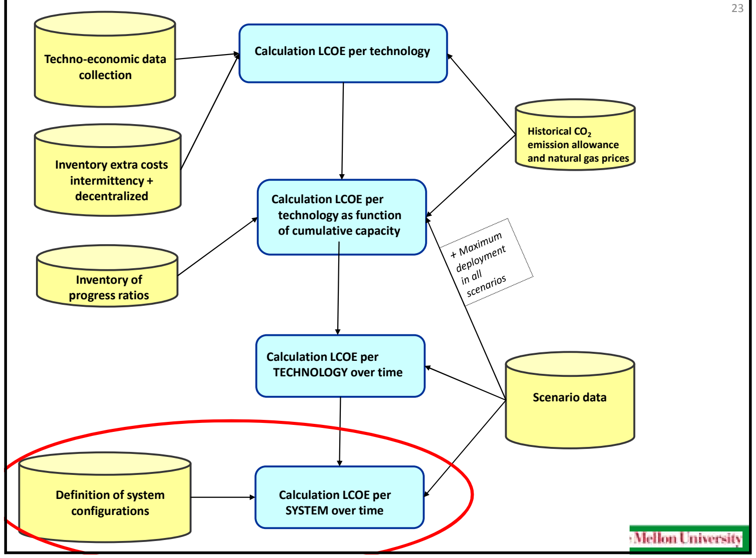
LCOE over time under medium conditions in the Base 450 scenario



Sensitivities of LCOEs for different variants in 2040



Note: power costs to charge storage systems are not included



Techno-economic data collection

Inventory extra costs intermittency + decentralized

Inventory of progress ratios

Definition of system configurations

Calculation LCOE per technology

Calculation LCOE per technology as function of cumulative capacity

Calculation LCOE per TECHNOLOGY over time

Calculation LCOE per SYSTEM over time

Historical CO$_2$ emission allowance and natural gas prices

+ Maximum deployment in all scenarios

Scenario data

Mellon University

Taking into account backup requirements

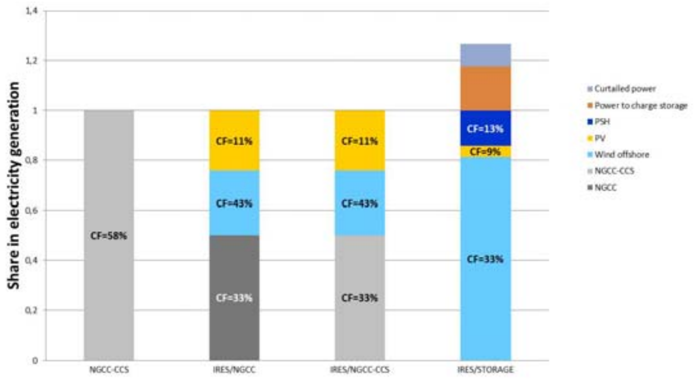
In order include additional costs for backup requirements, we designed four stylized systems based on:

- NGCC-CCS
- IRES/NGCC
- IRES/NGCC-CCS
- IRES/energy storage

Note: All investigated scenarios have a broader portfolio of technologies than these four stylized systems. We only use these stylized systems in order to make some estimates of the backup costs.

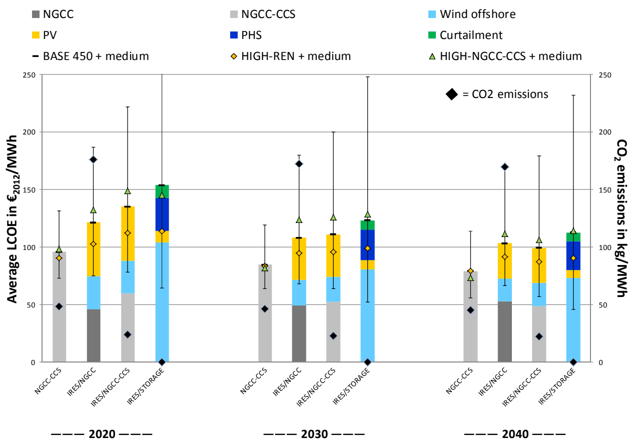
We treat these stylized systems as isolated systems (e.g. on an island) in a world which follows the BASE 450 scenario, the HIGH-REN 450 scenario, or the HIGH-NGCC-CCS 450 scenario.

Share of electricity generation in stylized systems



The percentage values indicate the capacity factors of the different technologies. Capacity factors (CFs) of wind and PV in the IRES/STORAGE system are lower, because part of the produced power is curtailed or used to charge power storage.

Taking into account adequacy requirements

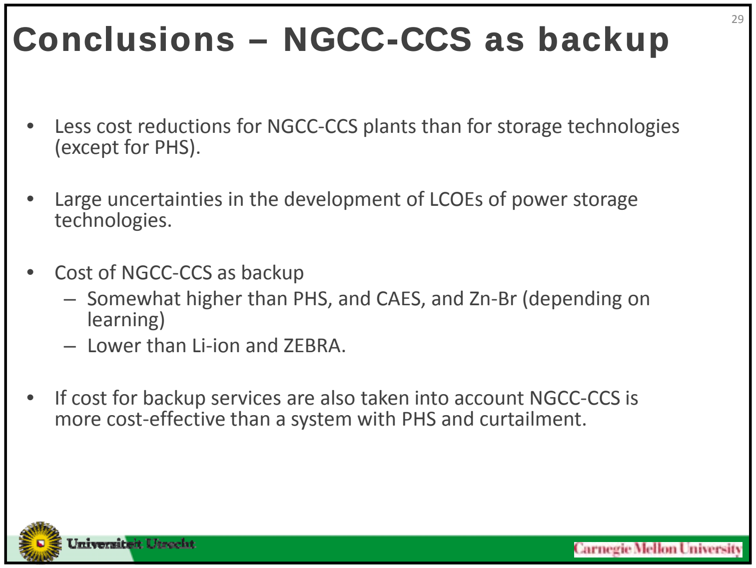


Caveats -> further research

- Techno-economic data uncertain, especially, for novel technologies like ZEBRA and Zn-Br
- Progress ratios not always available or based on short historical time series.
- No deployment projections on storage capacity in global energy scenarios
- Limited power system simulation modelling results of low carbon electricity generation portfolios with power storage
- Demand side management is not included

Conclusions – NGCC-CCS as baseload

- Less cost reductions for NGCC and NGCC-CCS plants than for the renewable energy technologies.
- Large uncertainties in the development of LCOEs of renewables.
- cost-effectiveness compared to alternatives over time
  - depends on deployment.
  - under medium conditions:
    - cost of NGCC-CCS in same range as offshore wind and CSP
    - cost of NGCC-CCS lower than PV.



Conclusions – NGCC-CCS as backup

- Less cost reductions for NGCC-CCS plants than for storage technologies (except for PHS).
- Large uncertainties in the development of LCOEs of power storage technologies.
- Cost of NGCC-CCS as backup
  - Somewhat higher than PHS, and CAES, and Zn-Br (depending on learning)
  - Lower than Li-ion and ZEBRA.
- If cost for backup services are also taken into account NGCC-CCS is more cost-effective than a system with PHS and curtailment.