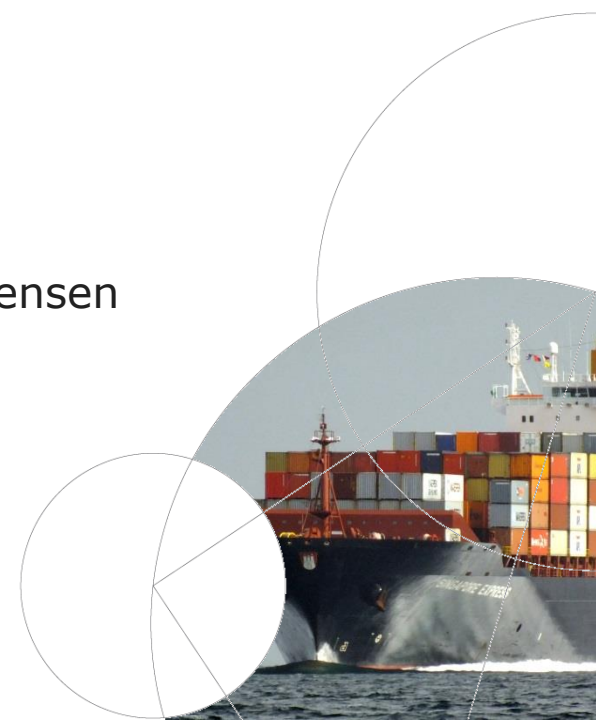
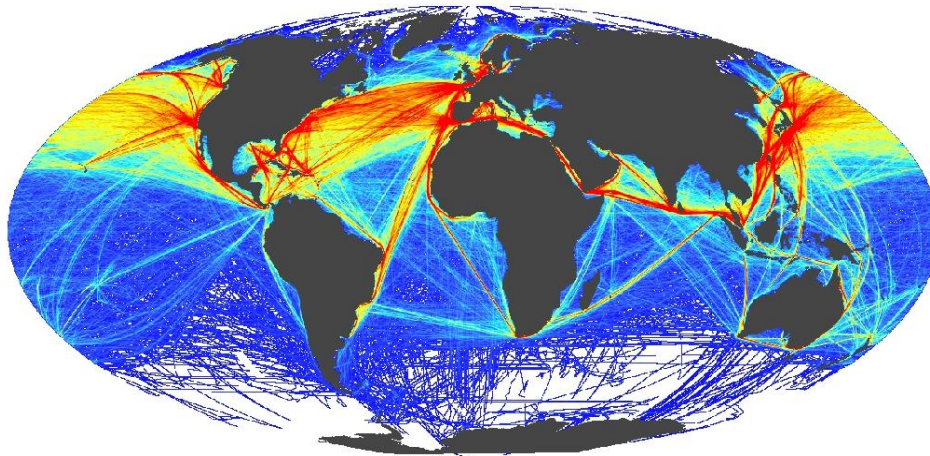


Potentials and challenges of drop-in marine biofuels

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University of Copenhagen, Faculty of Science
November 2016



The global shipping sector



- Merchant shipping responsible for 90% of international trade
- Small and medium sized vessels make up the largest percentage of the fleet by number, but large vessels consume 70% of the marine fuel available
 - Demand for shipping fuel approx 330 MT a year (2014)
- Most energy efficient way of transporting goods, but accounts for 2-3% of global CO₂ emissions
- Shipping Industry is expected to grow with increasing demand for traded goods
 - Operation on a global scale, as opposed to local/regional for road transport



Marine fuels are about scale!

Ocean-going container ship

- Holds 15,000+ containers (165,000 DWT)
- Dual two-stroke diesel engines driving two propellers
- Designed for slow steaming at 19 knots (35 km/h)
- Storage capacity of 10-14 kilotonnes of fuel

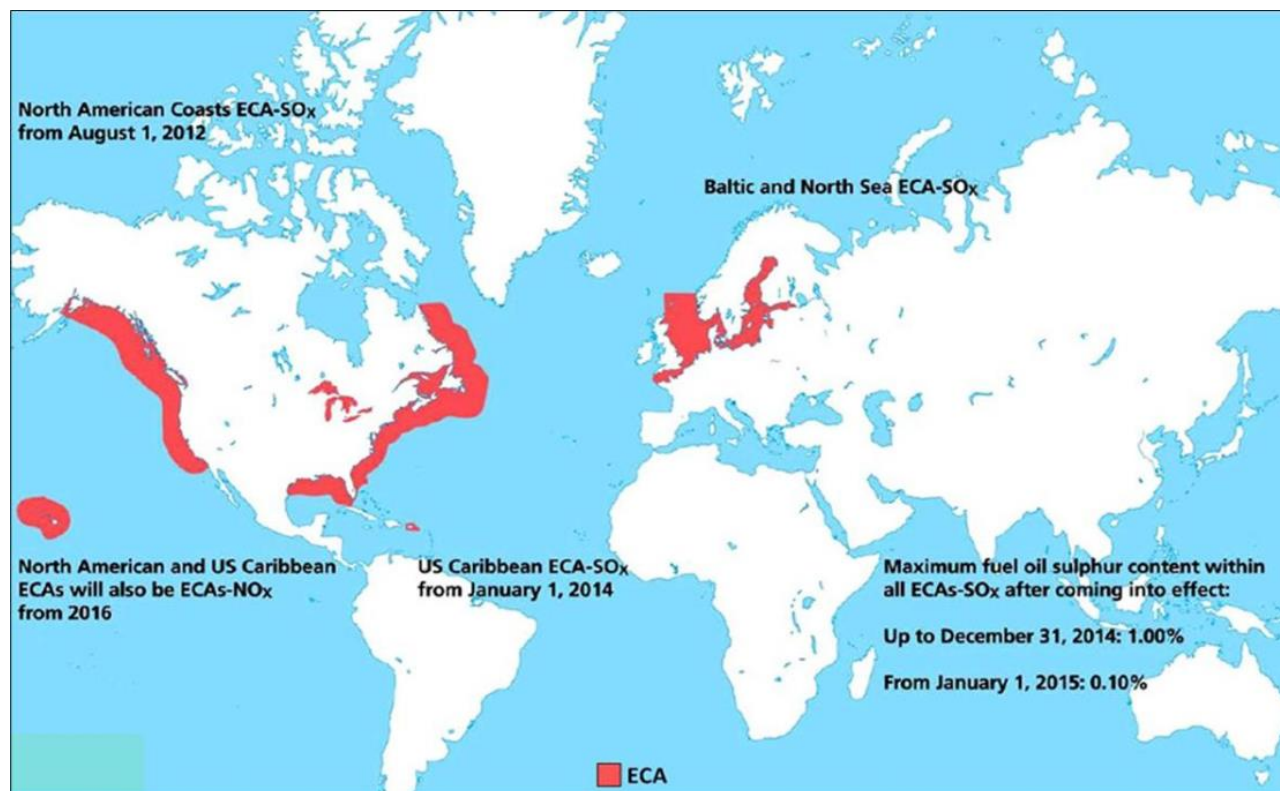


- Consumes 200-250 tons of fuel per day (refuelling every 40 days)
- Lower GHG emissions than road and aviation transport
- High SO_x and NO_x emissions



Marine fuel regulations

The international maritime organisation (IMO) has established emission control areas (ECAs) enforcing strict controls on SO_x, NO_x, and particulate matter



* Photo credit: Ivan Komar and Branko Lalić (2015). Sea Transport Air Pollution, Current Air Quality Issues, Associate Prof. Farhad Nejadkoorki (Ed.), InTech, DOI: 10.5772/59720.

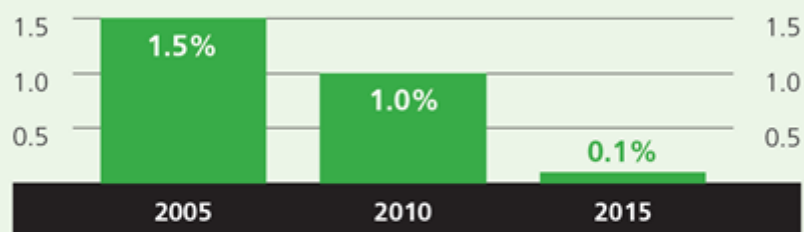


International fuel regulations will tighten

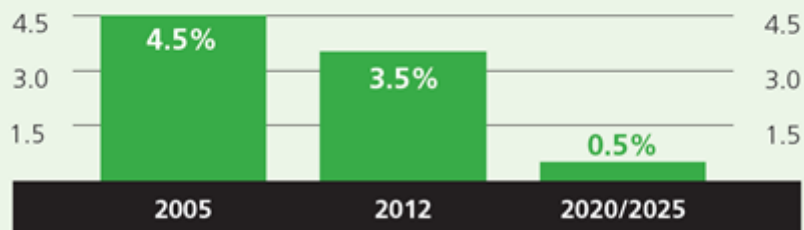
-Sulfur and nitrogen oxide limits for shipping fuels

IMO AGREEMENT TO REDUCE ATMOSPHERIC POLLUTION FROM SHIPS

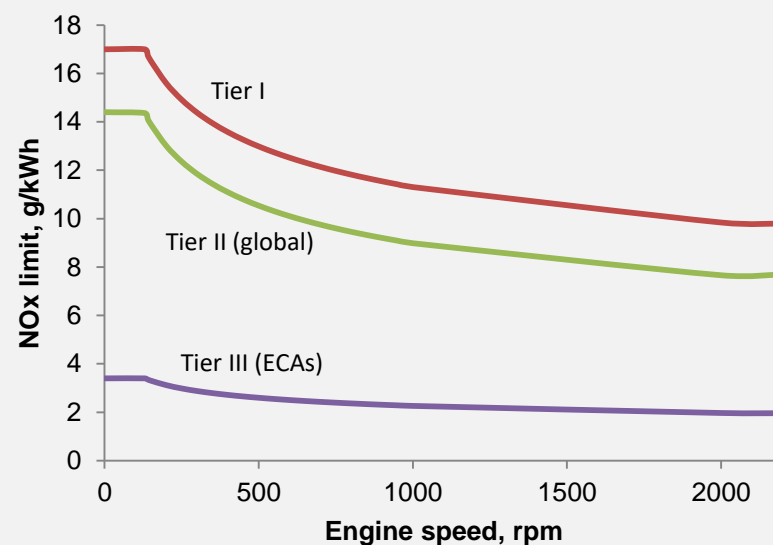
Sulphur content of fuel permitted in Emission Control Areas



Sulphur content of fuel permitted outside Emission Control Areas



NOx emission limits in NOx-Emission Controlled Areas



NOx restrictions only applicable in North American ECA on vessels built later than January 2000 (Tier I), January 2010 (Tier II), or January 2021 (Tier III)

80% of current fuel/engines needs to be modified



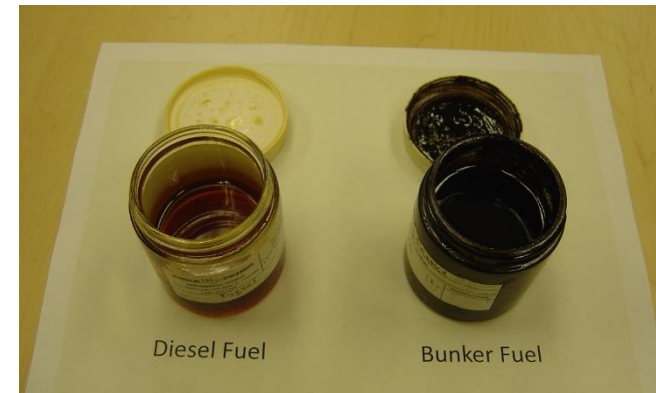
New CO₂ monitoring regime for ships

- Implemented by ECSA - The European Community Shipowners' Associations. To be verified by the EU
- MRV -monitoring, reporting and verification. Reporting will be cargo related
- IMO is expected to follow with similar instruments
- A first step towards CO₂ regulation of the global shipping sector



Marine fuel characteristics

- Generally two types of fuel: distillate and residual fuel
- Main fuel used is low-cost residual bunker fuel
- Fuel makes up about 50% of shipping vessel operational costs
- Lower quality and price compared to other transportation fuels
- Chemical characteristics for diesel engine-compatible fuels:
 - Long chain hydrocarbon
 - High flash point, low auto-ignition temperature
 - Higher viscosities
 - Must be non-corrosive
 - Must be sand-free



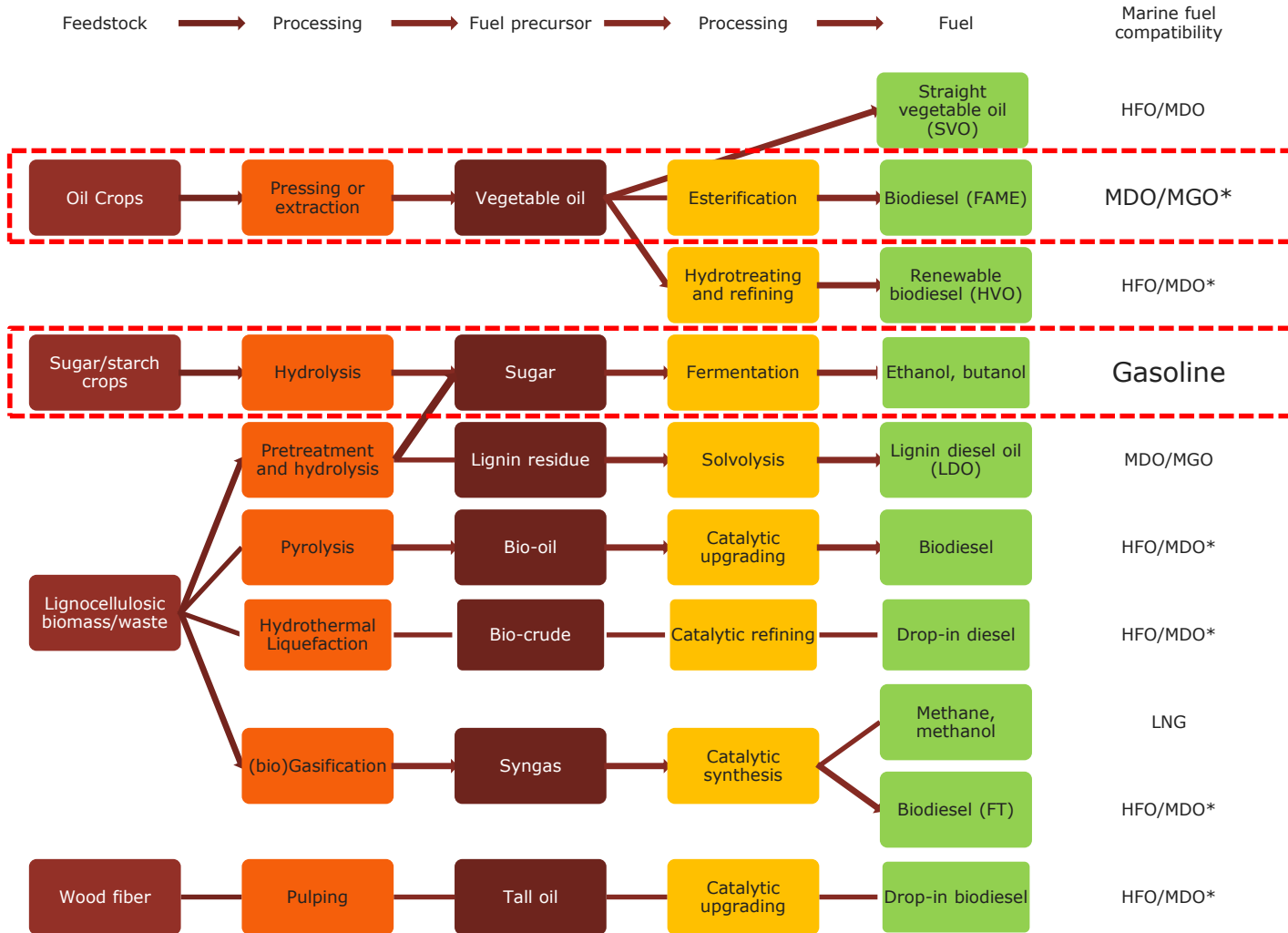
Fuel specifications

	HFO Heavy fuel oil	MDO Marine diesel oil	MGO Marine gas oil	FAME Biodiesel	HVO Hydrotr. veg. oil	Jet A Kerosene- type jet fuel
Kinematic viscosity (mm ² /s)	<380	2 – 11	2 – 6	4.2 – 4.5	2.5 – 3.5	<8 at -20°C
Heating value (MJ/kg)	40.5 – 43	42 – 48	44 – 45.3	37.3 – 39.8	44 – 47.3	43.02
Density at 15°C	<991	<900	<890	880 – 920	770 – 790	775-840
Flash point (°C)	>60	>60	>60	110 – 195	>61	38
Pour point (°C)	>30	0 – 6	-6 – 0	-4 – 6	-5 – -25	-55
Sulfur (mass %)	<3.5	0.3-2.0	0.1-1.5	0	0	0
Price \$/mt 20 Oct 2016	290	482	471	1040	\$2.05/gallon (delivery to US Navy)	487

Minor use of LNG and methanol as fuels



Current biofuel production technologies



* Can be blended with conventional fuels or used as a drop-in fuel



Marine biofuel testing and market penetration

US Navy's Great Green Fleet initiative: use 50% renewable alternative energy to power the Navy's fleet by 2020

- Collaborations with Mærsk, Solazyme, Renewable Energy Group, Amyris, and the Australian Navy
- 50% biofuel blend trials have been successful
- Future supply and policies are not known

GoodFuels Marine:

- Marine biofuel provider offering biodiesel from organic waste residues. GoodFuels works with fuel providers and customers to integrate the entire supply chain
 - Partnered with the Port of Rotterdam, Boskalis, and Wärtsilä to accelerate the development of marine drop-in fuels in the supply chain



Fuel development for marine diesels requires scale!



- Small test engine 200 l
- Engine test bench 2000 l
- One-cylinder large-scale test 20-200 tons



Marine biofuel development outlook

- Advanced fuels needs to be developed at a large scale
- **We need a basic proces for large-scale cracking of biomass components!**
 - Simple (one-pot)
 - No hydrogen
 - No catalyst
- Thermal proces most likely –but combination with biochemical process most efficient
- Upgrading with hydrogen, may be replaced by decarboxylation!
- The demand for



Technology example: Integration of marine biofuels in Commercial-scale biorefineries

- Integrated processing of carbohydrates and lignin
- Pressurised steam pretreatment, acidic conditions

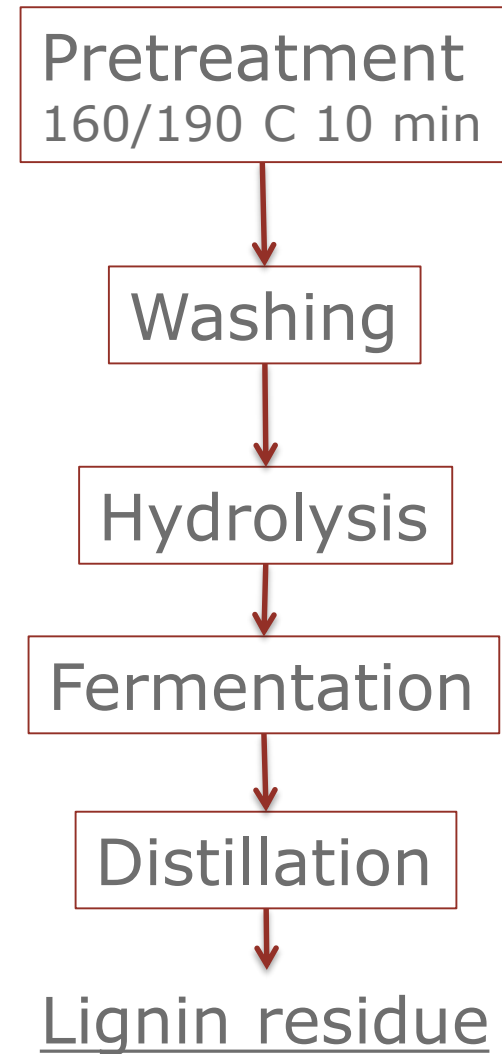


Typical proces

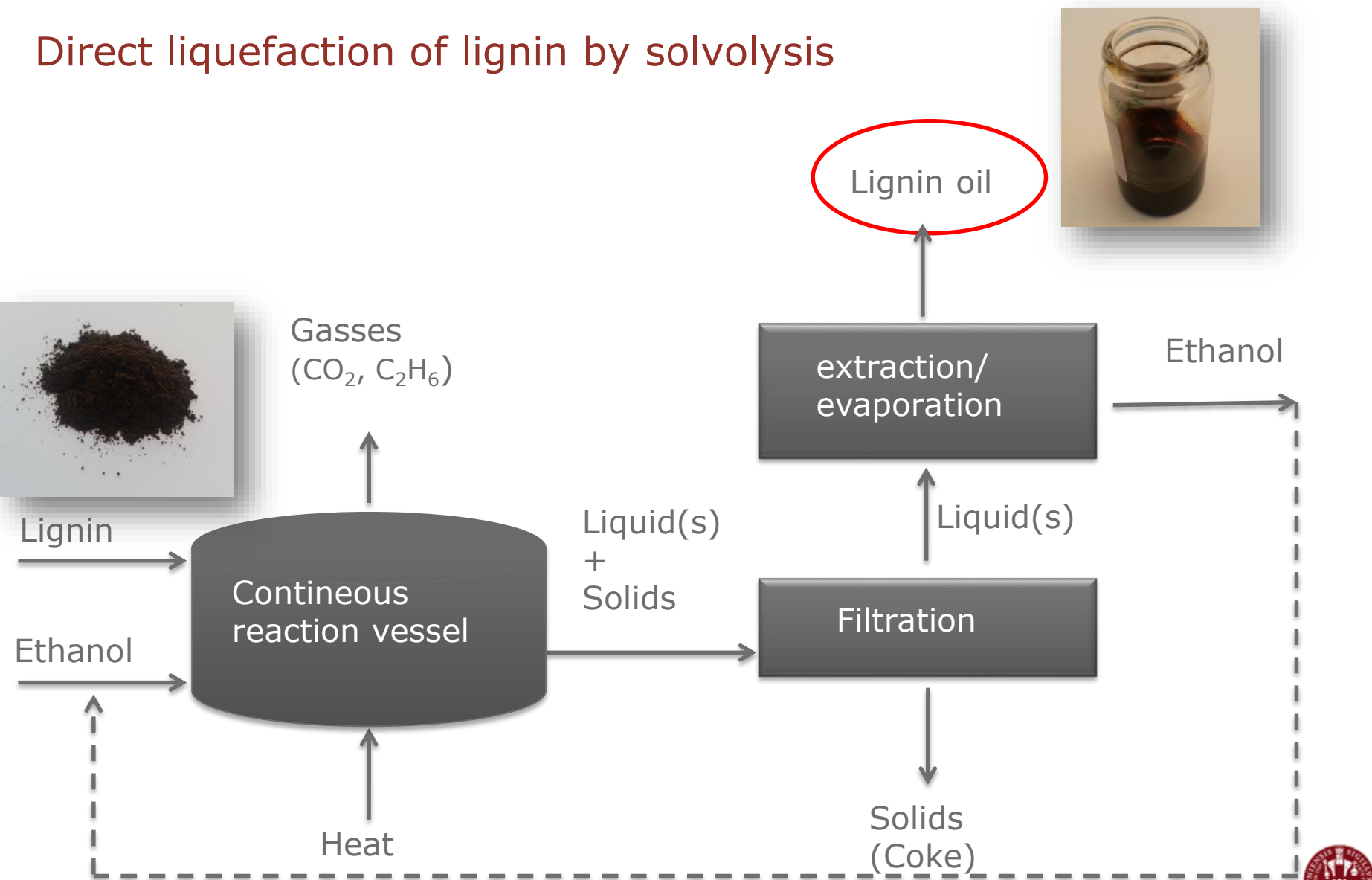
- Agricultural residue feedstock
- Process steps: Pretreatment, enzymatic saccharification, fermentation and distillation



Lignin	Carbohydrate	Ash
65%	20%	15%



Direct liquefaction of lignin by solvolysis

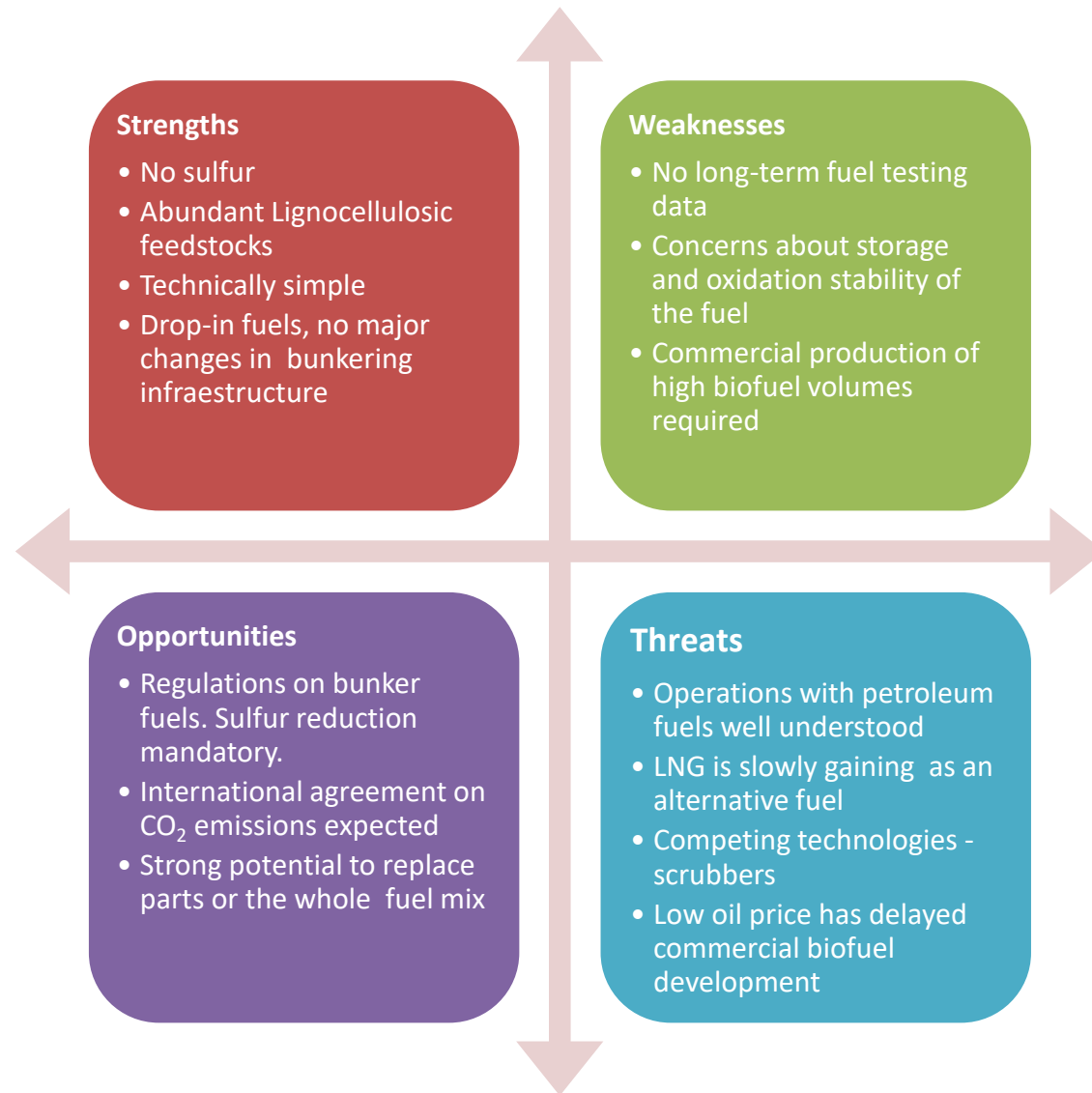


Lignin solvolysis

- Lignin is depolymerized by heating to 350 deg. C
- Re-polymerisation is avoided by ethanol quenching the thermoradicals
- 40% of the lignin can be converted to oil with low solvent loss
- The process can be run at 20-40% lignin
- The oil is fully miscible with diesel, is non-corrosive, heating value of 35 MJ/kg and Mw of 1200 Da
- Main process parameters to be controlled are the heating and cooling profiles
- The residual coke has an energy density of 30 MJ/kg



The case for marine biofuels: SWOT analysis



Marine biofuels -where to go?

- Large demand, large potential!
- Commercially established biofuel production routes:
 - Vegetable oils –low potential, sustainability issues
 - Ethanol –low compability with infrastructure
 - Thermal bio-oil process needed
- Marine biofuel supply needed within the next 10 years
 - Lignocellulosic feedstocks has the highest potential and sutainability
 - **Commercial scale production facilities needed**
- Perform full-scale tests on ocean going vessels
- Work with IMO on regulations to facilitate biofuel infrastructure
- Long term policies and/or mandatory targets are a must!



Acknowledgements



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