Prioritizing biomass in the sustainable 'Smart Society'

Henrik Wenzel
University of Southern Denmark

4th Generation District Heating – Second Annual Conference

Aalborg University, Copenhagen
21 August 2013

Content

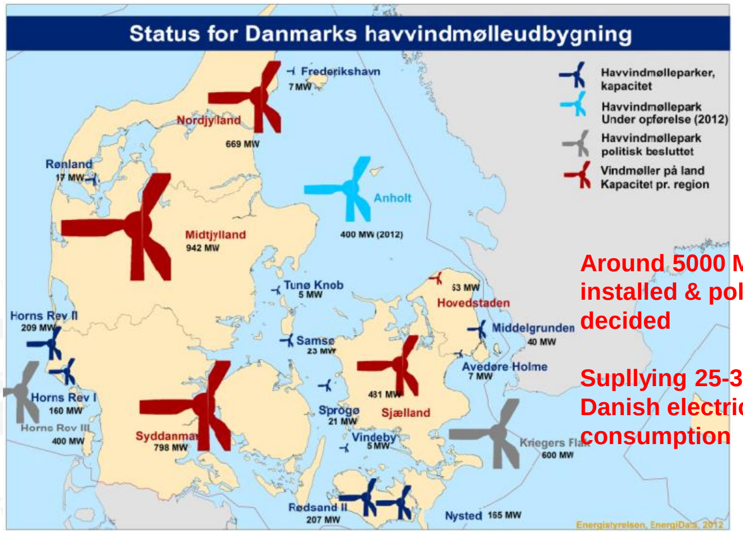
1. Why smart grid?
2. Why not smart grid – but smart energy systems?
3. Why not smart energy systems – but smart society?

… and how does it all relate to our energy policy and the prioritization of biomass in the Danish renewable energy system?

Syddansk Universitet

SYDDANSK UNIVERSITET

Danish wind power status



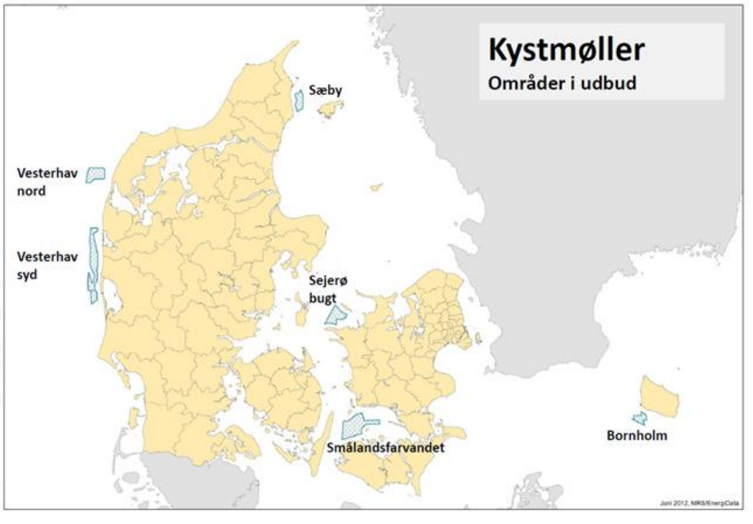
Around 5000 MW installed & politically decided

Supllying 25-30 % of Danish electricity consumption

Syddansk Universitet

SYDDANSK UNIVERSITET

Further coastal wind power calls



Danish energy policy milestones

Year	Target	Political status
2020	50 % wind power 50 % of manure used for biogas	Parliament agreement
2030	Coal phased out Oil for heat phased out	Government policy
2035	100 % renewable energy for power and heat	Government policy
2050	100 % renewable energy – also in transport	Government policy

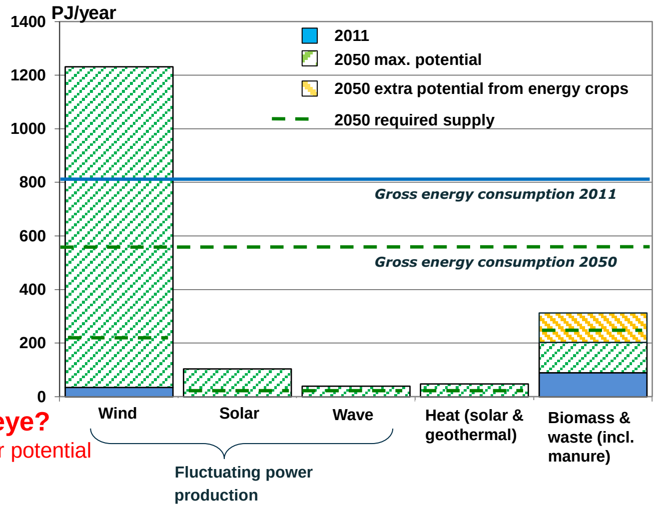
Danish RE system research

Some of the most important studies on renewable energy system design:

1. **The Danish Climate Commission, 2010**
2. **The Danish TSO energinet.dk, www.energinet.dk**
3. **The research program 'Coherent Energy and Environmental System Analysis' – www.ceesa.dk**

The Danish Climate Commission

- domestic renewable resources for 100 percent renewable energy by 2050

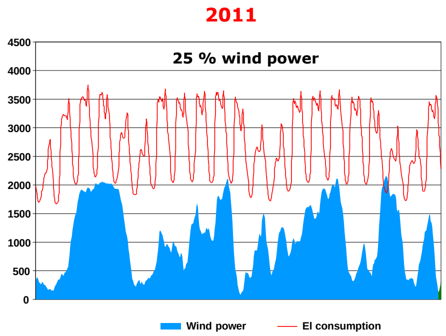


What catches the eye?

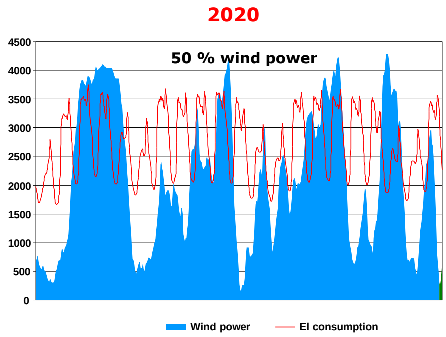
1. Abundant wind power potential – but fluctuating
2. Limited biomass

Why smart grid?

- balancing wind power



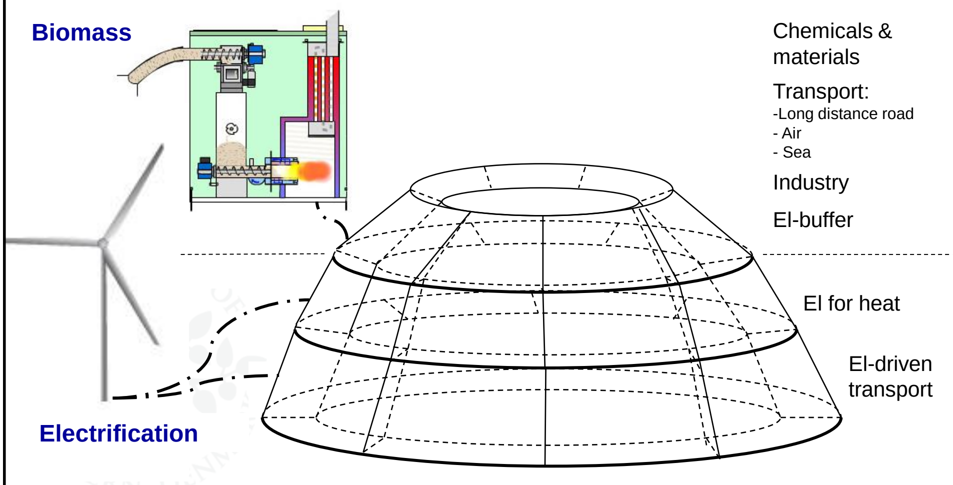
Wind power covered total power consumption in 275 hours in 2011



In the future, wind power can exceed consumption in more than 1000 hours per year

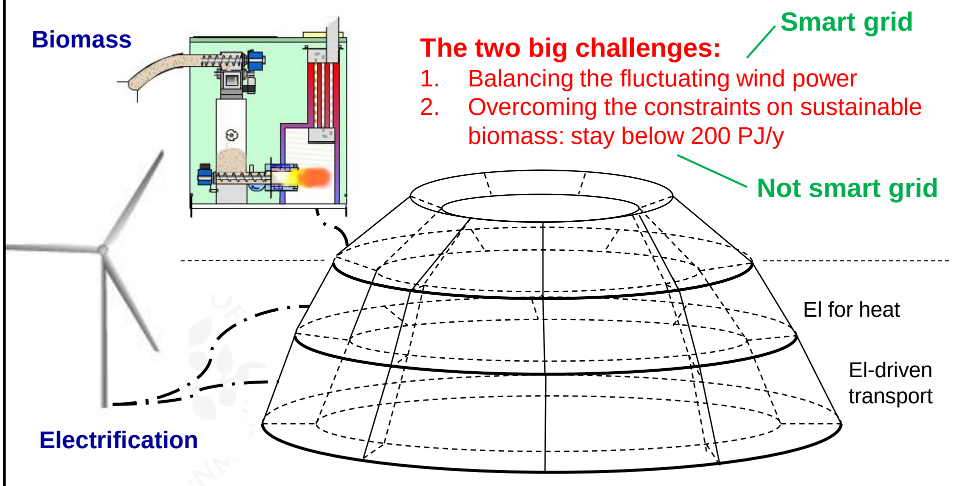
Ref: energinet.dk

The basis and challenges for the Danish RE system
- electrification, wind power and biomass

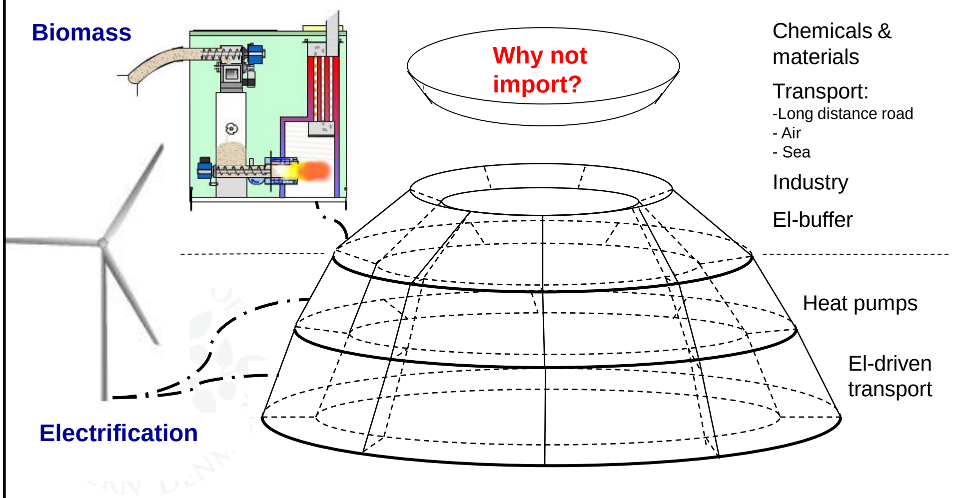


The basis and challenges for the Danish RE system
- electrification, wind power and biomass

The two big challenges:
1. Balancing the fluctuating wind power
2. Overcoming the constraints on sustainable biomass: stay below 200 PJ/y



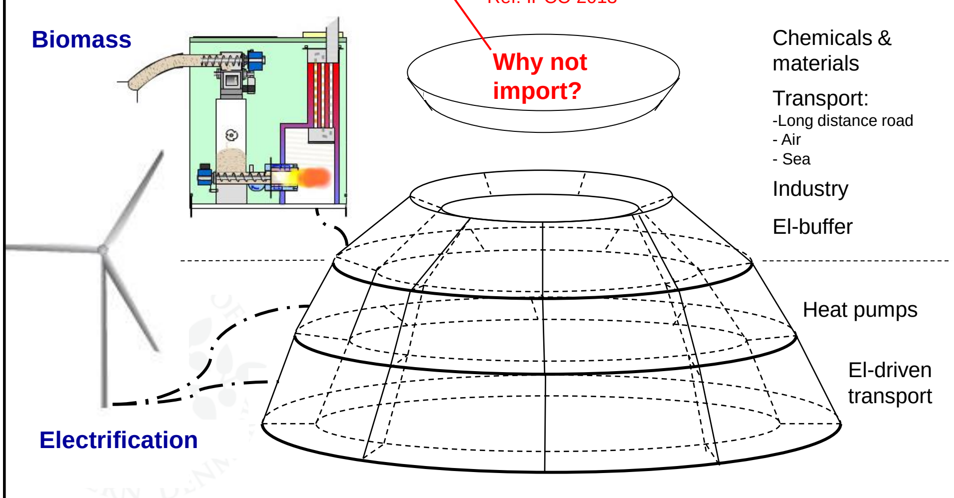
The biomass challenge



Syddansk Universitet
SYDDANSK UNIVERSITET

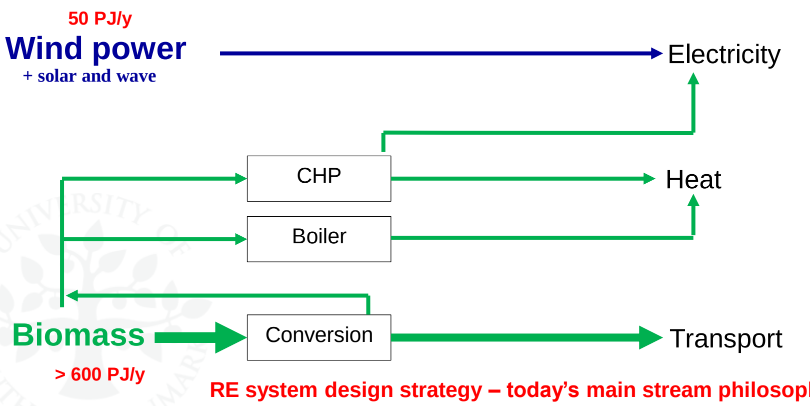
The biomass challenge

Danish residual biomass: 200 PJ/y ≈ 40 GJ/capita
Globally: 100 – 300 EJ/y ≈ 10 – 30 GJ/capita
Ref: IPCC 2013



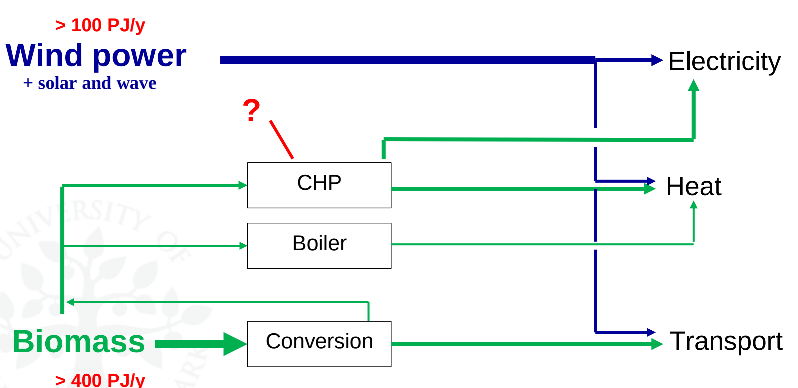
Det Tekniske Fakultet, Institut for Kemi-, Bio- og Miljøteknologi

Why smart energy systems?
- power, heat and transport integration



RE system design strategy – today's main stream philosophy?:
1) Large scale biomass CHPs for balancing power, 2) Biomass for heat
3) Conventional biofuels for transport

Why smart energy systems?
- power, heat and transport integration



RE system design strategy – how far smart grid takes us?:
1) Electricity for heat and transport, 2) Still some biomass for heat
3) Conventional biofuels for fuel demanding transport

Smart energy systems – how?

- minimizing biomass use

Wind power → + solar and wave

Biomass →

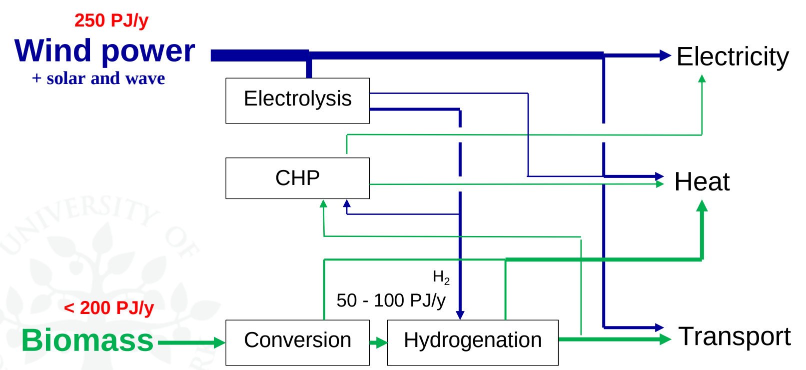
Smart energy systems design strategy:

1. Maximize electrification of heat and transport
2. Convert wind power to fuels through electrolysis
3. Integrate hydrogen with biomass conversion
4. Prioritize biomass for transport fuels mainly
5. Use heat loss from fuel production for heat services
6. Use small scale CHP for balancing power: gas motors, fuel cells

→ El – non-flexible
→ El – flexible
→ Heat – individual
→ Heat – district
→ Heat/steam – industry
→ Transport – rail
→ Transport – road/light/short
→ Transport – road/light/long
→ Transport – road/heavy
→ Transport – sea
→ Transport – air

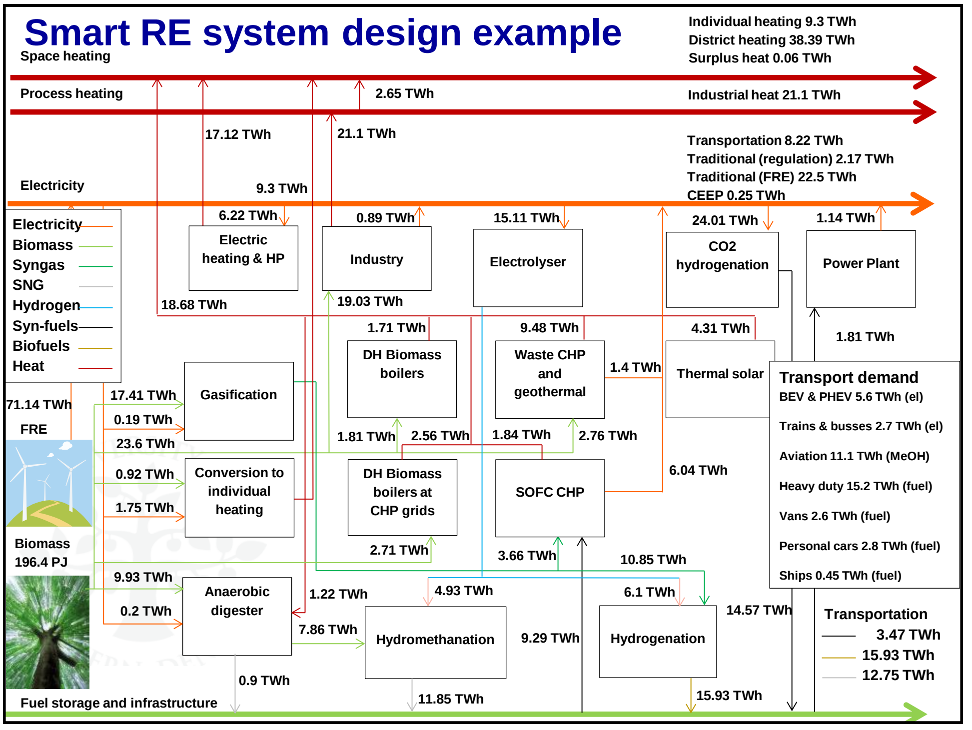
Why smart energy systems?

- power, heat and transport integration



Smart RE system design strategy:
Design principles 1 – 6 from prior slide

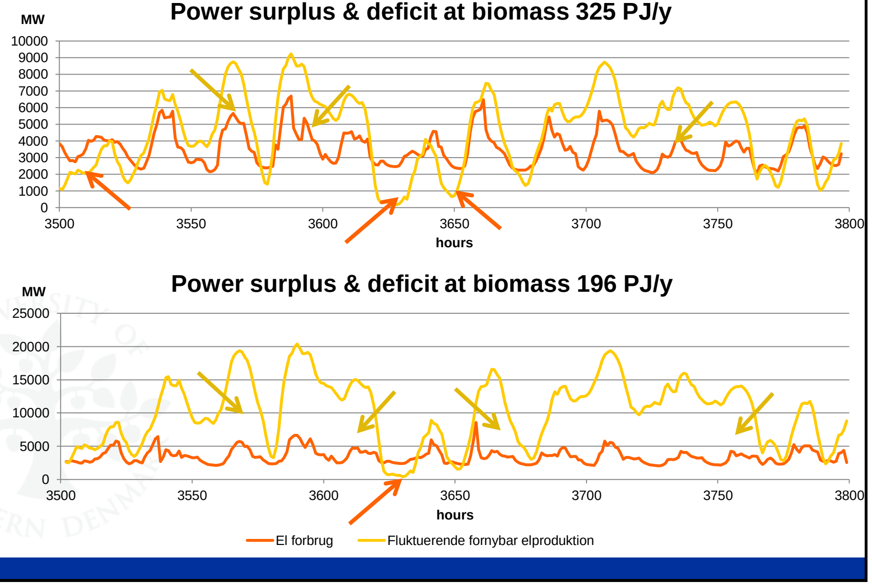
Smart RE system design example



Syddansk Universitet

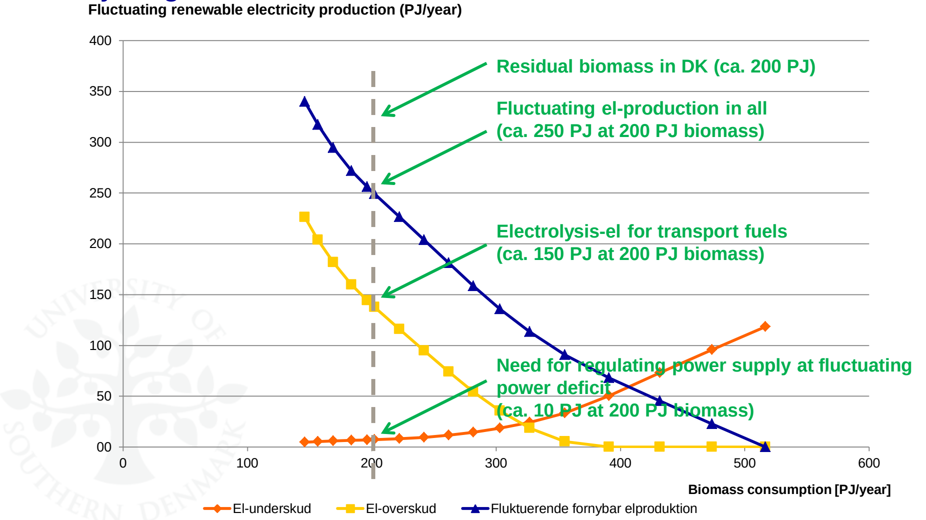
Smart RE system design example

- power balancing task at varying biomass



Smart RE system design example

- the hydrogen/biomass relation



Syddansk Universitet
SYDDANSK UNIVERSITET

Smart RE system design example

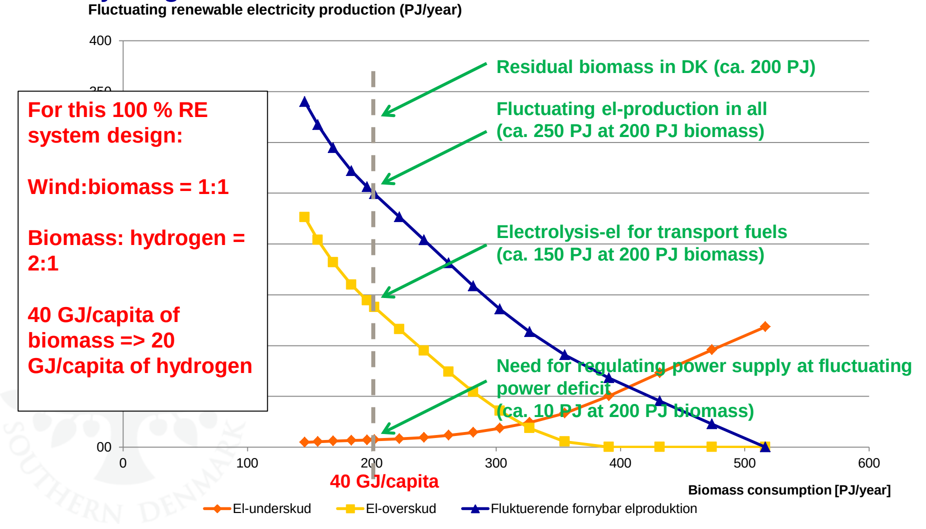
- the hydrogen/biomass relation

For this 100 % RE system design:

Wind:biomass = 1:1

Biomass: hydrogen = 2:1

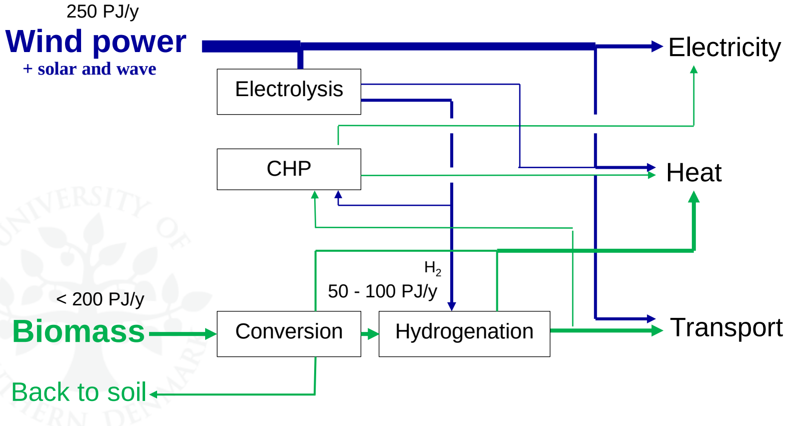
40 GJ/capita of biomass => 20 GJ/capita of hydrogen



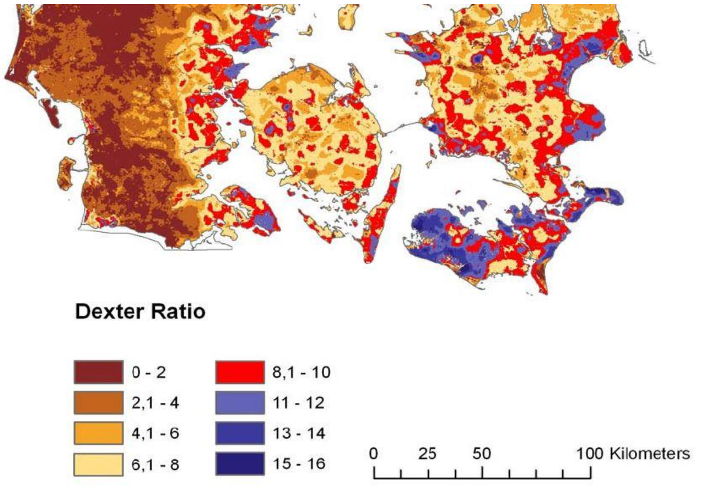
Grandal 2013, eksamensprojekt SDU

Smart RE society

- respect soil carbon needs



Soil carbon needs



Smart RE society

- case of biomass conversion priority: how do we best use straw?

Advantage of straw for biogas compared to large scale straw combustion CHP:

1. **Synergy with manure biogas**
   - High dry matter carbon co-substrate for the dilute manure => manure biogas becomes possible
   - Better C/N ratio
   - Avoiding conventional manure management, avoiding energy crops
2. **Better use of N and P i the straw**
3. **An elegant carbon balance: the degradable C in straw => biogas, the non-degradable C => soil**
4. **Better flexibility/integration with wind power:**
   - Biogas is stored and used for balancing
   - Gas motors attractive at low operation hours due to low investment per kW
   - Methane can be used in transport
   - Methane can be used as a precurser for chemical production
   - Biogas is an attractive media to assimilate hydrogen. Methane ensures the highest possible H_2 assimilation per carbon

Conclusion

If we are to succeed in having a 100 % RE system:

- Do not use biomass to satisfy heat/steam demands
- Do not use biomass to provide continuous power
- Do not use biomass to satisfy transport services that can be electrified
- Integrate electrolysis and hydrogenation with biomass conversion to fuels
- Thermally gasify wooden biomass and hydrogenate syngas to gaseous or liquid fuels. Place thermal gasification on the 3-4 major city district heating grids in DK
- Co-digest manure, straw and wet, degradable biomasses to biogas and hydrogenate biogas to methane. Place biogas and gas CHPs on the smaller district heating grids. Take digestate back to soils to maintain soil carbon and to utilize fertilizer value
- Use thermal heat losses from biomass conversion, electrolysis and hydrogenation for heat services
- Use heat pumps for any remaining heat services

… otherwise biomass use will not be sustainable!

Discussion

- Wake me from my nightmare and tell me where I am mistaken

- …or help me give the Danish Energy Agency and the Ministry of Energy & Climate a wake-up call ?

Thank you for your attention!

Extra slides

System integration by hydrogen

- upgrading biomass and recycling carbon

Hydrogenation of cellulose to methane:

biomass		hydrogen		methane		water
$C_6(H_2O)_5$	+	$12\ H_2$	→	$6\ CH_4$	+	$5\ H_2O$
2,8 MJ		2,9 MJ		4,8 MJ		

CO_2 to methane:

carbon dioxide		hydrogen		methane		water
$6\ CO_2$	+	$24\ H_2$	→	$6\ CH_4$	+	$12\ H_2O$
0 MJ		5,8 MJ		4,8 MJ		

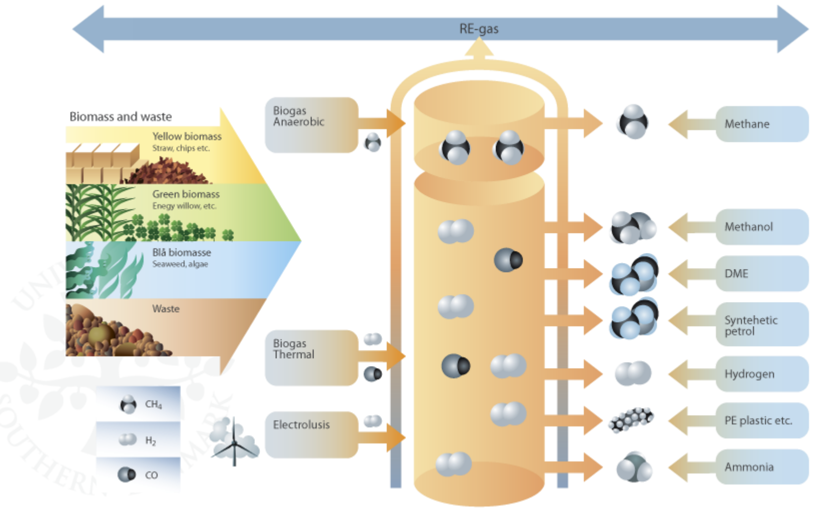
System integration by hydrogen

- five-doubling the benefit og biomass by upgrading and recycling bio-C

Conversion process	Inputs (PJ)		Outputs (PJ)		
	biomass	hydrogen	solid fuel	liquid fuel	methane
Fermentation Inbicon 2G ethanol	100		50	22	
Gasification and hydrogenation of cellulose to methane	100	100			170
CO_2 to methane	100	200	100		170
Cellulose & CO_2 to methane	100	300			340

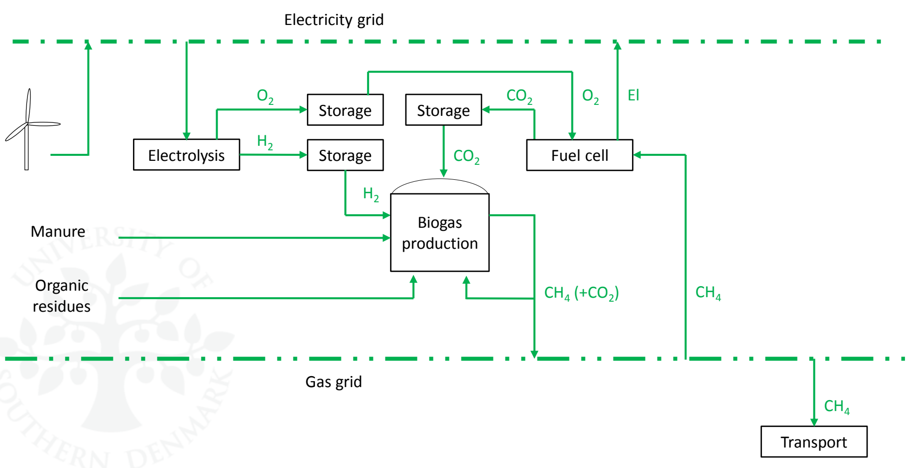
System integration by hydrogen

- the RE gas vision of Energinet.dk, the Danish TSO



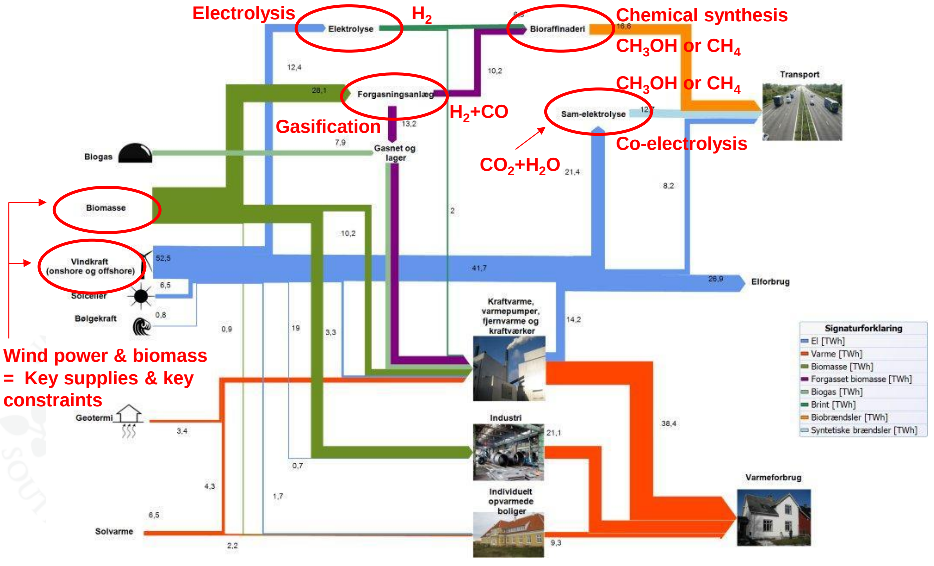
System integration by hydrogen

- the RE gas vision of agriculture



System integration by hydrogen

- the RE system design of the CEESA research program



www.ceesa.dk

Syddansk Universitet

Closing the carbon gap

- a back-of-the-envelope look at the cost of recycling bio-C

Based on the following assumptions:

- Off-shore wind power: 0 – 10 eurocents/kWh
- Energy efficiency of electrolysis: 75 %
- Operation cost of hydrogen: 0 – 4.4 €/kg = 0 – 1.5 €/kg oil equivalent = 0 – 200 €/barrel oil equivalents
- Total cost of hydrogen including amortized investment: 50 – 250 €/ barrel oil equivalents
- Total cost of methane: max 100 – 300 €/barrel oil equivalents
- Petrol reference: 75 €/barrel oil equivalent

we find a max. extra cost of synthetic fuel = 300 – 75 = 225 €/barrel oil equivalent.

At 100 PJ CCR fuel/year this would imply an extra cost of maximum 4 billion €/year, being equal to 2 % of Danish GDP today. Or 1% of Danish GDP in 2050.

System integration by hydrogen

- an ethical dimension?

Off-shore wind turbines with a yearly production of 100 PJ can save 5000 km^2 agricultural land with a crop production equivalent to the yearly calorific intake of 10 million world average citizens. The Danish population is ca. 5 million people

The extra cost of this would be max. 1 % of GDP