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_2 eq; use of 42 Gt CO_2 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_2, use the existing CH_4 system for transportation and storage; some energy to be delivered as molecules, not by wire => need for power - **AND** H_2 infrastructure)

=> decarbonisation pre-combustion*** of hydrocarbons to H_2;

large scale => by MSR**** with large-scale disposal of CO_2

⇒ Fast system transformation from CH_4 to H_2 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

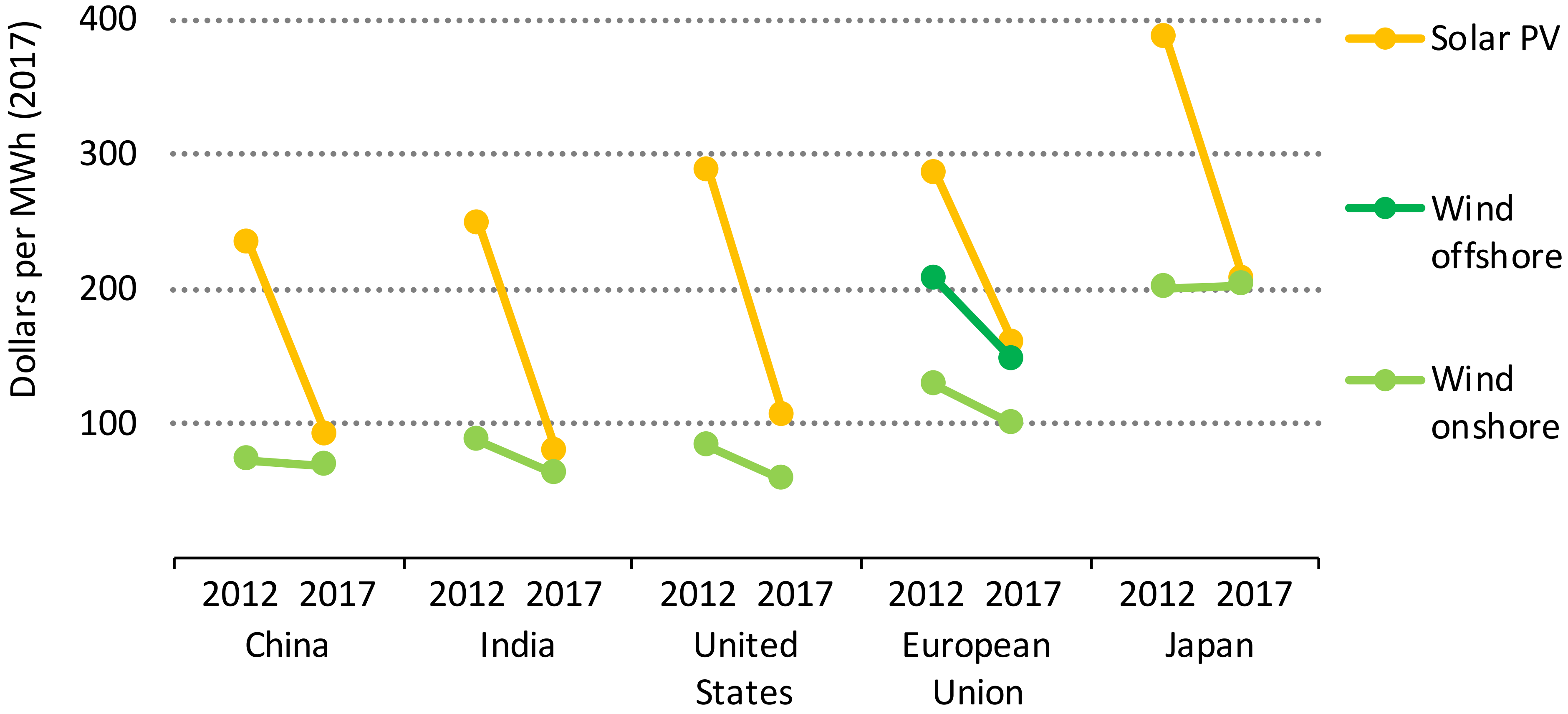
**** MSR: methane steam reforming, the only available large-scale technology

Developments 2000-2016

	2000	2016
Total primary energy demand (Mtoe)	**10035**	**13760**
of which:		
- Coal	2311	3755
- Oil	3670	4388
- Gas	2071	3007
- Nuclear	676	681
- Hydro	225	350
- Bioenergy*	1023	1354
- other renewable (Mtoe)	60	225
Share of fossil fuel (%)	**80%**	**81%**
CO_2 emissions (Gt)	**23.0**	**32.1**
*includes traditional biomass		

Source: World Energy Outlook 2017

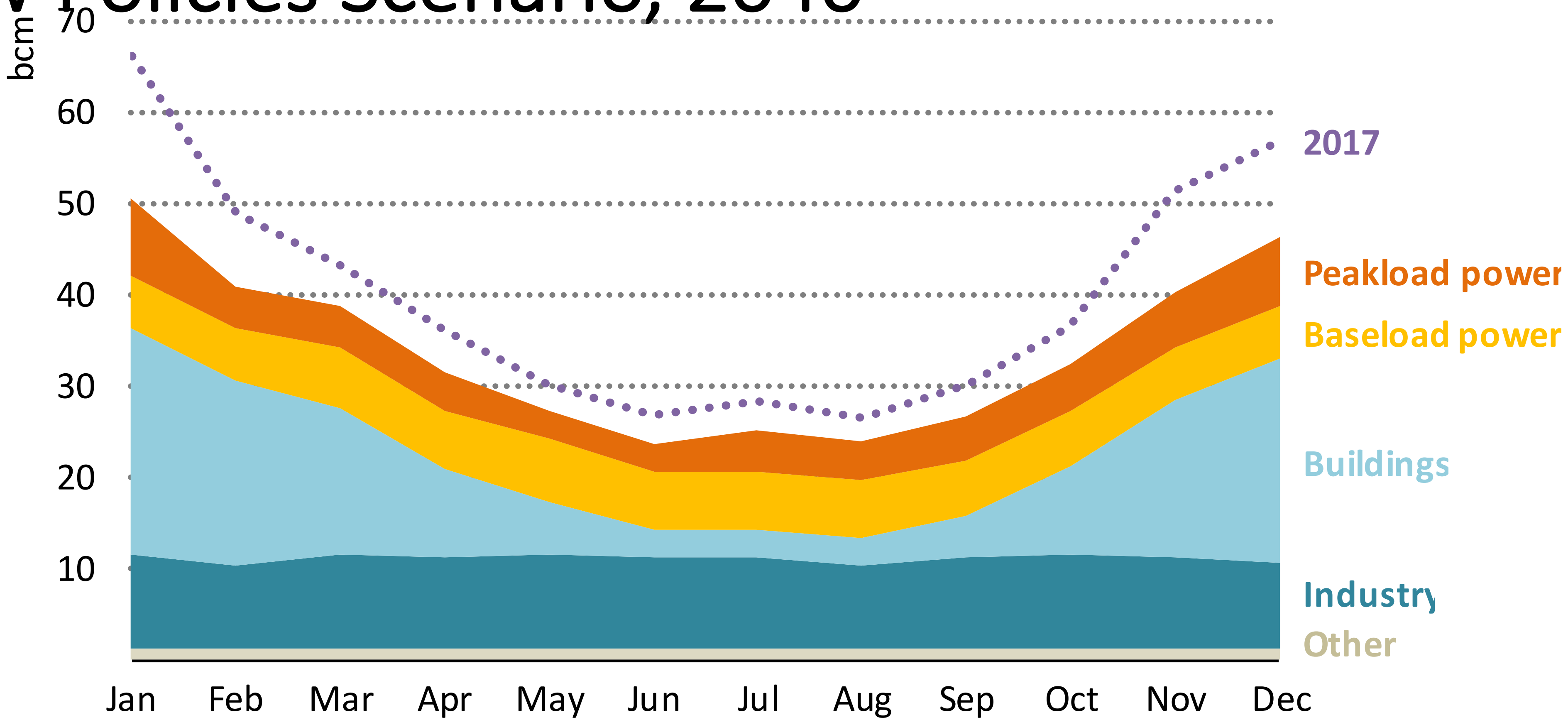
Levelised costs of electricity by selected technologies and regions, 2012-2017



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

Source: World Energy Outlook 2018

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

Source: World Energy Outlook 2018

IPCC Special Report on Global Warming of 1.5°C

Global indicators	**P1**	**P2**	**P3**	**P4**
Pathway classification	**No or low overshoot**	**No or low overshoot**	**No or low overshoot**	**High overshoot**
CO_2 emission change in 2030 (% rel to 2010)	-58	-47	-41	4
→ in 2050 (% rel to 2010)	-93	-95	-91	-97
Kyoto-GHG emissions in 2030 (% rel to 2010)*	-50	-49	-35	-2
→ in 2050 (% rel to 2010)	-82	-89	-78	-80
*Final energy demand** in 2030 (% rel to 2010)*	-15	-5	17	39
→ in 2050 (% rel to 2010)	-32	2	21	44
Renewable share in electricity in 2030 (%)	60	58	48	25
→ in 2050 (%)	77	81	63	70
Primary energy from gas in 2030 (% rel to 2010)	-25	-20	33	37
→ in 2050 (% rel to 2010)	-74	-53	21	-48
Primary energy from non-biomass renewables in 2030 (% rel to 2010)	430	470	315	110
→ in 2050 (% rel to 2010)	832	1327	878	1137
Cumulative CCS until 2100 ($GtCO_2$)	0	348	687	1218
→ of wich BECCS ($GtCO_2$)	0	151	414	1191

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

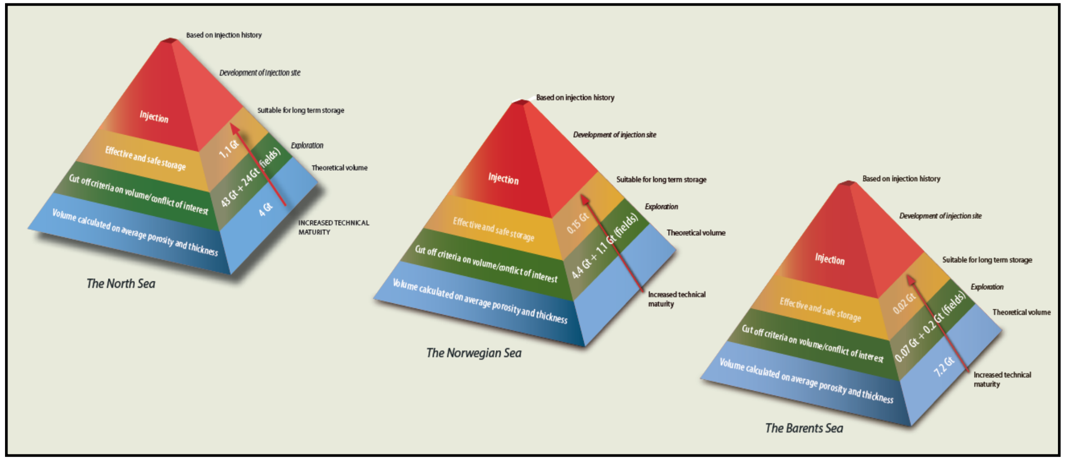
** Changes in energy demand are associated with improvements in energy efficiency and behaviour change

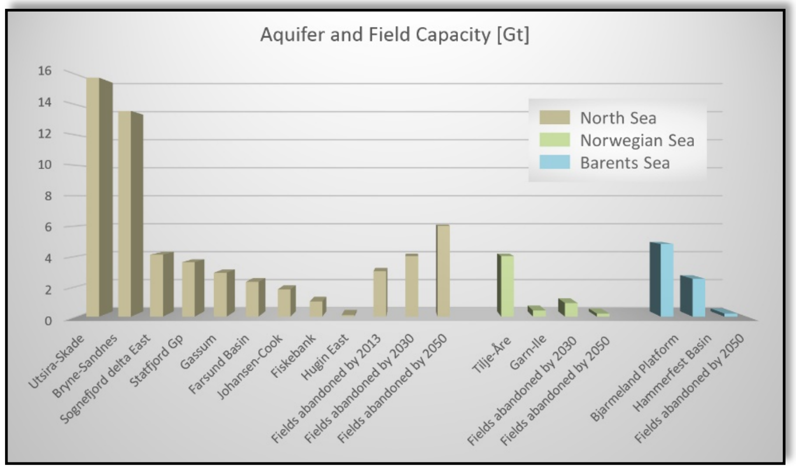
SAR: Second Assessment Report, GWP: Global Warming Potential, from IPCC 2018 SPM, p. 13

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_2
- Equinor: H_2 projects, developed together with customers, taking back the CO_2 from MSR (by ship / for UK by pipeline)
- 40+ Gt of CO_2 storage potential in the Norwegian North Sea alone (Germany according to Bundesanstalt für Geowissenschaften und Rohstoffe: 20 +/- 8 Gt of CO_2)
- Beyond CO_2 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_2 storage: proven and simple technology (reinjecting a non-flammable, non-toxic liquid); has to be monitored

CO_2 Storage Capacity
Norwegian Continental Shelf





How much is a Gigaton?

1 tonne	= one metric tonne	= 1000 kg	
1 Mt	= one megatonne	= 10^6 tonnes	
1 Gt	= one gigatonne	= 1000 Mt	= 10^9 tonnes

	Volume/weight	Energy	CO_2 formed
Natural gas	532 GSm^3	5300 TWh	1 Gt
Diesel	372 Mt	3800 TWh	1 Gt
Coal	413 Mt	2800 TWh	1 Gt

NPD

Reflections: NL / Gasunie

- Testing / projects to convert the increasingly idle L-Gas infrastructure to H_2

- Insular solutions, to be linked up, also with existing H_2-system

- CO_2 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_2 may become necessary; Russia may first look at cheaper options (tapping the bounty of energy efficiency)

(ii) Cooperation

- in knowledge sharing (mainly on H_2 technology infrastructure and application)
- In developing the H_2 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_2 vs CH_4 -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_2), thereby for decarbonisation
- Subject to competition / markets
- Costs to produce the product (decarbonised H_2) and bring it to the market are borne along the chain; finally deducted from the revenue ex wellhead (determining the resource rent)

=>

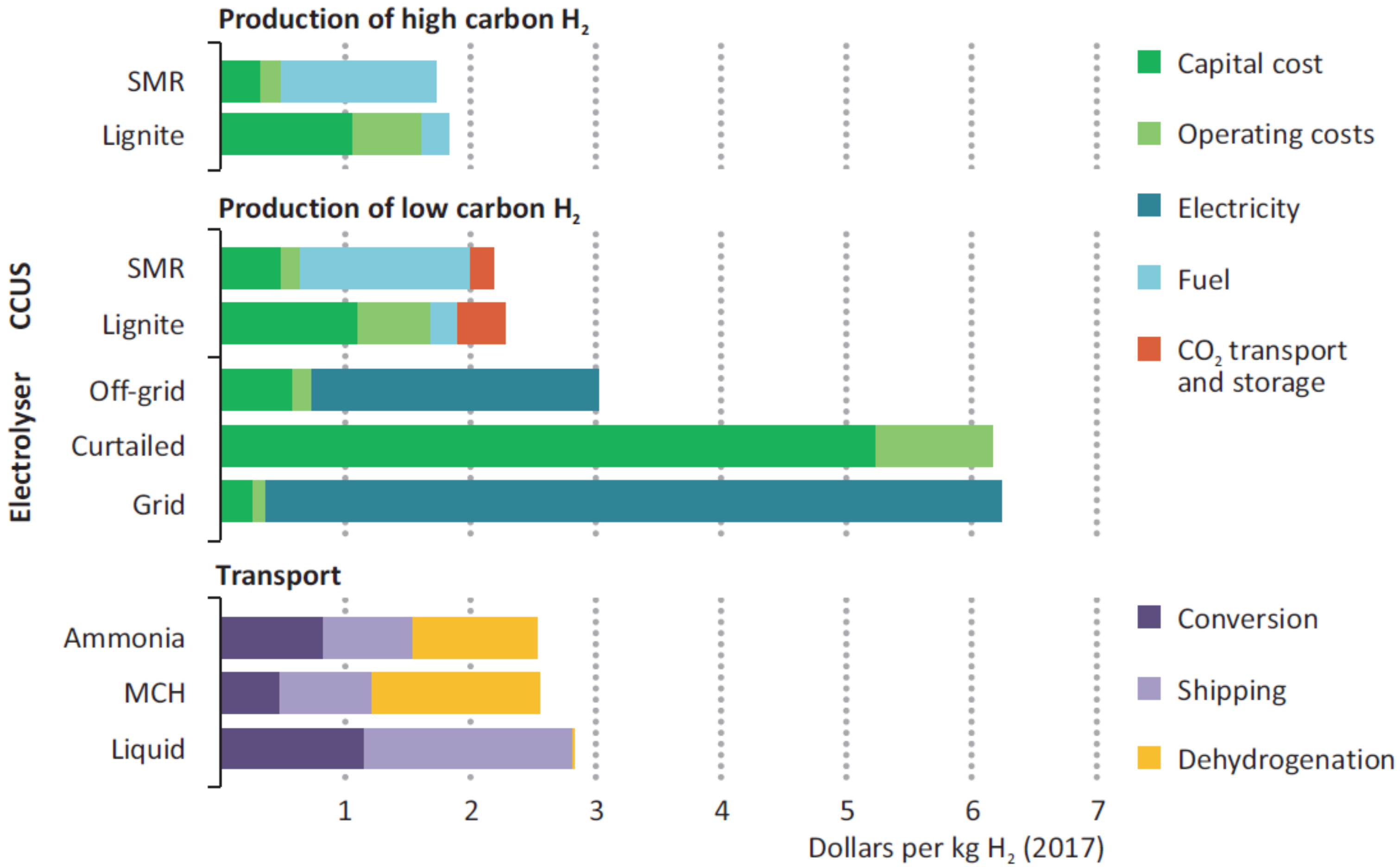
different (higher) value for a different product in the market (determined by competition / markets for H_2 and its infrastructure)

but also higher costs to produce / deliver H_2 compared to CH_4)

Net back in an H_2 System

Renewable H_2 from electrolysis				**Feed**		**H_2 from decarbonizing gas**						
				into								
domestic	H_2 from renewable electrolysis		**=>**	**H_2**	**<=**				**<= transport of H_2**	**H_2 <=**	CH_4 by **MSR**	CH4 prod.
									= 90% of CH_4	local heat losses 25%		
				S				**b**		disposal of CO_2*		
imported	H_2 from renewable electrolysis	**bor**	**=>**	**y**		via CH_4 storage		**o**	<= transport of CH_4			CH4 prod.
	(H_2 => NH_3 => H_2) *	**der**		**s**		or direct feed into		**r**				
				t	**<=**	**H_2 <=**	CH_4 by **MSR**	**d**				
				e		local heat losses 25%		**e**				
				m		disposal of CO_2		**r**				
				or	**<=**				**<= transport of H_2**	**H_2 <=**	CH_4 by **MCr**	CH4 prod.
				M					= 90% of CH_4	local heat losses 13%		
				a						disposal as C* (40% of En)		
				r								
				k		via CH_4 storage			<= transport of 2 x CH_4			CH4 prod.
MSR	Methane Steam reforming			**e**		or direct feed into						
MCr	Methane Cracking			**t**	**<=**	**H_2 <=**	CH_4 by **MCr**					
						local heat losses 13%						
* needs certification						disposal of 40% as C						

Costs of selected options to produce H_2 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_2 in 2040

Source: World Energy Outlook 2018

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_2 (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_2 disposal: may be a regulated business; but cross-border issues, certification needed

Reflections on who pays?

- Putting a price on CO_2 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_2 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_2 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_2-free renewable fuel (H_2) likely to become a yardstick for other CO_2-free fuel

=> bringing the costs of electric H_2 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_2 taxes; must be flanked by social policies)

Time is of the essence!
And cooperation!

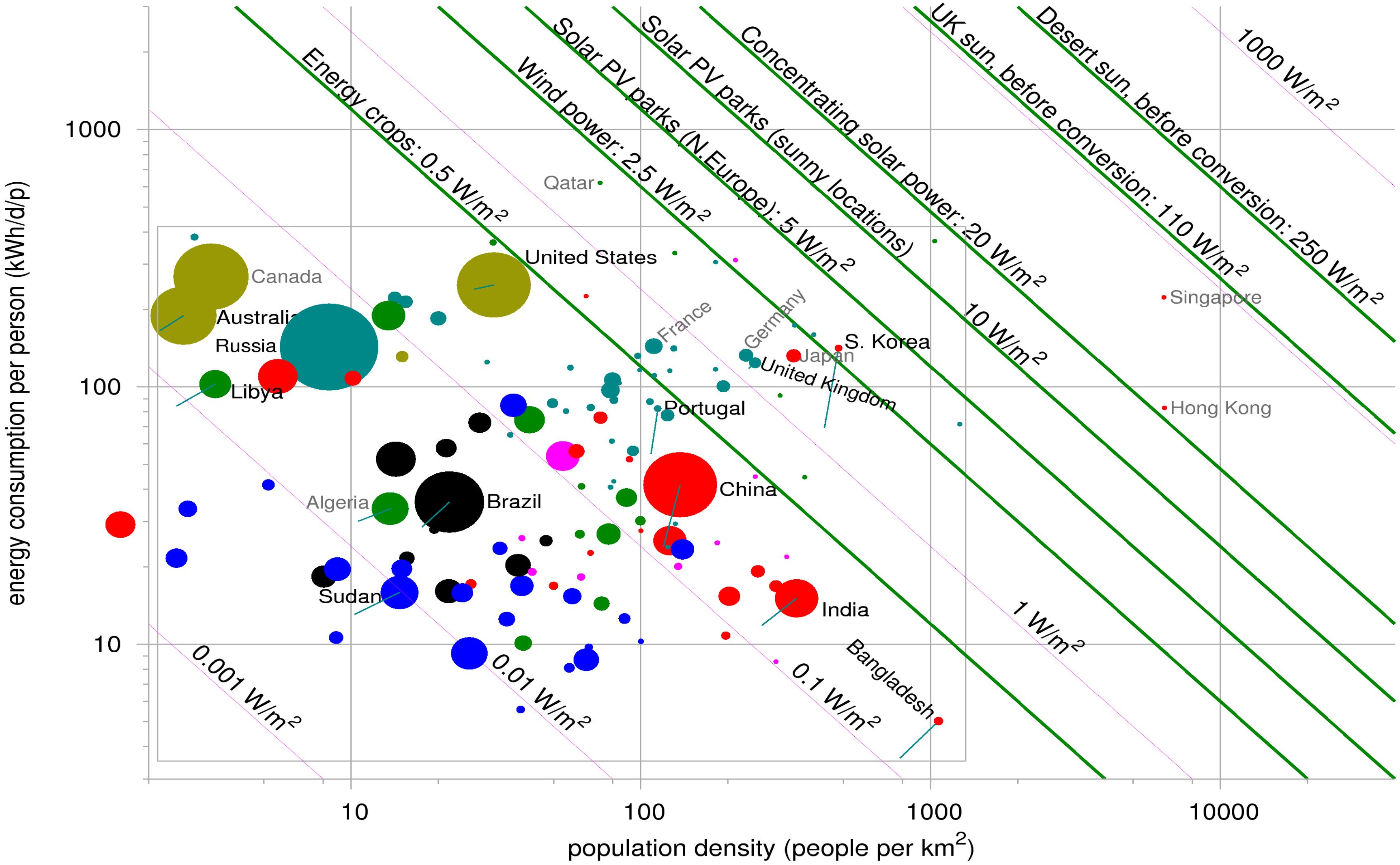
- We live in an era in the history of nations where there is greater need than ever for co-ordinated political action and responsibility

- 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 elctrolysis 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_2 disposal	no	no	CO_2 disposal		use / dispose of C	
where?	n.a.	n.a.	**upstream**	**downstream**	**upstream**	**downstream**
intermittence (surplus) power	regulate down	use of gas storage for H_2 but only 30% capacity	use of gas storage for H_2 but only 30% capacity		use of gas storage for H_2 but only 30% capacity	
intermittence (deficit) power	remaining fossil power with CCS?	use of H_2 from storage for power from H_2	use of stored H_2 for power from H_2	use of stored H_2 plus decarb CH_4	use of stored H_2 for power from H_2	use of stored H_2 plus decarb CH_4
implication gas import structure	becomes idle	becomes idle	conversion to H_2	remains	conversion to H_2	remains, but 2x capacity needed
replacing domestic gas supply	add system equivalent to gas system duplicating gas system	all gas system changed to H_2 H_2 storage (only 30%) conversion of system and appliances	all gas system changed to H_2	system partially changed to H_2	all gas system changed to H_2	system partially changed to H_2

Properties

CH_4

- GCV: 889 kJ/mol

Relevant for energy stored

- Wobbe Index: 53.45 MJ/Nm^3

Relevant for energy transportation capacity

H_2

- GCV: 286 kJ/mol

= 32% of CH_4

- Wobbe Index: 48.34 MJ/Nm^3

= 90% of methane

(L-Gas: up to 46,8 MJ/Nm^3)

- More compression needed
- More aggressive then CH_4
- Check compatibility along the chain and in applications

Decarbonising CH_4 pre-combustion by steam reforming: producing H_2 and safely disposing of CO_2

Steam reforming (SR – getting the energy out of C and H_4, less process losses):

- Add H_2O (steam) plus energy (endothermic reaction)
- Global industrial application (ca. 150 bcm/year of natural gas)
- SR possible for C, CH_4, CnH_{2n+2}, i.e. coal, gas and liquid hydrocarbons
  - $C + 2\ H_2O \Rightarrow CO_2 + 2 \times H_2$ — coal: 2 H_2 pro 1 CO_2
  - $2_n \times H_2O + C_nH_{2n+2}$, $\Rightarrow n \times CO_2 + 2n\ H_2 + n+1\ H_2$ — gas: 4 H_2 pro 1 CO_2; hydrocarbons in general: $(3 + 1/n)$ H_2 pro 1 CO_2
- Dispose of CO_2 in geological structures (EOR, EGR, depleted reservoirs, aquifers)

Decarbonising CH_4 pre-combustion by methane cracking: producing H_2 and safely disposing of C

Methane cracking: (getting the energy of H_4, less process losses plus getting carbon black)

- KIT process with fluid tin at experimental stage
- Next step TRL 6, using 3 m^3/h = 25 000 m^3/year

=> Very substantial scaling up needed

- CH_4 (889 kJ/mol) =>
  C (carbon black) + 2 H_2 (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_4 plus process losses > 50%)

Energy taxation and implicit carbon pricing in Germany, 2016

		Nominal tax rate	Implicit tax rate	Excl. infrastructure costs*		Excl. counter-factual invest**
				€ 15b p.a.	€ 35b p.a.	
		€ per unit	€ per t CO_2	€ per t CO_2	€ per t CO_2	€ per t CO_2
Gas oil	EUR/1,000 l	61,35	23,03			
Heavy fuel oil (heating)	EUR/t	25,00	7,87			
Heyvy 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	-11,37	-159,73	
Gasoline leaded***	EUR/1,000 l	721,00	315,90	279,79	134,93	
Gaseline unleaded***	EUR/1,000 l	654,50	286,76	253,99	122,49	
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			45,20
Electricity total	EUR/MWh	102,69	113,51			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_2 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