

# Reflections on recent discussions

(Pathways to 2050: Opportunities for the EU - 25 October 2018 at GP office in Brussels  
and Energetika 14-16 November 2018 , St Petersburg)

The need / opportunity to complement renewables by decarbonised gas

**GAC WS 2**

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# PA\* and its consequences

PA: keeping well below 2.0°C, if possible – below 1.5°C

⇒ Keep within a budget of 770 mln t CO<sub>2</sub> eq; use of 42 Gt CO<sub>2</sub> eq/year: **time is running**

- renewables and energy efficiency will not deliver in time; nuclear limited, problematic
- overshooting 1.5°C, later compensated by BECCS \*\* – a mortgage on the future

=> fossil fuels have to be decarbonised quickly and on a large scale

(disparity of the supply and demand pattern of electric renewables => balance by electrolysis of surplus power to H<sub>2</sub>, use the existing CH<sub>4</sub> system for transportation and storage; some energy to be delivered as molecules, not by wire => need for power - **AND** H<sub>2</sub> infrastructure)

=> decarbonisation pre-combustion\*\*\* of hydrocarbons to H<sub>2</sub>;

large scale => by MSR\*\*\*\* with large-scale disposal of CO<sub>2</sub>

⇒ Fast system transformation from CH<sub>4</sub> to H<sub>2</sub> and push for large-scale carbon capture

**Questions:** who has to take the initiative, who has to pay, how to finance?

\* Sustainable atmosphere under the Paris Agreement implies carbon-free energy, not necessarily renewable, as long-term sustainable energy

\*\* BECCS: bioenergy with carbon capture and storage

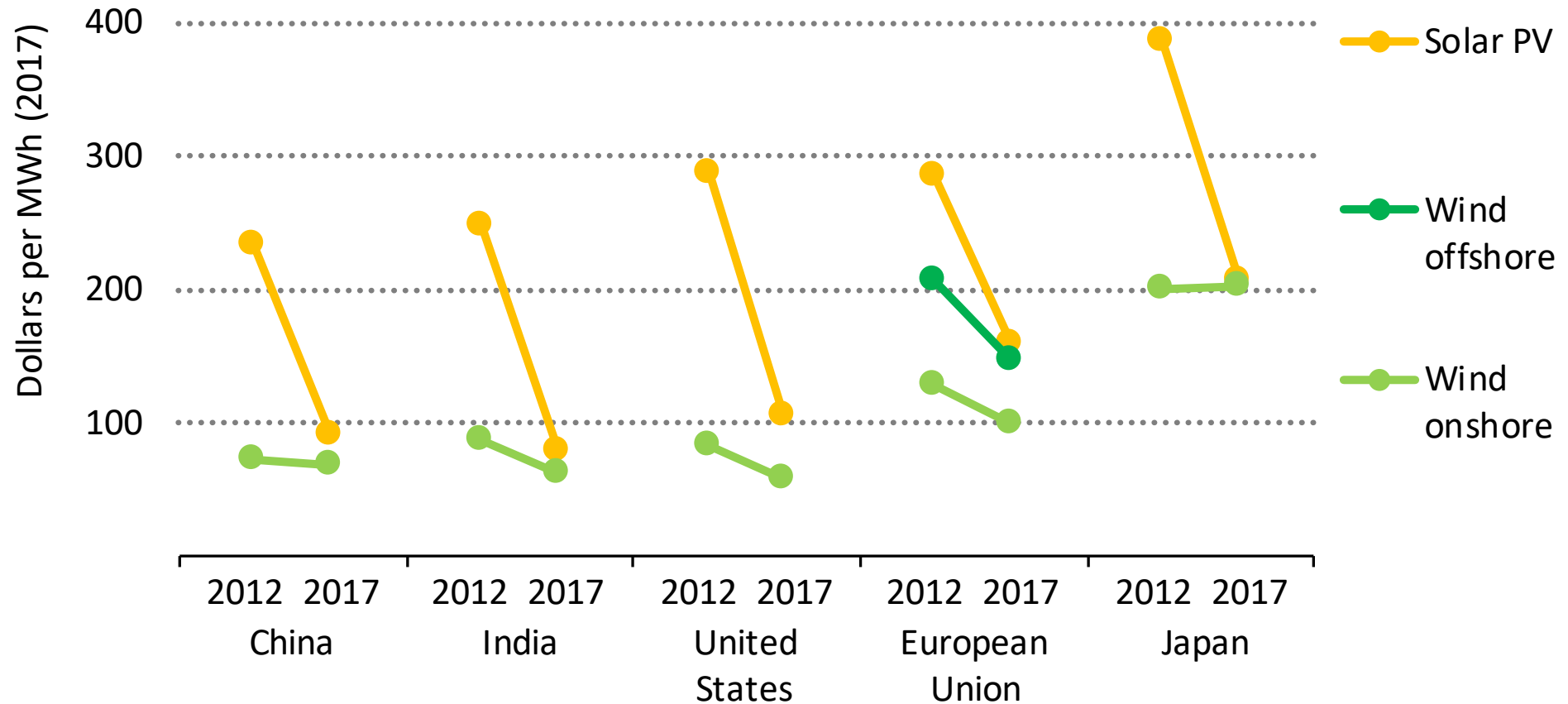
\*\*\* post-combustion produces energy as power, not as molecules

\*\*\*\* MSR: methane steam reforming, the only available large-scale technology

# Developments 2000-2016

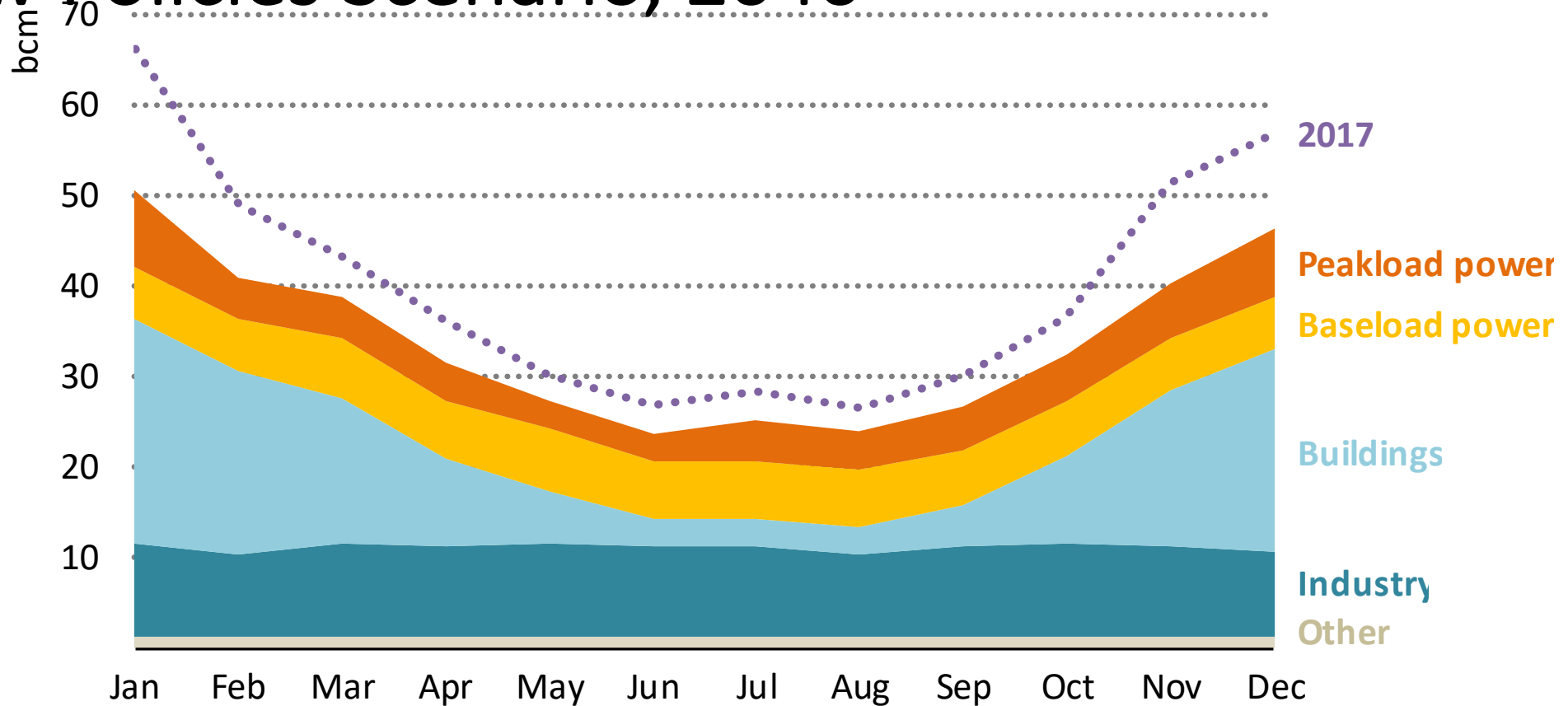
			<b>2000</b>	<b>2016</b>
<b>Total primary energy demand (Mtoe)</b>			<b>10035</b>	<b>13760</b>
<b>of which:</b>				
- Coal			2311	3755
- Oil			3670	4388
- Gas			2071	3007
- Nuclear			676	681
- Hydro			225	350
- Bioenergy*			1023	1354
- other renewable (Mtoe)			60	225
<b>Share of fossil fuel (%)</b>			<b>80%</b>	<b>81%</b>
<b>CO<sub>2</sub> emissions (Gt)</b>			<b>23.0</b>	<b>32.1</b>
*includes traditional biomass				

# Levelised costs of electricity by selected technologies and regions, 2012-2017



*Solar PV has seen the biggest cost reductions in utility-scale renewables with cost cuts up to 70% in major markets*

# Seasonal gas demand in the European Union in the New Policies Scenario, 2040



*Despite a 50% increase in peak gas demand in the electricity sector, the efficiency-driven drop in consumption for space heating leads to an overall decline in peak demand*

# IPCC Special Report on Global Warming of 1.5°C

Global indicators	P1	P2	P3	P4
<i>Pathway classification</i>	No or low overshoot	No or low overshoot	No or low overshoot	High overshoot
<i>CO<sub>2</sub> emission change in 2030 (% rel to 2010)</i>	-58	-47	-41	4
→ <i>in 2050 (% rel to 2010)</i>	-93	-95	-91	-97
<i>Kyoto-GHG emissions* in 2030 (% rel to 2010)</i>	-50	-49	-35	-2
→ <i>in 2050 (% rel to 2010)</i>	-82	-89	-78	-80
<i>Final energy demand** in 2030 (% rel to 2010)</i>	-15	-5	17	39
→ <i>in 2050 (% rel to 2010)</i>	-32	2	21	44
<i>Renewable share in electricity in 2030 (%)</i>	60	58	48	25
→ <i>in 2050 (%)</i>	77	81	63	70
<i>Primary energy from gas in 2030 (% rel to 2010)</i>	-25	-20	33	37
→ <i>in 2050 (% rel to 2010)</i>	-74	-53	21	-48
<i>Primary energy from non-biomass renewables in 2030 (% rel to 2010)</i>	430	470	315	110
→ <i>in 2050 (% rel to 2010)</i>	832	1327	878	1137
<i>Cumulative CCS until 2100 (GtCO<sub>2</sub>)</i>	0	348	687	1218
→ <i>of which BECCS (GtCO<sub>2</sub>)</i>	0	151	414	1191

\* Kyoto-gas emissions are based on SAR GWP-100

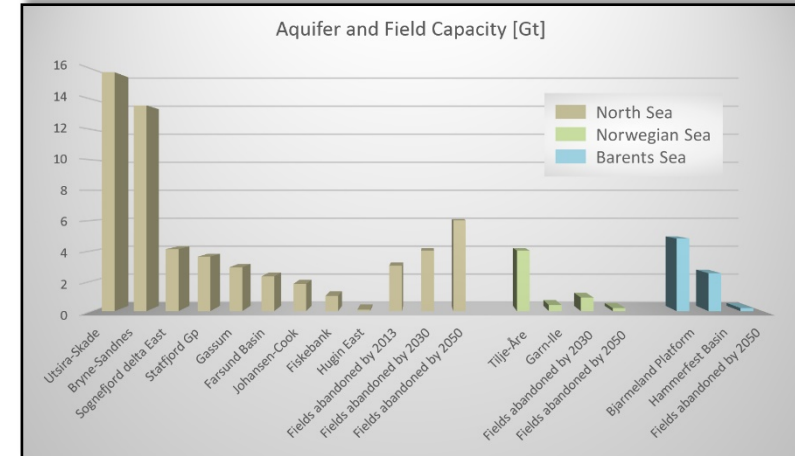
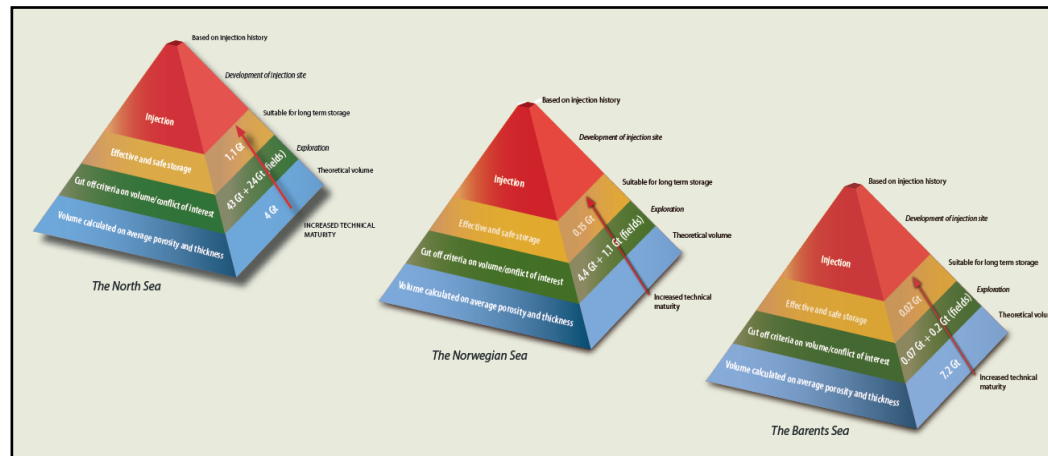
\*\* Changes in energy demand are associated with improvements in energy efficiency and behaviour change

# Reflections:

## Norway / Equinor as gas producing country / company

- Motivation: gas producers hit twice by shrinking volumes: lower volume and price => look to preserve sales volumes in form of H<sub>2</sub>
- Equinor: H<sub>2</sub> projects, developed together with customers, taking back the CO<sub>2</sub> from MSR (by ship / for UK by pipeline)
- 40+ Gt of CO<sub>2</sub> storage potential in the Norwegian North Sea alone ( Germany according to Bundesanstalt für Geowissenschaften und Rohstoffe: 20 +/- 8 Gt of CO<sub>2</sub>)
- Beyond CO<sub>2</sub> from Norway's gas supplies (125 bcm/year corresponding to ca. 0.25 Gt/year), **BUT** why should Norway do the job for others?
- CO<sub>2</sub> storage: proven and simple technology (reinjecting a non-flammable, non-toxic liquid); has to be monitored

# CO<sub>2</sub> Storage Capacity Norwegian Continental Shelf



## How much is a Gigaton?

1 tonne = one metric tonne = 1000 kg  
 1 Mt = one megatonne = 10<sup>6</sup> tonnes  
 1 Gt = one gigatonne = 1000 Mt = 10<sup>9</sup> tonnes

	Volume/weight	Energy	CO <sub>2</sub> formed
Natural gas	532 GSm <sup>3</sup>	5300 TWh	1 Gt
Diesel	372 Mt	3800 TWh	1 Gt
Coal	413 Mt	2800 TWh	1 Gt



# Reflections: NL / Gasunie

- Testing / projects to convert the increasingly idle L-Gas infrastructure to H<sub>2</sub>
- Insular solutions, to be linked up, also with existing H<sub>2</sub>-system
- CO<sub>2</sub> from MSR exported to Norway

BUT: little financial room as regulated business, slowing down development

# Reflections on: (i) split of work between EU and Russia regarding PA and (ii) cooperation

- (i) PA Article 3: Each country commits by NDC to ambitious measures, checked every 5 years (blame and shame) with ratcheting up

Methane is about 50% of Russian PEC, decarbonisation / H<sub>2</sub> may become necessary; Russia may first look at cheaper options (tapping the bounty of energy efficiency)

## (ii) Cooperation

- in knowledge sharing (mainly on H<sub>2</sub> technology infrastructure and application)
- In developing the H<sub>2</sub> market in the EU

# Reflections related to gas imports

EU looking to decarbonise gas (also in the interest of gas producers to remain in the game)

- Carbon-free  $H_2$  from  $CH_4$  via MSR and CCUS: a volume issue for  $CO_2$  disposal and a netback issue for  $CH_4$
- Process and location: a question of optimisation (of netback value at the well head) along the chain: process, location and flexibility
- Why should Russia solve the EU's political problem with  $CO_2$  storage?
- Methane cracking vs. MSR: volume consequences and speed of progress; enough Russian gas available to back either process
- GP bound long term by contractual quality provisions (beyond spec of infrastructure)
- GP vs Equinor: factual differences; Equinor pioneer, GP follower?

# H<sub>2</sub> vs CH<sub>4</sub> -export: principles remain, details change

- Paris Agreement does not impose an obligation / restriction regarding the export of resources, UNGA resolution 1802 of 1963 remains valid
- Customers pay (also for decarbonised H<sub>2</sub>), thereby for decarbonisation
- Subject to competition / markets
- Costs to produce the product (decarbonised H<sub>2</sub>) and bring it to the market are borne along the chain; finally deducted from the revenue ex wellhead (determining the resource rent)

=>

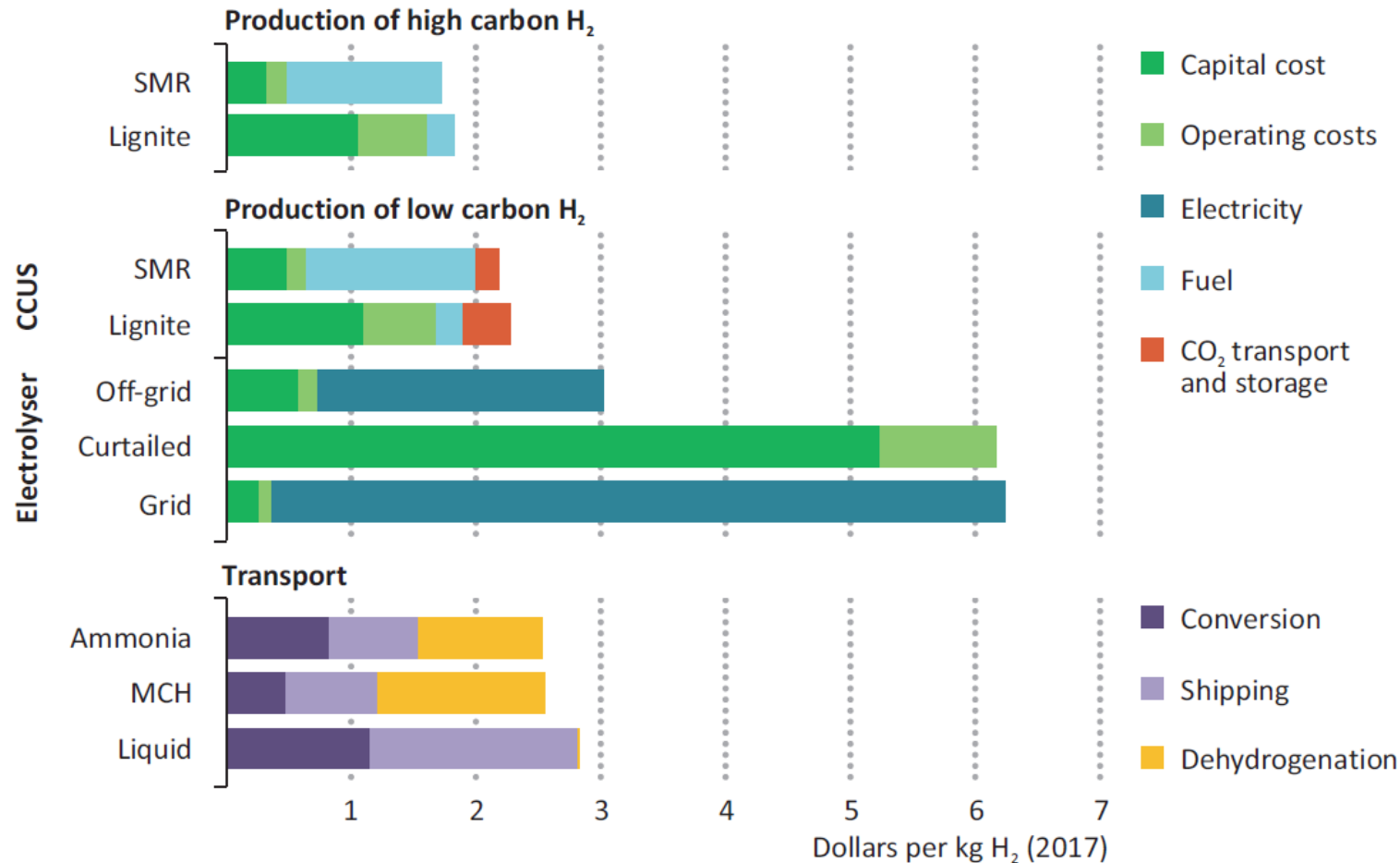
different (higher) value for a different product in the market (determined by competition / markets for H<sub>2</sub> and its infrastructure)

but also higher costs to produce / deliver H<sub>2</sub> compared to CH<sub>4</sub>)

# Net back in an H2 System

Renewable H2 from electrolysis				Feed into	H2 from decarbonizing gas				
domestic	H2 from renewable electrolysis	=>	H2	<=		<= transport of H2	H2 <=	CH 4 by MSR	CH4 prod.
						= 90% of CH4		local heat losses 25%	
			S					disposal of CO2*	
imported	H2 from renewable electrolysis	border	=>	y	via CH4 storage	<= transport of CH4			CH4 prod.
	(H2 => NH3 => H2) *	der	s		or direct feed into				
			t	<=	H2 <=	CH 4 by MSR			
			e		local heat losses 25%				
			m		disposal of CO2				
			or	<=		<= transport of H2	H2 <=	CH 4 by MCr	CH4 prod.
			M			= 90% of CH4		local heat losses 13%	
			a					disposal as C* (40% of En)	
			r						
			k		via CH4 storage	<= transport of 2 x CH4			CH4 prod.
MSR	Methane Steam reforming		e		or direct feed into				
MCr	Methane Cracking		t	<=	H2 <=	CH 4 by MCr			
					local heat losses 13%				
					disposal of 40% as C				
* needs certification									

# Costs of selected options to produce H<sub>2</sub> in Australia and transport it to Japan in New Policies Scenario, 2040



*SMR equipped with CCUS is the cheapest source of low-carbon hydrogen, but electrolysers using off-grid renewables could provide hydrogen for \$3/kg H<sub>2</sub> in 2040*

# Reflections on the players' role

DO NOT wait for Godot (= decarbonisation technology to be free of costs)!!

Technology neutrality: there will be a mix between renewables (Wind , PV) and decarbonised hydrocarbons, the balance to be sorted out by competition, based on an effective price signal for CO<sub>2</sub> (i.e. reflecting cost level)

- Governments of resource owning countries: promote transformation to preserve market position, accept netback consequences
- Commercial oil and gas companies: profit for shareholders, some profit spent to secure long-term business / advertisement  
BUT buy back shares or modify business always an option
- Governments of consuming / importing countries: provide for effective market signals reflecting the substantial costs of decarbonisation; otherwise only non-action will be optimised
- Regulated infrastructure: regulated asset base with regulated profit, depreciation time to make it financeable (initiative has to come from politics)
- C / CO<sub>2</sub> disposal: may be a regulated business; but cross-border issues, certification needed

# Reflections on who pays?

- Putting a price on CO<sub>2</sub> high enough to trigger developments / for fuel switching
- In the end, consumers pay extra costs for a decarbonised world
- De-carbonization / a price on CO<sub>2</sub> may change resource rents included in present energy price level (for fuel and gas):
  - Example US gas-coal: no extra costs, rent for low-carbon fuel but paid out of rent for liquid fuel, as gas is a must-sell by-product
  - Now the UK mixture of floor price for EUA and LCPD => gas exporters benefit by volume
  - Renewables put a ceiling on the CO<sub>2</sub> price at a level for switching from gas to renewables
- If all countries make similar efforts to decarbonise: little distortion from different decarbonisation approaches
- In the future: CO<sub>2</sub>-free renewable fuel (H<sub>2</sub>) likely to become a yardstick for other CO<sub>2</sub>-free fuel

=> bringing the costs of electric H<sub>2</sub> down, brings overall costs of decarbonisation down, inclusive of resource rent for decarbonised methane

BUT: (substantial) decarbonisation costs, needs effective signals initiated by governments (can be income-neutral CO<sub>2</sub> taxes; must be flanked by social policies)



Time is of the essence!  
And cooperation!

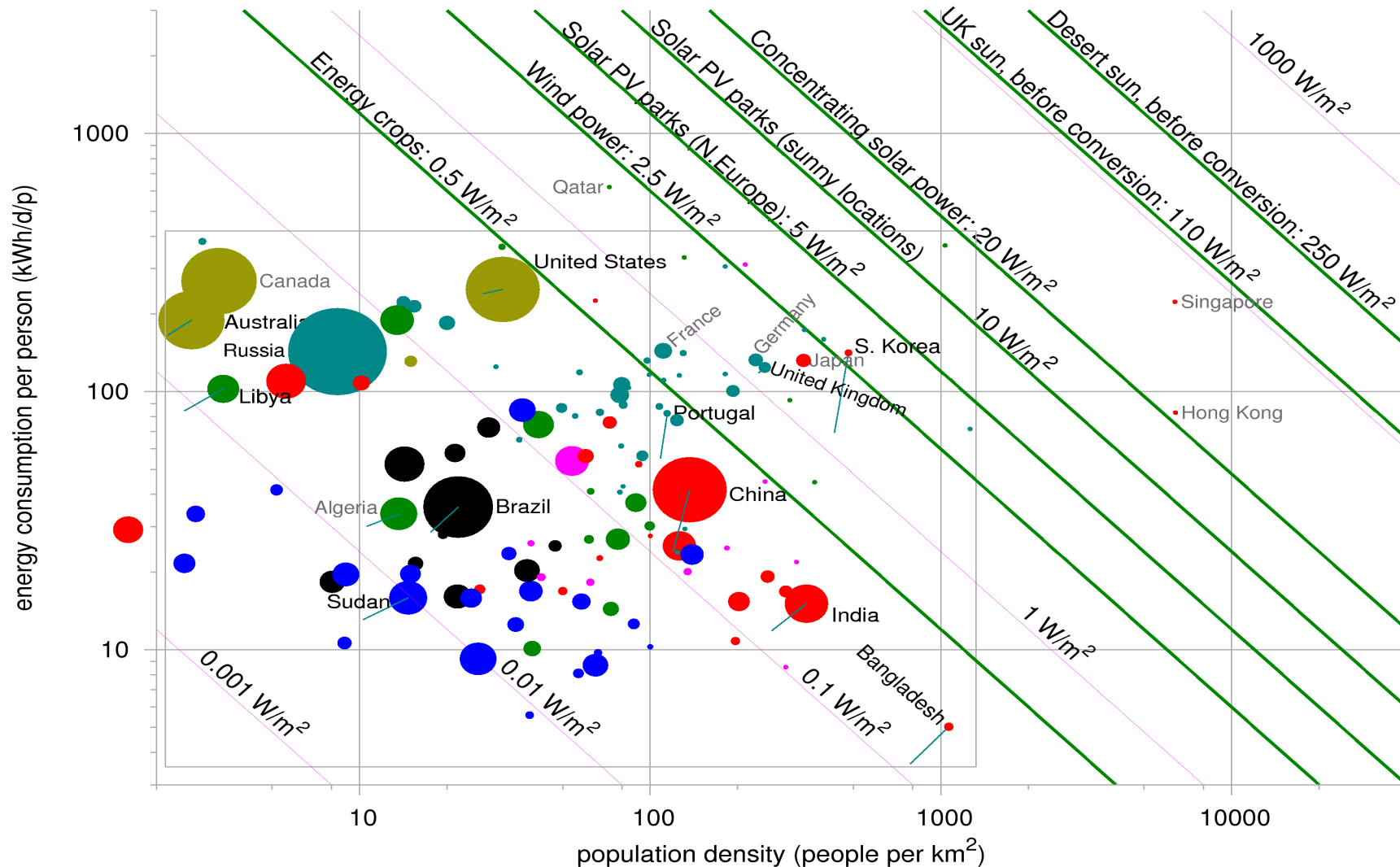


- We live in an era in the history of nations where there is greater need than ever for co-ordinated political action and responsibility
- Perhaps our most urgent task is to persuade nations of the need to return to multilateralism

From the Foreword to Our Common Future,  
World Commission on Environment and  
Development, Gro Harlem Brundtland, Oslo,  
**20 March 1987**

# **Reserve Slides**

Sol lucet omnibus:  
but PV insufficient to meet the carbon budget on  
time



# Three cases: electric renewables and hydrogen

	Pure electric system	Hydrogen only from electrolysis surplus wind / PV	Hydrogen also from natural gas and electrolysis (and import)			
			MSR		Methane cracking	
use of gas infrastructure	no	yes	yes		yes	
use of gas resources	no	no	yes		yes	
C / CO <sub>2</sub> disposal where?	no n.a.	no n.a.	CO <sub>2</sub> disposal		use / dispose of C	
			upstream	downstream	upstream	downstream
intermittence (surplus) power	regulate down	use of gas storage for H <sub>2</sub> but only 30% capacity	use of gas storage for H <sub>2</sub> but only 30% capacity		use of gas storage for H <sub>2</sub> but only 30% capacity	
intermittence (deficit) power	remaining fossil power with CCS?	use of H <sub>2</sub> from storage for power from H <sub>2</sub>	use of stored H <sub>2</sub> for power from H <sub>2</sub>	use of stored H <sub>2</sub> plus decarb CH <sub>4</sub>	use of stored H <sub>2</sub> for power from H <sub>2</sub>	use of stored H <sub>2</sub> plus decarb CH <sub>4</sub>
implication gas import structure	becomes idle	becomes idle	conversion to H <sub>2</sub>	remains	conversion to H <sub>2</sub>	remains, but 2x capacity needed
replacing domestic gas supply	add system equivalent to gas system duplicating gas system	all gas system changed to H <sub>2</sub> H <sub>2</sub> storage (only 30%) conversion of system and appliances	all gas system changed to H <sub>2</sub>	system partially changed to H <sub>2</sub>	all gas system changed to H <sub>2</sub>	system partially changed to H <sub>2</sub>

# Properties

## CH<sub>4</sub>

- GCV: 889 kJ/mol

Relevant for energy stored

- Wobbe Index: 53.45 MJ/Nm<sup>3</sup>

Relevant for energy  
transportation capacity

## H<sub>2</sub>

- GCV: 286 kJ/mol

= 32% of CH<sub>4</sub>

- Wobbe Index: 48.34 MJ/Nm<sup>3</sup>

= 90% of methane

(L-Gas: up to 46,8 MJ/Nm<sup>3</sup>)

- More compression needed
- More aggressive than CH<sub>4</sub>
- Check compatibility along the chain and in applications

# Decarbonising CH<sub>4</sub> pre-combustion by steam reforming: producing H<sub>2</sub> and safely disposing of CO<sub>2</sub>

**Steam reforming (SR – getting the energy out of C and H<sub>4</sub>, less process losses):**

- Add H<sub>2</sub>O (steam) plus energy (endothermic reaction)
- Global industrial application (ca. 150 bcm/year of natural gas)
- SR possible for C, CH<sub>4</sub>, C<sub>n</sub>H<sub>2n+2</sub>, i.e. coal, gas and liquid hydrocarbons
  - C + 2 H<sub>2</sub>O => CO<sub>2</sub> + 2 x H<sub>2</sub>      coal: 2 H<sub>2</sub> pro 1 CO<sub>2</sub>
  - 2<sub>n</sub> x H<sub>2</sub>O + C<sub>n</sub>H<sub>2n+2</sub>,      gas: 4 H<sub>2</sub> pro 1 CO<sub>2</sub>  
=> n x CO<sub>2</sub> + 2n H<sub>2</sub> + n+1 H<sub>2</sub>      hydrocarbons in general:  
  (3 + 1/n) H<sub>2</sub> pro 1 CO<sub>2</sub>
- Dispose of CO<sub>2</sub> in geological structures  
(EOR, EGR, depleted reservoirs, aquifers)

# Decarbonising CH<sub>4</sub> pre-combustion by methane cracking: producing H<sub>2</sub> and safely disposing of C

## **Methane cracking: (getting the energy of H<sub>4</sub>, less process losses plus getting carbon black)**

- KIT process with fluid tin at experimental stage
- Next step TRL 6, using 3 m<sup>3</sup>/h = 25 000 m<sup>3</sup>/year  
=> Very substantial scaling up needed
- CH<sub>4</sub> (889 kJ/mol) =>  
C (carbon black) + 2 H<sub>2</sub> (GCV = 2 x 286 kJ/mol)
- Use of C = carbon black, limited by global market (<10 mln t/year at present), beyond that => dispose of C!
- Energy contained in C is produced (and transported), but lost energetically (40% of energy of CH<sub>4</sub> plus process losses > 50%)



# Energy taxation and implicit carbon pricing in Germany, 2016

		Nominal	Implicit	Excl. infrastructure costs*		Excl. counter-factual invest**
		tax rate	tax rate	€ 15b p.a.	€ 35b p.a.	€ per t CO <sub>2</sub>
		€ per unit	€ per t CO <sub>2</sub>	€ per t CO <sub>2</sub>	€ per t CO <sub>2</sub>	
Gas oil	EUR/1,000 l	61,35	23,03			
Heavy fuel oil (heating)	EUR/t	25,00	7,87			
Heavy fuel oil (power)	EUR/t	25,00	7,87			
Natural gas (heating)	EUR/MWh	5,50	30,23			
Natural gas (motor fuel)***	EUR/MWh	13,90	76,40	-26,00	-198,20	
LPG (heating)	EUR/100 l	6,06	20,56			
LPG (motor fuel)***	EUR/100 l	18,03	61,16			
Gasoline leaded***	EUR/1,000 l	721,00	315,90			
Gasoline unleaded***	EUR/1,000 l	654,50	286,76			
Diesel***	EUR/1,000 l	470,40	179,06	165,55	35,23	
Coal (non-power)	EUR/GJ	0,33	3,47			
Electricity ETS	EUR/EUA	5,35	5,35			
Electricity tax	EUR/MWh	20,50	22,78			
Electricity surcharges	EUR/MWh	76,84	85,38			
Electricity total	EUR/MWh	102,69	113,51			45,20
						73,33
Notes: * Considering road infrastructure financing from motor vehicle tax (€ 8.7b) and truck toll (€ 3.1b). The lower range of infrastructure costs represents the annual investments and the upper range the annuity of total road system costs. - ** Considering a counterfactual investment of 36 €/MWh. - *** The implicit CO <sub>2</sub> tax rate for motor fuels covers also other significant transport externalities (other pollutants, noise, health impacts) which are less significant for other energies.						

Source: Felix Matthes, Decarbonizing Germany's Power Sector, p. 24; Note d'IFRI, Dec 2017