Stiesdal Fuel Technologies

SkyClean

Carbon-Negative
Fuel Concept

Henrik Stiesdal, January 1, 2019

Framework

Company Structure

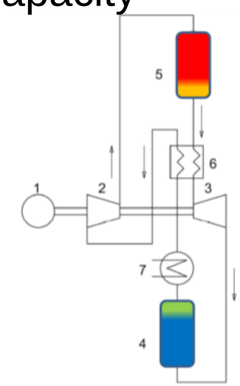
- Climate technology company with focused subsidiaries

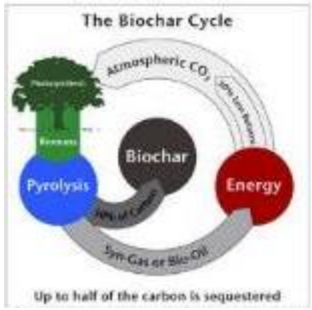
Purpose

- Combat climate change by developing and commercializing solutions to key challenges

Stiesdal A/S

	Stiesdal Offshore Technologies A/S	Stiesdal Storage Technologies A/S	Stiesdal Fuel Technologies A/S
Project	**Tetra**	**GridScale**	**SkyClean**
Target	Unlimited low-cost offshore wind energy	Unlimited share of renewables on grid	Carbon capture and sequestration
Means	Industrialized fixed & floating foundations	Storage system w. 10h – 10d capacity	Carbon-negative jet fuel





Key motivation for storage – renewable power integration

The green transformation is moving rapidly on electricity

- In 2017, Denmark had 44% share of wind in the electricity mix
- Nobody has been required to change behavior for this to happen

Nobody notices the green transformation!

The implication

- Not noticing facilitates transformation

In transportation …

- You <u>do</u> notice the transformation if we speak e-mobility as solution – the range is reduced, and for many use cases liquid fuel remains the only option
- You <u>cannot</u> have e-mobility for long-distance aviation transportation

The green transformation of transportation will be more difficult than it has been on electricity

We have been using biomass in transportation before

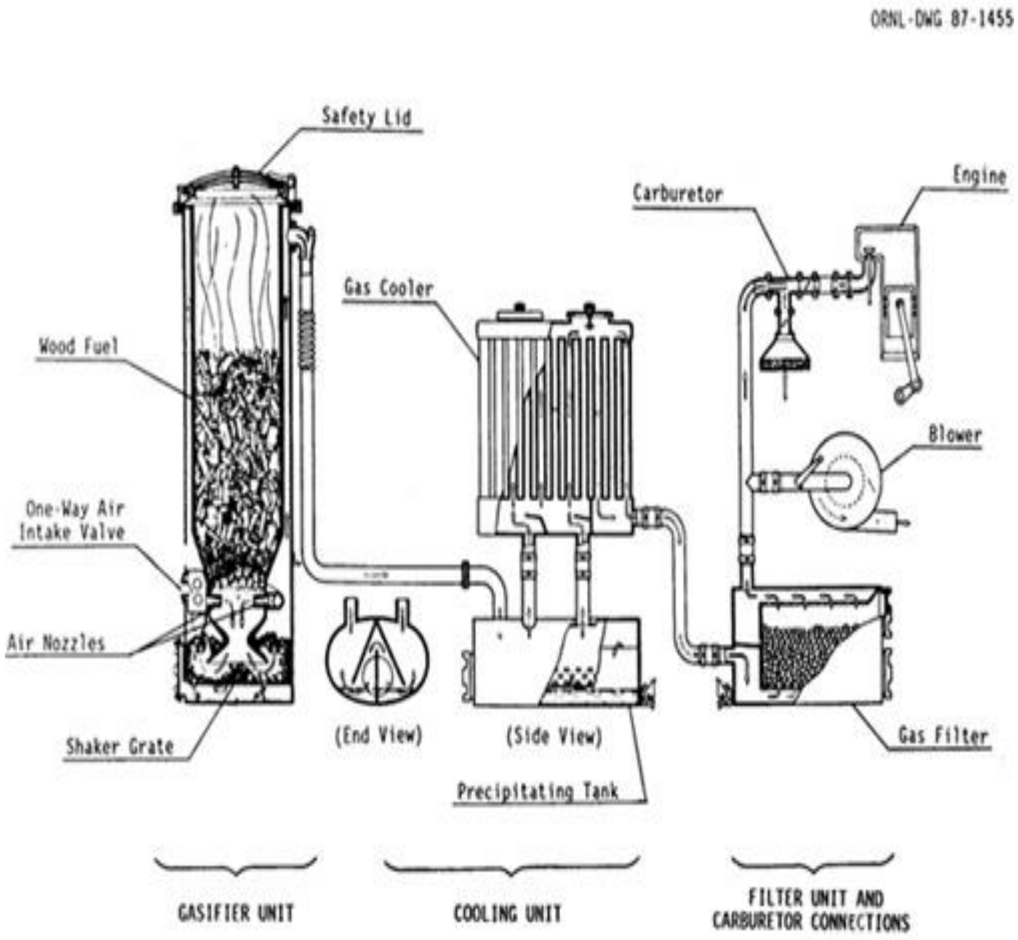
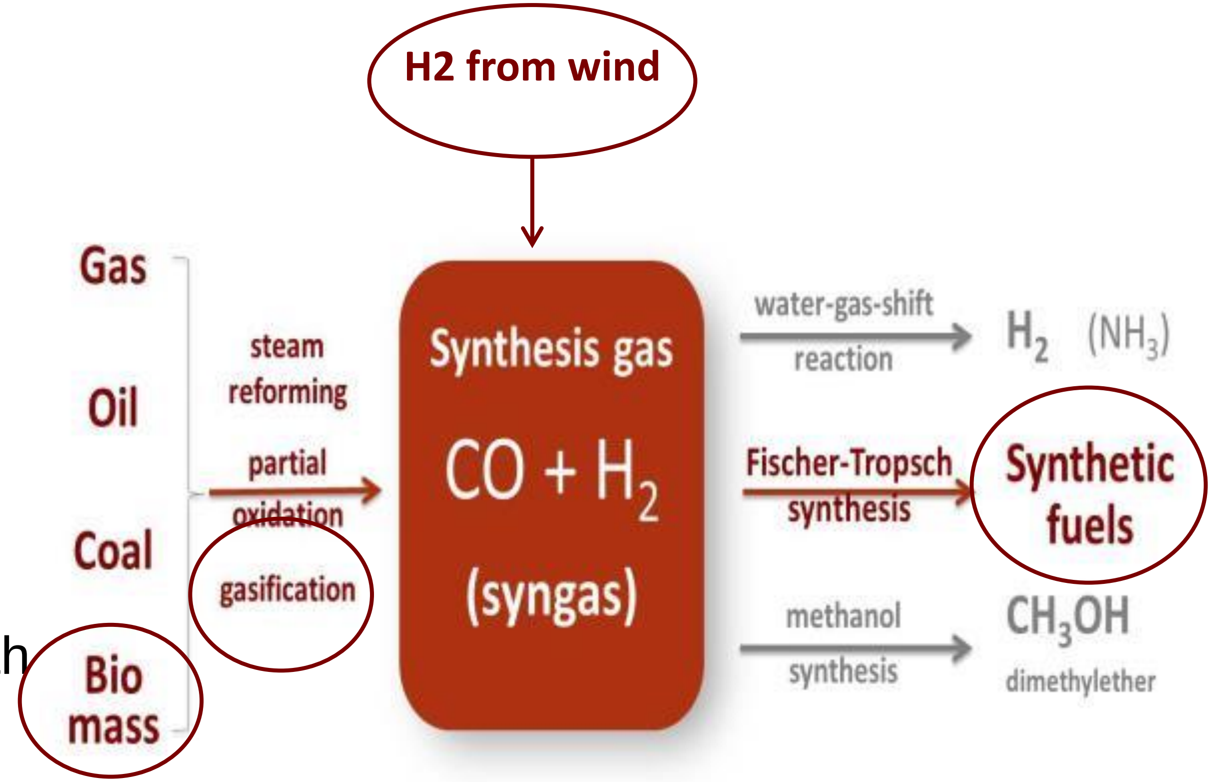


Fig. 1-2. Schematic view of the World War II, Imbert gasifier.

Solid fuels are not convenient. We need liquid fuels – with a twist

Principles

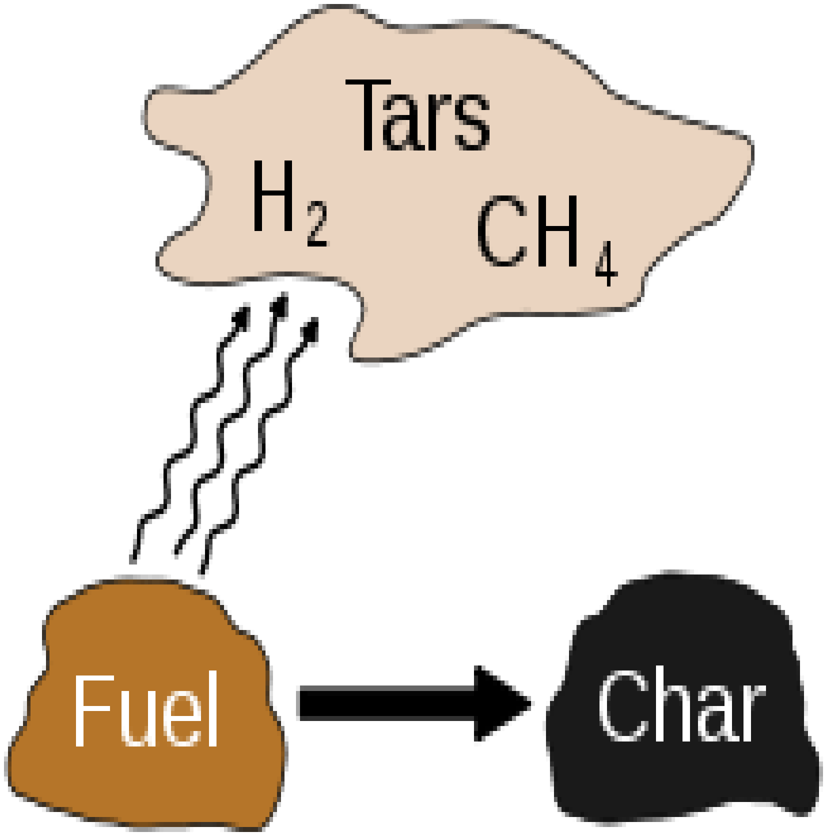
- Pyrolyse biomass to yield bio-oil and gas
- Add moderate amounts of H2 from electrolyzed water using wind electricity
- Create synthetic fuel from oil and gas (gasoline, jet fuel) with industrial processes
- **The twist: Do <u>not</u> optimize pyrolysis process!**



The buzzword: Carbon-negative

Turning the art of pyrolysis upside-down

- “Proper” pyrolysis is about maximizing the yield of oil and gas
- A classical yardstick of gasification skill is minimal solid residue.
- We are after the opposite thing, a high amount of residue
- The solid residue (char) is carbon captured from the atmosphere.
- Char is a long-term stable form of carbon. It can be deposited for millennia.



Biofuels made with char as by-product are carbon-negative

The classical biofuel arrangement

- Plants use CO_2 from the atmosphere to produce biomass
- Biomass is fermented to produce ethanol
- Ethanol is used as a gasoline additive, reducing the fossil-fuel content
- Residues from the process are deposited or are partly used in agricultural production
- The fuel part of the carbon goes back into atmosphere after combustion
- The residue part of the carbon also goes back into the atmosphere after having rotted or as a result of farm animal metabolism

Since equipment used in production and transportation of the biofuel cannot use ethanol exclusively but also requires fossil fuels, the classical biofuel process is not carbon-neutral

The SkyClean biofuel arrangement

- Plants use CO2 from the atmosphere to produce biomass
- Biomass is pyrolyzed at moderate temperature to produce oil and syngas
- Oil and gas are used to produce diesel, gasoline or jet fuel
- Residues from the process are biochar, which can be used for enrichment of agricultural soils; nutrients will leach out of the char.
- The fuel part of the carbon goes back into atmosphere after combustion
- The residue part of the carbon does not rot, it remains stable in the soil for millennia.

The new biofuel process is not just carbon-neutral, it is carbon-negative. The more fuel we produce, the more carbon we remove from the atmosphere!

Project target #1

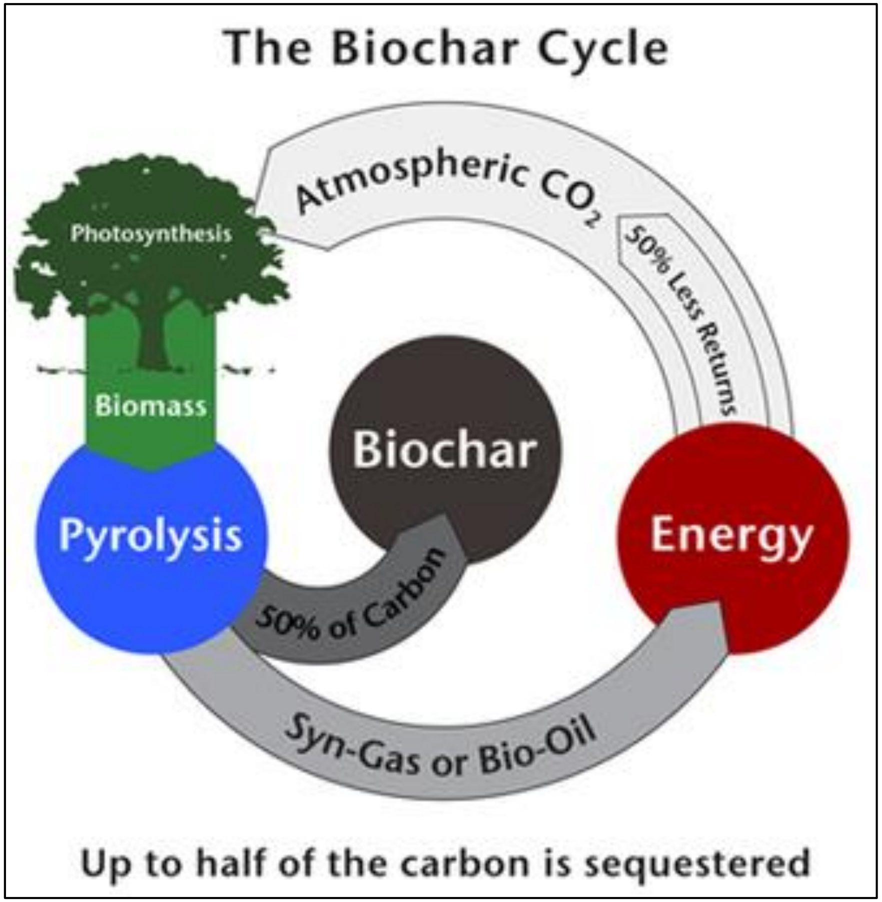
Carbon-negative jet fuel

- Short-range aviation may in theory be electrified, but there is no technical solution to electrification of medium- and long-range aviation
- Bio-based jet fuels offer a solution to aviation, but in the simple form they only contribute to reduced emissions, not to atmospheric clean-up
- Through combination with biochar production bio-based jet fuels will make a significant contribution to atmospheric clean-up
- A true paradigm change – the more we fly, the more we help to reduce atmospheric CO2-levels

Project target #2

Biochar for carbon sequestration

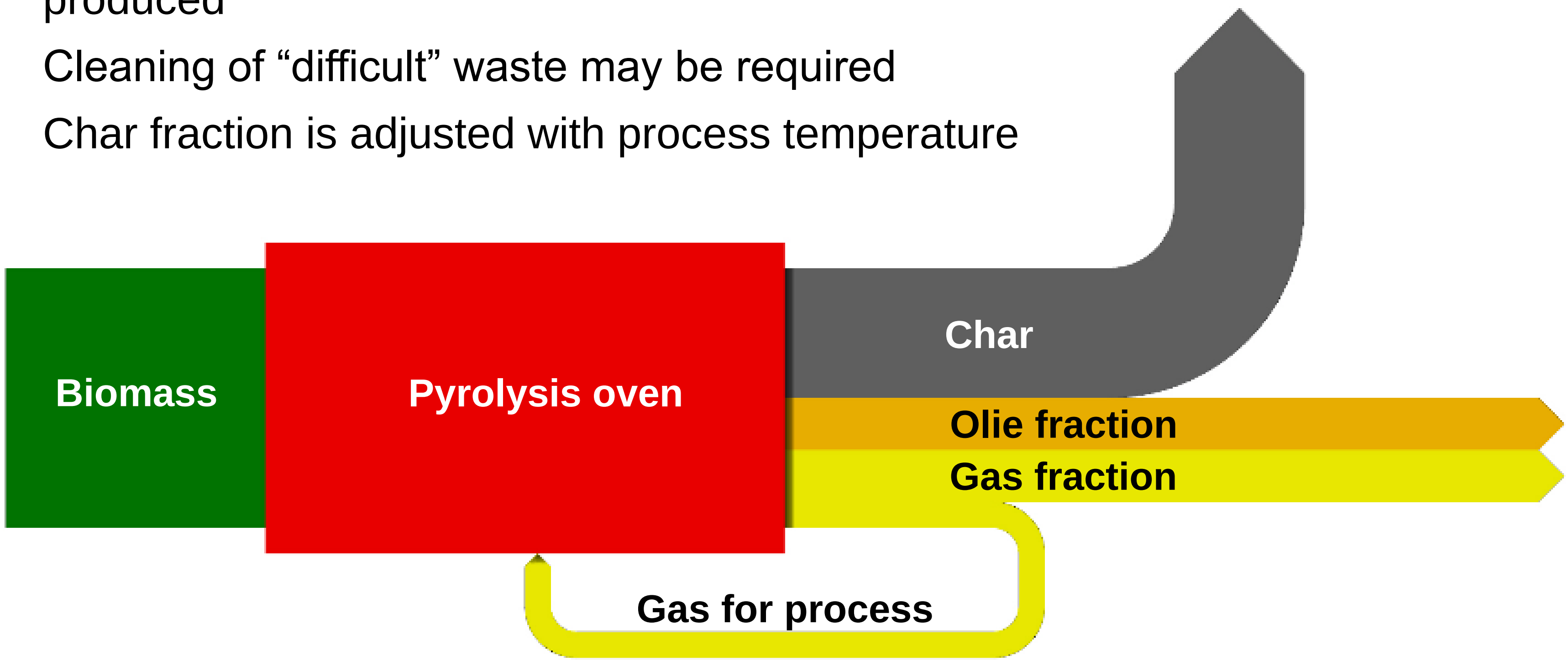
- Biochar is carbonized plant material; charcoal if made from wood, fibrous or powdery if made from straw or other less dense biological materials
- Biochar does not rot and is stable in the ground for thousands of years, offering efficient carbon sequestration
- Biochar from clean feedstock can be used for soil enrichment, increasing organic matter content, biodiversity, and soil ecosystem regulating services, including water infiltration capacity, P and K fertilization, slow release of nutrients, etc.
- Biochar from "difficult" waste will need cleaning or must be deposed safely



Basic concept

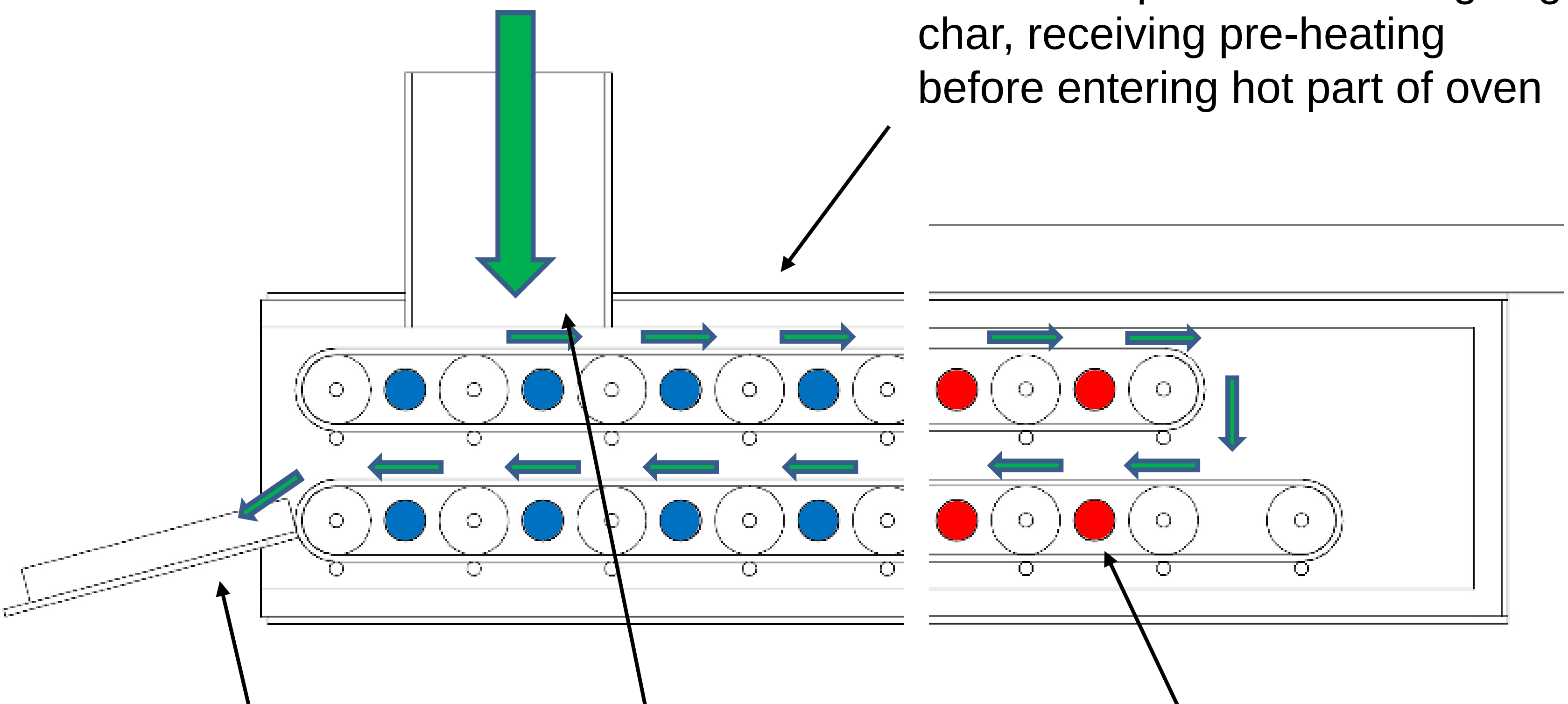
Fundamental principle: Keep it simple

- Low-cost, low-temperature, ambient-pressure pyrolysis oven with countercurrent heating arrangement
- Gas to achieve and maintain pyrolysis process is diverted from syngas produced
- Cleaning of “difficult” waste may be required
- Char fraction is adjusted with process temperature



Process flow in countercurrent pyrolysis oven

Feedstock passes over outgoing char, receiving pre-heating before entering hot part of oven



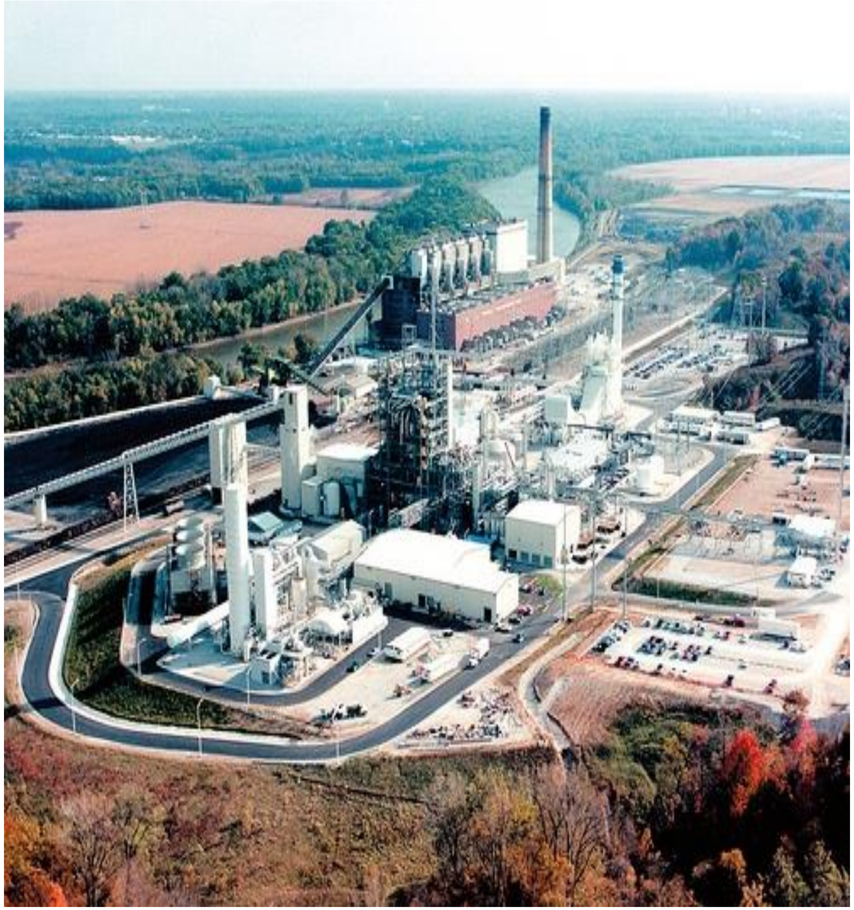
Excess water vapor escapes at feedstock inlet and char outlet, eliminating need for gas control

Heat input through meandering flue gas tube

The paradigm change caused by high penetration of renewables

High RE penetration removes a key obstacle to gas-to-liquid process

- The chemical processes of liquid fuel synthesis from gas are relatively energy-intensive
- The nature-driven character of wind and PV leads to periods when market mechanisms cause low or negative electricity prices
- With cheap electricity we can use fuel-producing processes which are not optimally energy efficient
- The Fischer-Tropsch synthesis arrangements are conventional and well-established



The implications

A green transformation of the transportation sector will be strongly facilitated if people do not have to change behavior

- Pyrolysis of waste biomass and subsequent enrichment of gas with wind-generated hydrogen could yield large volumes of liquid fuels
- By an appropriately tuned pyrolysis process the overall yield can be adjusted to a desired ratio of carbon sequestration, e.g. 50/50, so a ton of CO2 is sequestered for each ton of liquid fuel produced
- The 50% share of sequestered carbon can be used for soil enrichment
- The 50% share of fuel can be used in aircraft and also automobiles (if enough plant waste is available) in precisely the same way as conventional fuels, benefiting also from existing distribution networks
- The arrangement would utilize the “nobody notices” aspect for green transformation – aircraft are fueled just as now, and for automobiles the range limitations of electrical vehicles are avoided

Some open questions

Is there sufficient waste biomass?

- Global production of residual biomass (i.e. biomass not used for food, building, clothing or other value-creating purposes) can yield about 1/3 of the current global energy consumption in the transport sector. This should be sufficient for aviation for many years, also some autos
- The associated carbon sequestration at 50/50 yield would correspond to about 10% of the global CO2 emissions

What is the cost?

- The cost of liquid fuels depends on a number of factors, including the feedstock prices, the energy prices, CAPEX and OPEX of the processing plant, and distribution costs
- Indications are that CAPEX and OPEX of the processing plant will lead to fuel prices (gasoline, jet fuel) roughly equivalent to the fuel prices at a crude oil price of $50 per barrel
- The cost may be offset by a CO2 premium due to the sequestration

Some open questions

Is it safe?

- The interim gasification products (syngas, methanol) are toxic, but no more than typical interim products in industrial processes
- The end products (jet fuel, gasoline) are identical to such fuels produced from fossil sources and therefore have the same level of toxicity as their fossil-produced equivalents
- The char residue may have certain cyclical components (tars) that could be carcinogenic. More research is needed in possible post-processing to ensure complete safety in soil enrichment

Is the sequestration permanent?

- It has duration of millennia, which should be sufficiently permanent to “buy time” for other, technological solutions to the excessive amounts of CO2 in the atmosphere

Some open questions

Are there any additional benefits?

- The process is not restricted to use of plant materials; it may equally well be used with other carbon-intensive materials as feedstock
- Plastics can be disposed of by gasification, preventing the return of a considerable part of the carbon content to the atmosphere
- One particularly attractive use case is the pyrolysis of old tires. Old tires left in nature invariably accumulate water in small internal ponds, and in tropical climates they serve as breeding grounds for mosquitos. A value-adding disposal process could allow for payment at return of old tires, thereby creating a motivation for populations in third world countries to remove tires from dumps and locations in nature

Project status

Main topic	Subtopic	Done	Open
Resource assessment	• Concept assessment based on 2010 data	✓	
	• Detailed assessment based on current data		✓
	• Extended assessment based on “for purpose” biomass production		✓
Process assessment	• Overall concept assessment	✓	
	• Pyrolysis concept	✓	
	• Gas-to-fuel concept	✓	
	• Detailed process design		✓
Cost assessment	• Gas-to fuel cost assessment	✓	
	• Gasification and compression assessment		✓
Partnering	• Research partners identified	(✓)	
	• NGO partners identified		✓
	• Commercial partners identified		✓

Thanks for your attention

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Introduction – Henrik Stiesdal

Former CTO of Siemens Wind Power, retired end 2014

Key Achievements

- Wind power pioneer, built first test turbine 1976, and first commercial turbine 1978; licensed wind turbine design to Vestas 1979, kick-starting modern Danish wind industry
- Served as technical manager of Bonus Energy A/S from 1988, ran company together with CEO until Siemens acquisition 2004, then took position as CTO of Siemens Wind Power
- Installed world's first offshore wind farm (1991) and world's first floating wind turbine (2009)
- Invented and implemented key technologies, including Siemens proprietary blade manufacturing, low-weight direct-drive turbines, variable-speed operation, energy storage, etc.
- Holds more than 800 patents

Post-Siemens activities include work on low-cost offshore infrastructure, high-capacity energy storage and carbon-negative fuels