TEKNOLOGISK
INSTITUT

it's all about innovation

Technological possibilities for further reduction of emissions from wood stoves and boilers

Anne Mette Frey

Outline

TEKNOLOGISK INSTITUT

- Introduction to technology transfer
- Biomass combustion in small scale optimization
  - Primary means
  - Secondary means
- Oxidation catalysts for wood stoves
- Transferability of technology from automotive industry
  - Catalysts and filters
- NO_x challenge and possible approach for boilers (and wood stoves)
- Sensor technology from automotive applications to biomass combustion

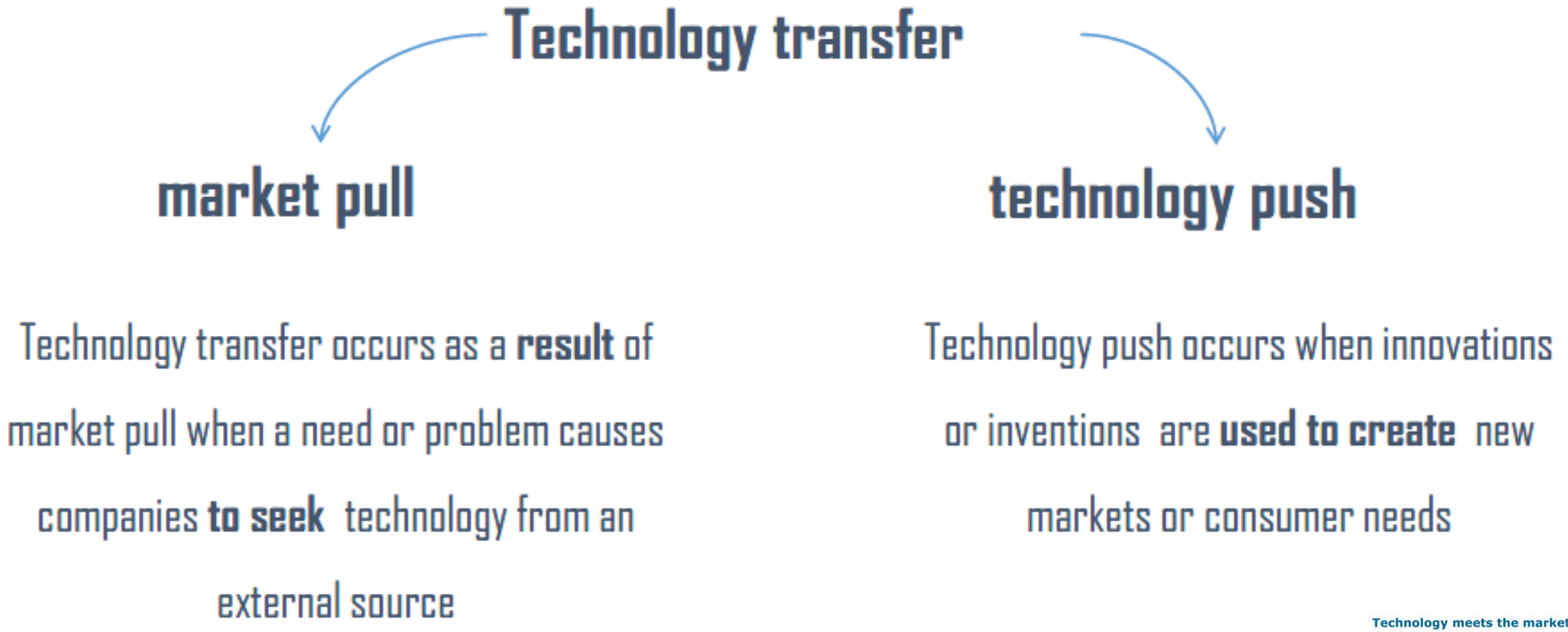
Technology transfer

Definition of technology transfer

- Technology transfer is the process by which technology or knowledge developed in one place or for one purpose is applied and **exploited in another place** for some other purpose

Technology transfer is the process of developing **practical applications** of the results of **scientific research** which are **easy to handle** , are of **societal relevance** and are **affordable**

Motivation



Technology meets the market: how technology transfer generates innovation?

Vienna, Austria

July 5th 2016

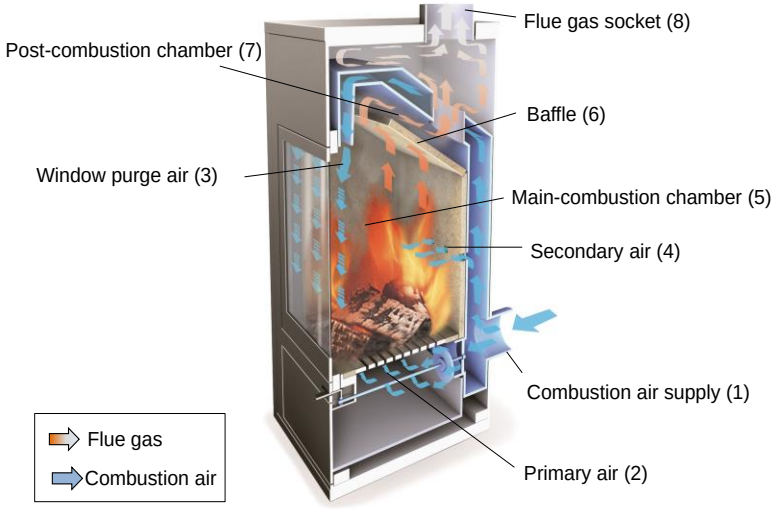
Raffaele Buompane

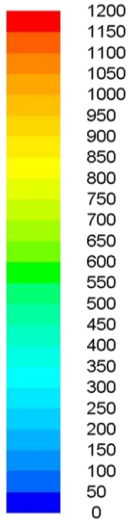
Biomass for combustion

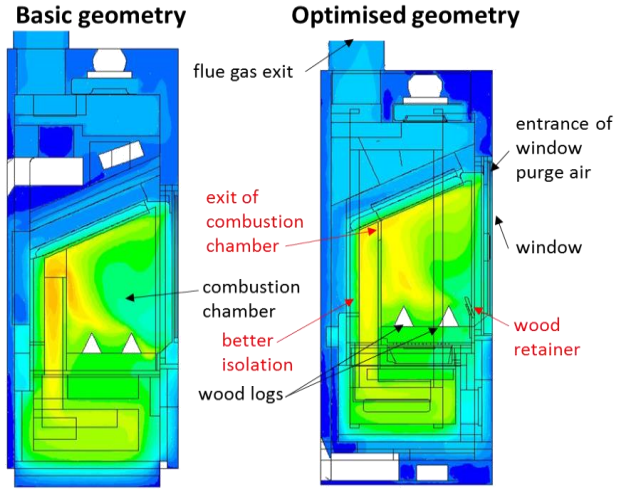
- Increasing importance of **energetic use of biomass**
- Energetic use mostly coupled **combustion process** → **Flue gases**
- **Primary measures** not sufficient to meet future emission limits
- Use of different biomasses → requires different **secondary measures**

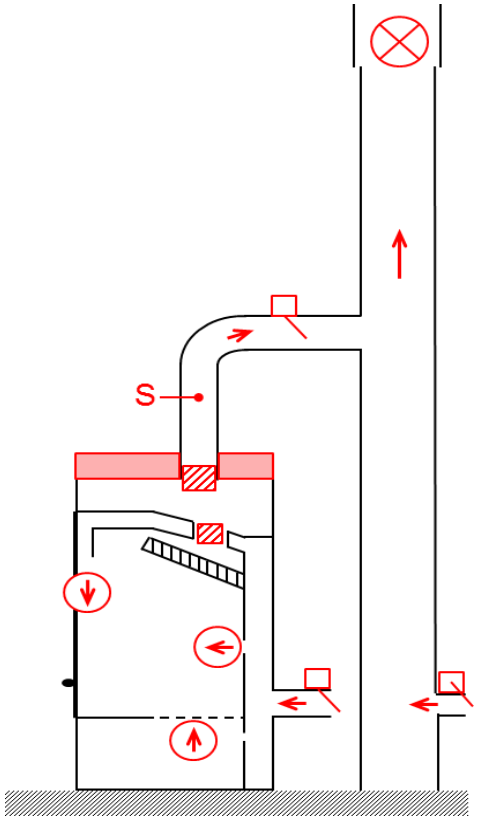
Primary improvements

- Guidelines for improved wood stoves
- Guidelines for air supply
- Guidelines for energy efficient building



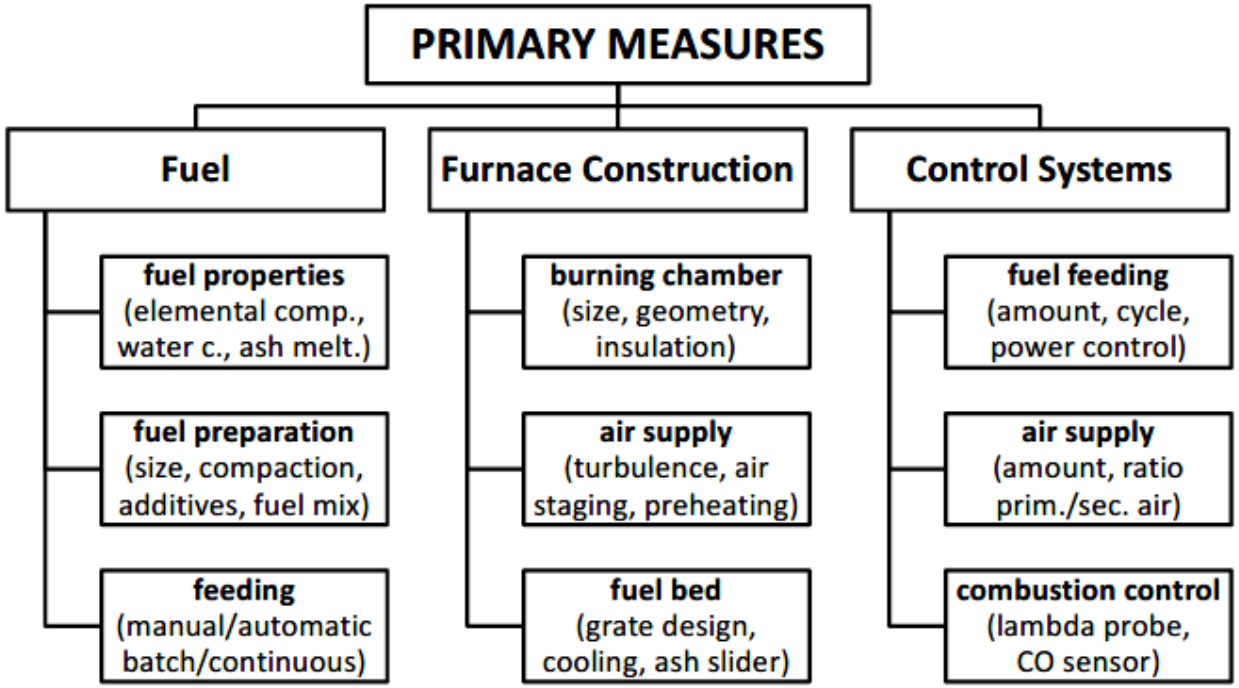






ERA-NET Bioenergy Project “WoodStoves2020

Factors to improve



For the development of micro-combustion systems 3 research topics were identified:

- fuel preparation and feeding (automatic and continuous fuel supply)
- Furnace construction (down draft, grate design)
- control systems (air supply, combustion control)

http://task32.ieabioenergy.com/iea-publications/events/workshop-highly-efficient-clean-wood-log-stoves-berlin-november-2015/

Oxidation catalysts for wood stoves

Catalysts – example of technology transfer

TEKNOLOGISK INSTITUT

- Well-know from other applications
  - Cars
  - CHP
  - Industrial processes

Catalyst for wood stove

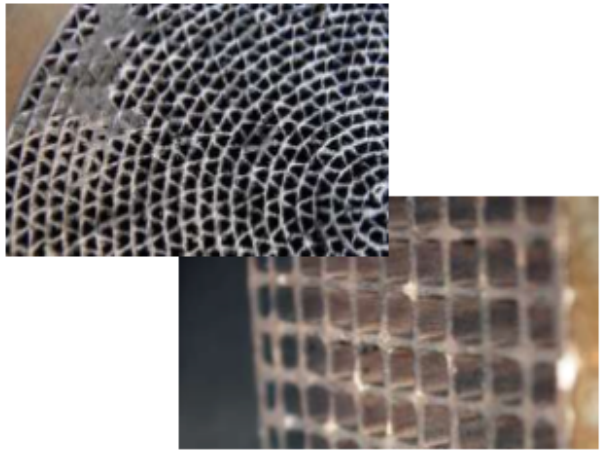
Wood log for heat production
instationary process
strong influence of the catalyst on the overall system
T > 770 K
High dust emission

➢ This leads to…

Requirements for emission control catalysts	
Integrated catalyst	Downstream Catalysts
Very low back pressure	Low back pressure
High temperature resistance (ca. > 1150 K) → **metal oxide**	Moderate temperature resistance (ca. < 950 K) → **noble metals**
high activity towards total oxidation of CO and C_XH_Y at high T	high activity towards total oxidation of C_XH_Y at T < 720 K

Catalysts for biomass combustion

- **Some catalysts are commercially available for biomass combustion systems**
  - Noble metals as active material on metal or ceramic support with γ-Al_2O_3 washcoat
- **Challenges for Application of Catalysts in smale scale biomass combustion**
  - Fluctuating temperatures and flue gas composition
  - Wide range of pollutants: CO, VOC, soot…
- **Deactivation of catalyst**
  - Catalyst poisons
  - Thermal
  - Blockage with particles



Main effects observed during use of commercial available catalysts

Transferability from automotive industry?

Emissions from vehicles

Vehicle Emissions fall into five main categories:

CO_2 **Carbon Dioxide (CO2)**, which is an inevitable product of burning a fuel which contains carbon (as all petroleum products do). CO2 does not pollute the air we breathe, but it is a main contributor to Global Warming and therefore has to be reduced. This means either using fuels containing less (or no) carbon (see the section on Alternative Fuels), or making vehicles and their engines more efficient – or both.

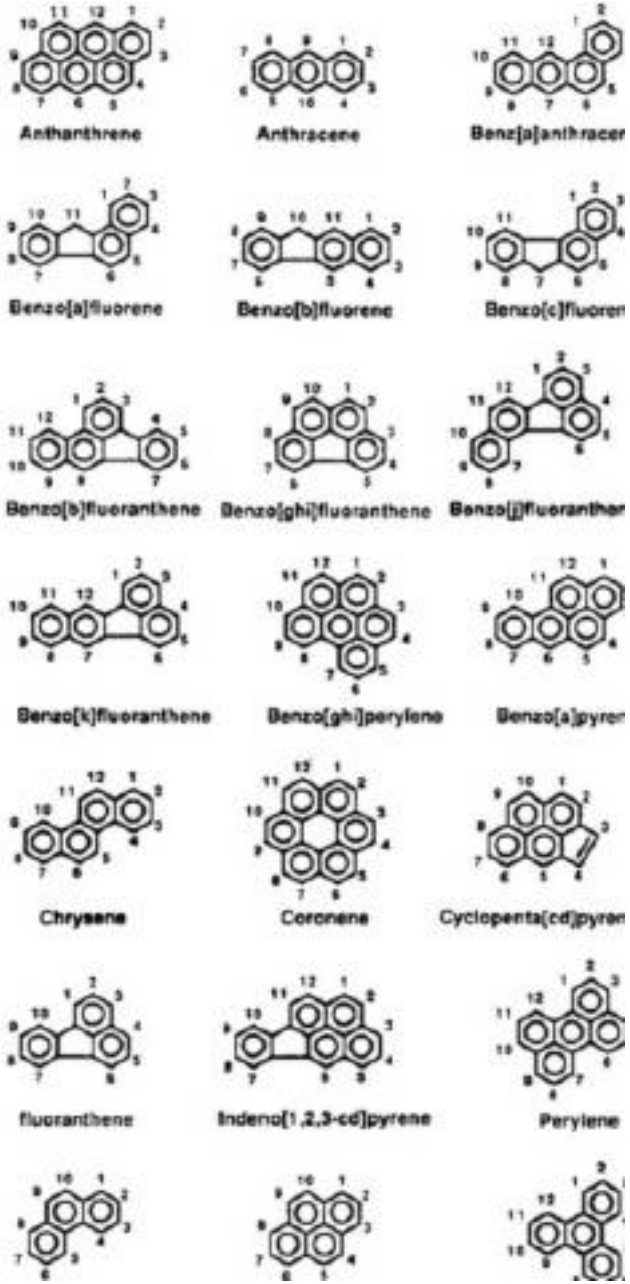
CO **Carbon Monoxide (CO)**, which is produced when a carbon-based fuel is burnt incompletely. In high concentrations it is poisonous and has to be controlled. It can be reduced by more efficient combustion in the engine (so that CO2 is produced instead of CO) and further reduced by oxidising after combustion, in a Catalytic Converter. [2xCO + O2 = 2xCO2]

HC **Hydrocarbons (HC)**, also known as "Volatile Organic Compounds (VOC) are really unburned fuel. They can be a problem to people with breathing difficulties and are a contributor to "Photochemical Smog" in certain climatic conditions. They can be reduced by more efficient combustion in the engine and further reduced by oxidising after combustion, in a Catalytic Converter. . [4HxCy + (x+4y)O2 = 2xH2O + 4yCO2]

NO_x **Oxides of Nitrogen (NOx)** are produced when air (which is mainly a mixture of Nitrogen and Oxygen) is heated as it is in an engine. NOx is a contributor to both Photochemical Smog and Acid Rain and can be an irritant to the lungs. Unlike CO and HC is cannot be removed by oxidation. The opposite process – the removal of Oxygen, known as "Reduction" is necessary to convert it back to Nitrogen and Oxygen.

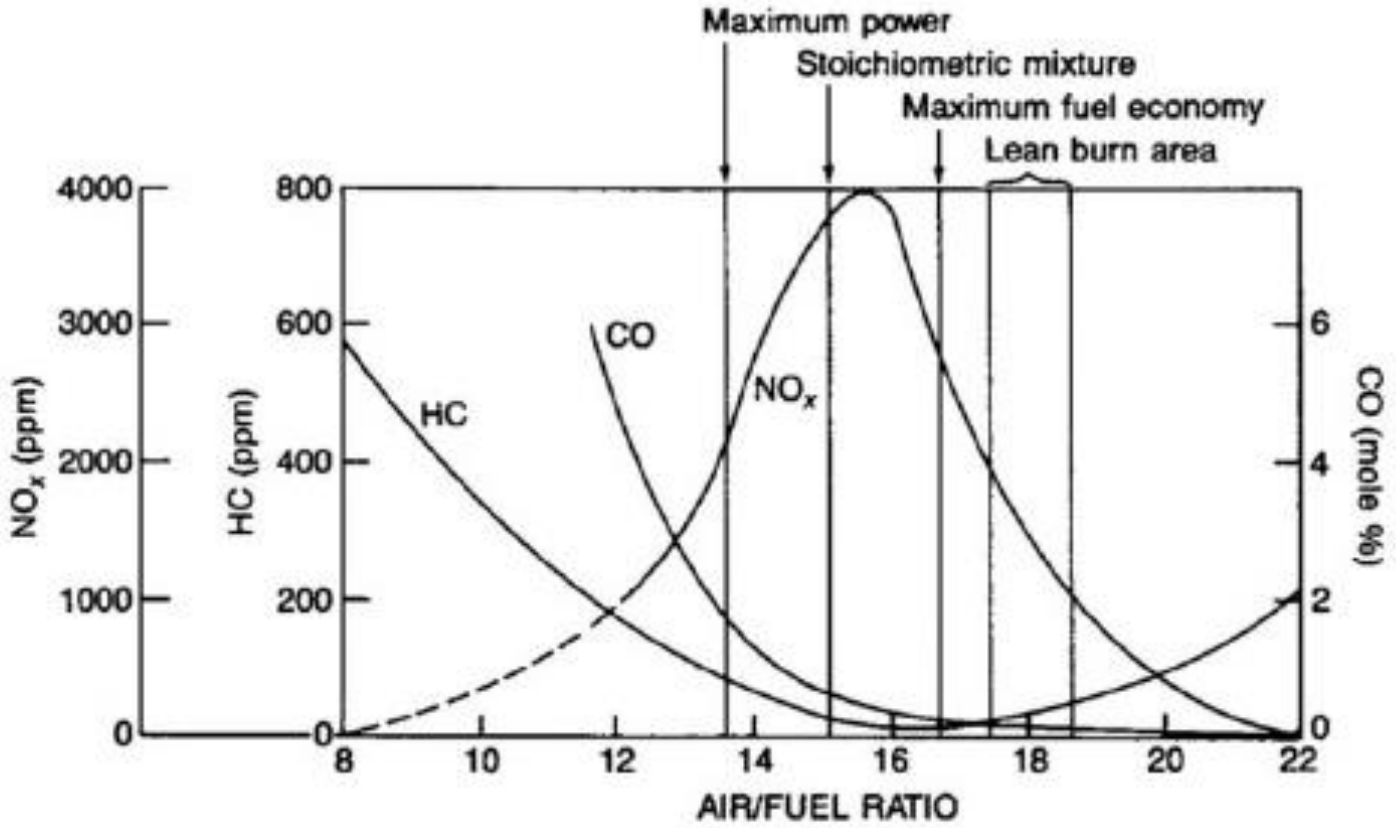
PM **Particulate Matter (PM)** is very small particles, mostly of unburnt Carbon.

PAHs

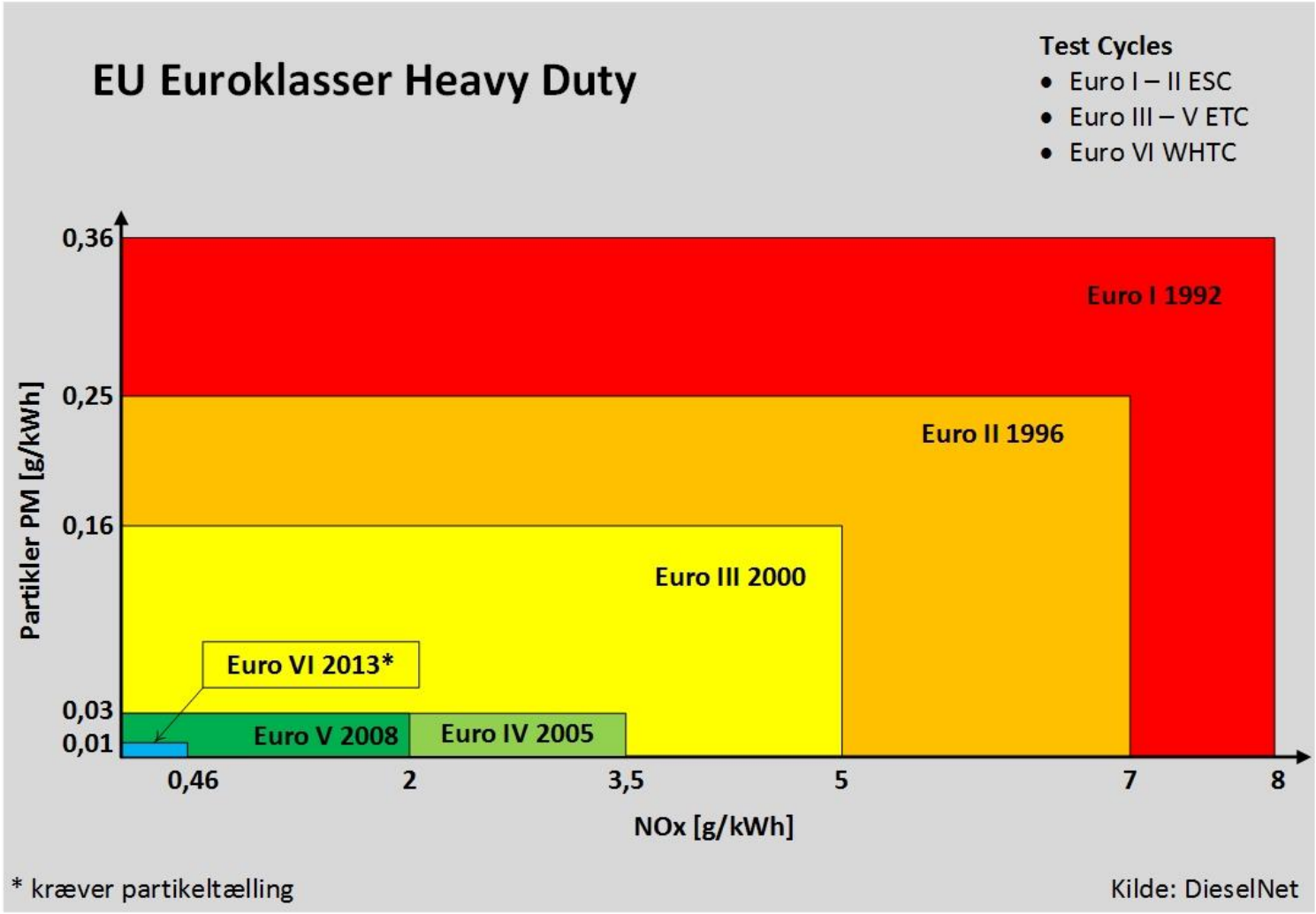


Sensor Technologies for Intelligent Transportation Systems Juan Guerrero-Ibáñez , Sherali Zeadally and Juan Contreras-Castillo

Emission formation at various air/fuel ratios: Gasoline engine



EU legislation

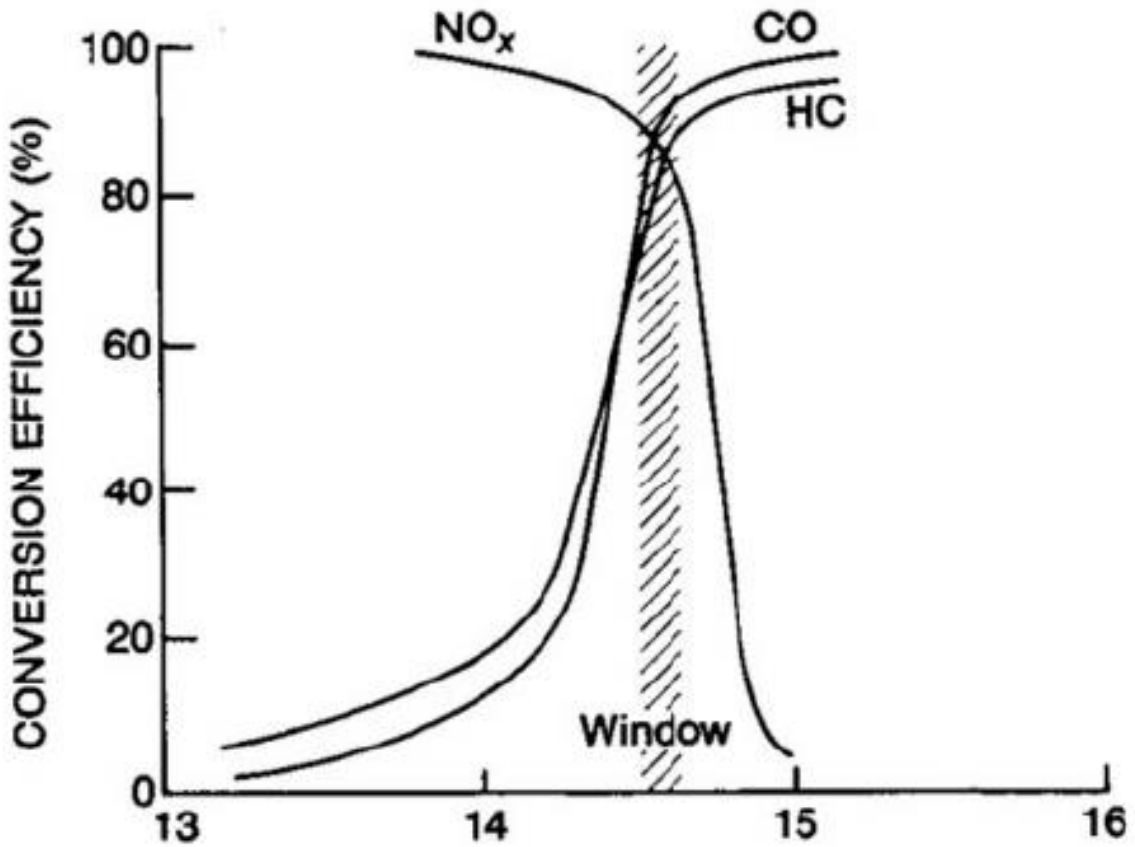


Global Exhaust Emission control device market

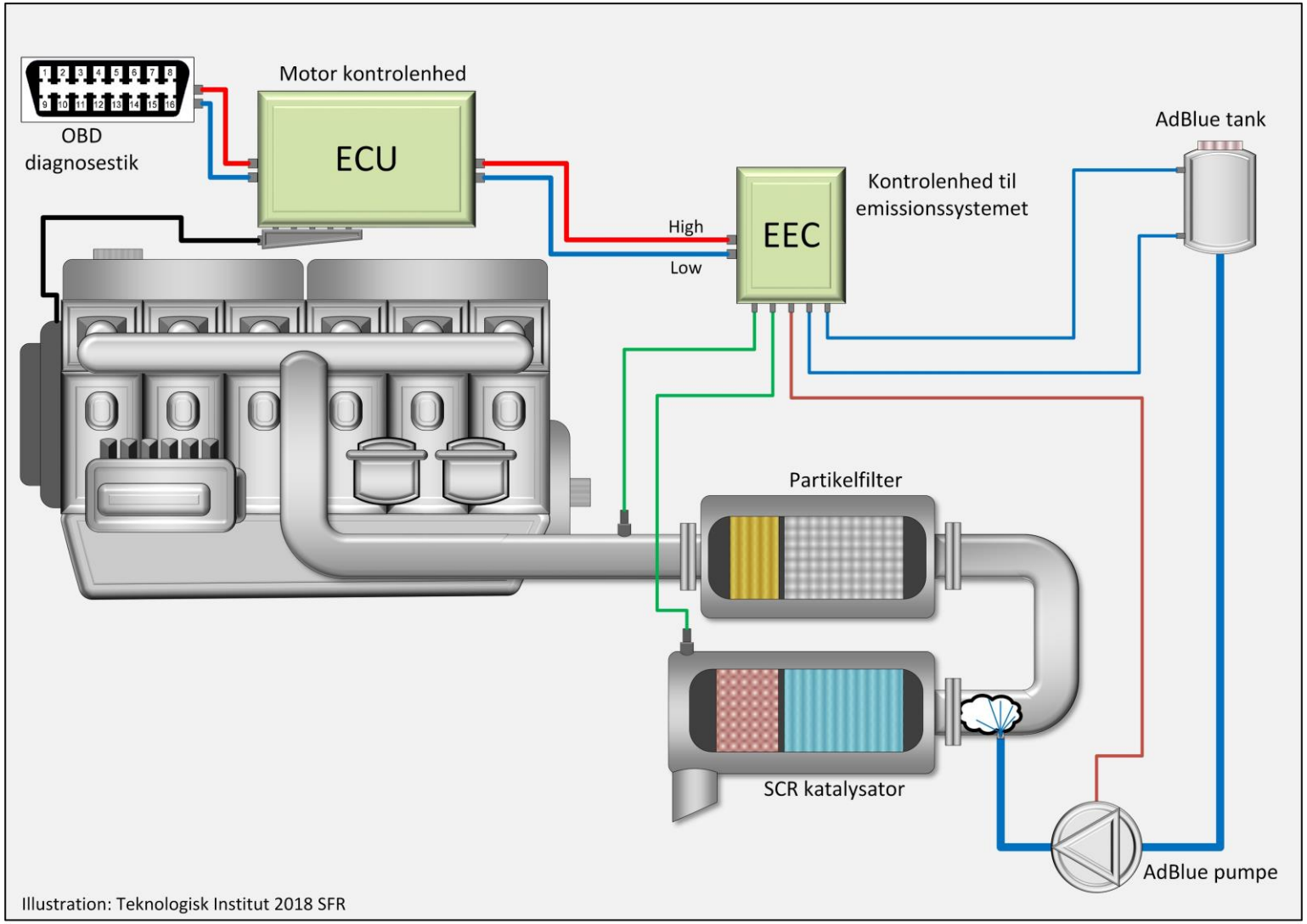
TEKNOLOGISK INSTITUT

- Three way catalytic converter (TWC)
- Gasoline particulate filter (GPF)
- Diesel particulate filter (DPF)
- Diesel oxidation catalyst (DOC)
- Selective catalytic reduction (SCR)
- Lean NO_x trap (LNT)

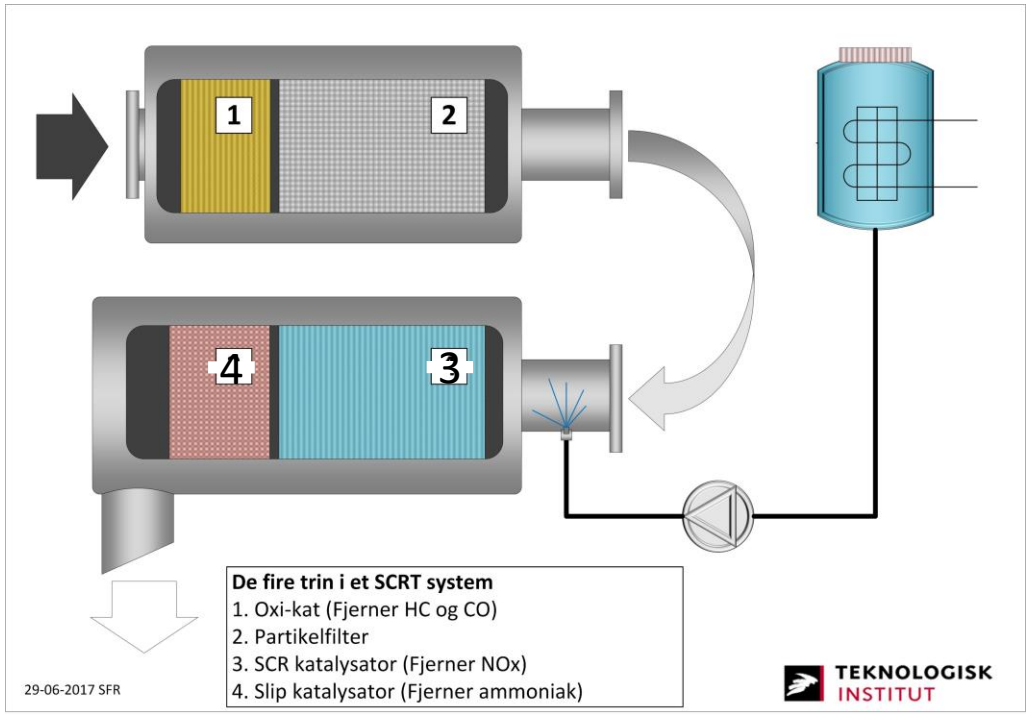
Conversion efficiency characteristics of a three way catalyst

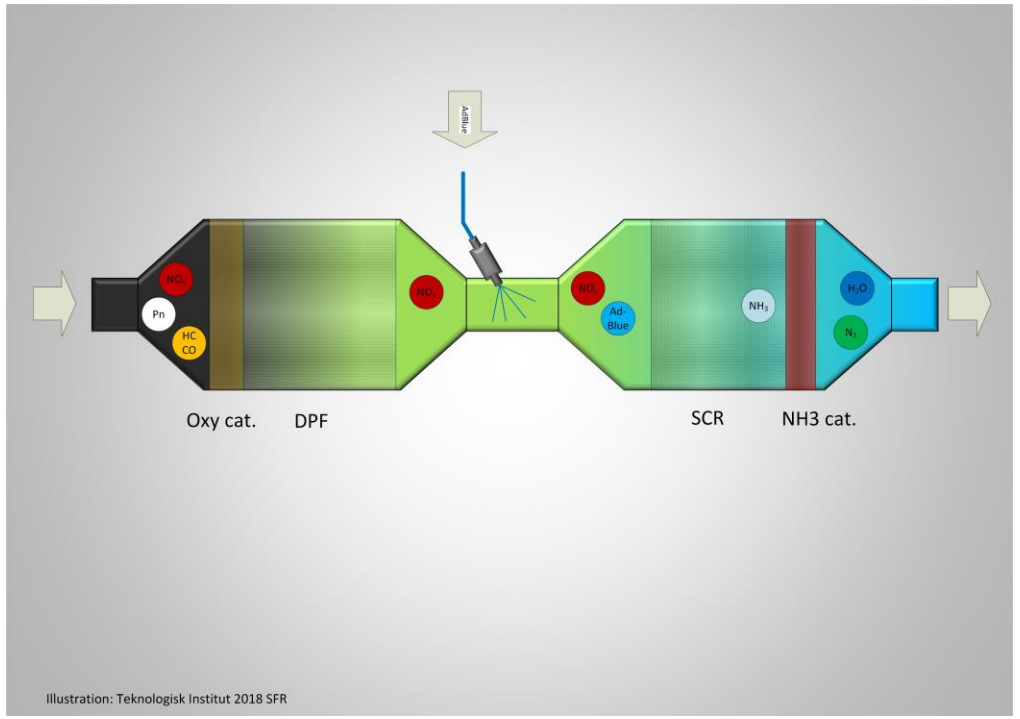


Automotive emission system



The steps - including filter and catalysts





TEKNOLOGISK
INSTITUT

NO_X challenge and possible approach for boilers

- NO_x is more problematic for e.g. diesel cars and bio combustion
- Lambda in these combustion processes makes it a challenge

NO_x legislation for boilers?

TEKNOLOGISK INSTITUT

- Not much in EU yet – EcoDesign from 2020 NO_X: 200 mg/m^3

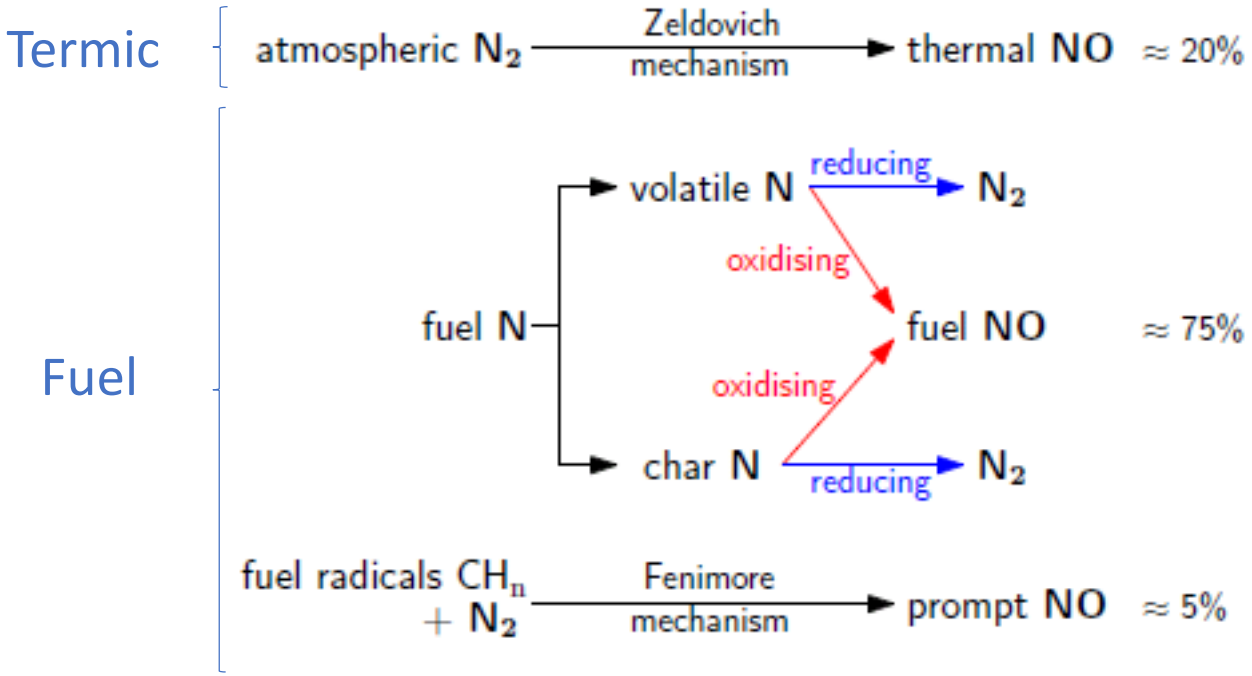
- Example: Austria
  - Limit value for small boilers 150 mg/MJ
- Subsidies are motivating for aiming for low emission of NO_x in e.g. Germany and The Netherlands

http://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=LrW&Gesetzesnummer=20000005

NO_x formation by combustion

TEKNOLOGISK INSTITUT

- NO_x normally covers NO, N_2O, NO_2
- Mainly NO is formed in combustion engines
- NO_x can depended on how it arises be characterized as
  - Thermic NO_x
  - Fuel NO_x



Biomass and boilers

TEKNOLOGISK INSTITUT

- A huge percentage of NO_x from small scale boilers origins from the fuel
- NO_x can thus not be avoided completely by primary means to improve the combustion

Chemical composition of various types of biomass

Material/Parameter	Ash 550 (wt%)	C (wt%)	H (wt%)	N (wt%)	O (wt%)	O/C	LHV (MJ/kg daf)
Bagasse	3.1	46.6	5.7	0.2	44.5	0.95	18.24
Grass seed hay	10.6	42.4	5.8	1.6	39.6	0.93	18.10
Road side grass	23.2	38.4	5.3	2.0	31.1	0.81	19.19
Straw	10.6	42.2	5.7	0.4	41.0	0.97	17.30
Beech	0.3	45.9	6.2	0.4	47.3	1.03	17.72
Poplar	1.1	47.2	6.0	0.0	45.7	0.97	17.68
Willow	1.7	47.7	6.0	0.4	44.3	0.93	17.43
Larch	0.1	47.4	6.1	0.6	45.9	0.97	18.20
Pine	0.5	48.7	6.3	0.1	44.4	0.91	18.53
Spruce	0.3	50.4	6.4	0.0	42.9	0.85	19.67
RDF	15.8	53.8	7.5	0.5	22.4	0.42	27.20
Trockenstabilat	23.2	41.3	5.4	1.3	28.8	0.70	20.40

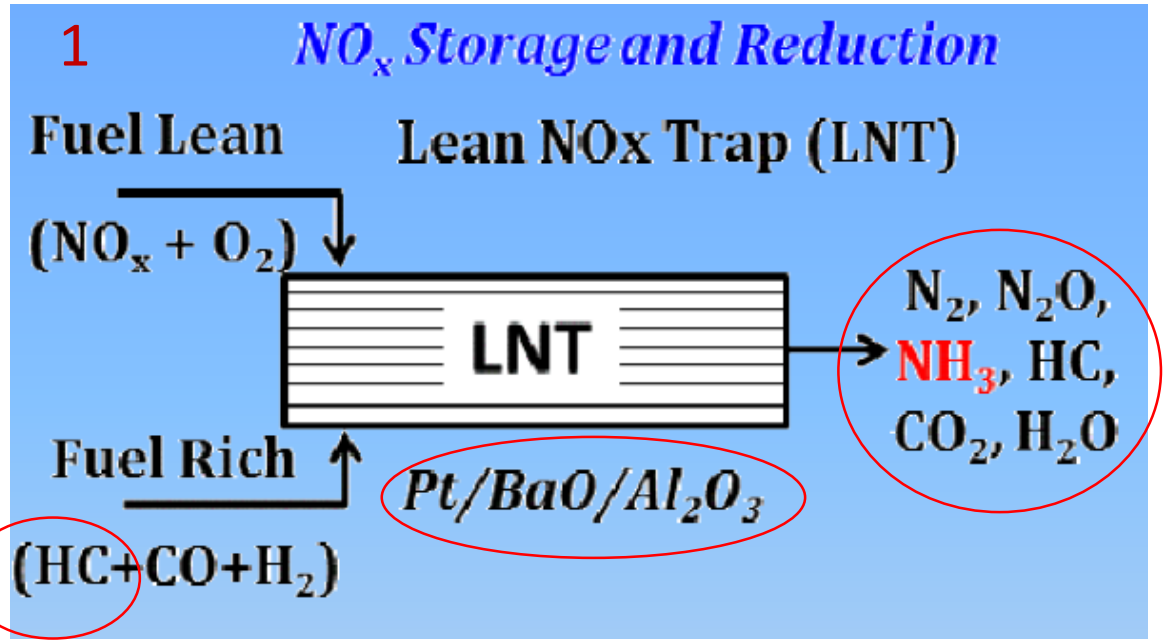
Verhoeff F, et al., Tor Tech, Torrefaction Technology for the production of solid bioenergy carriers from biomass and waste, ECN-E-11-039, 2011

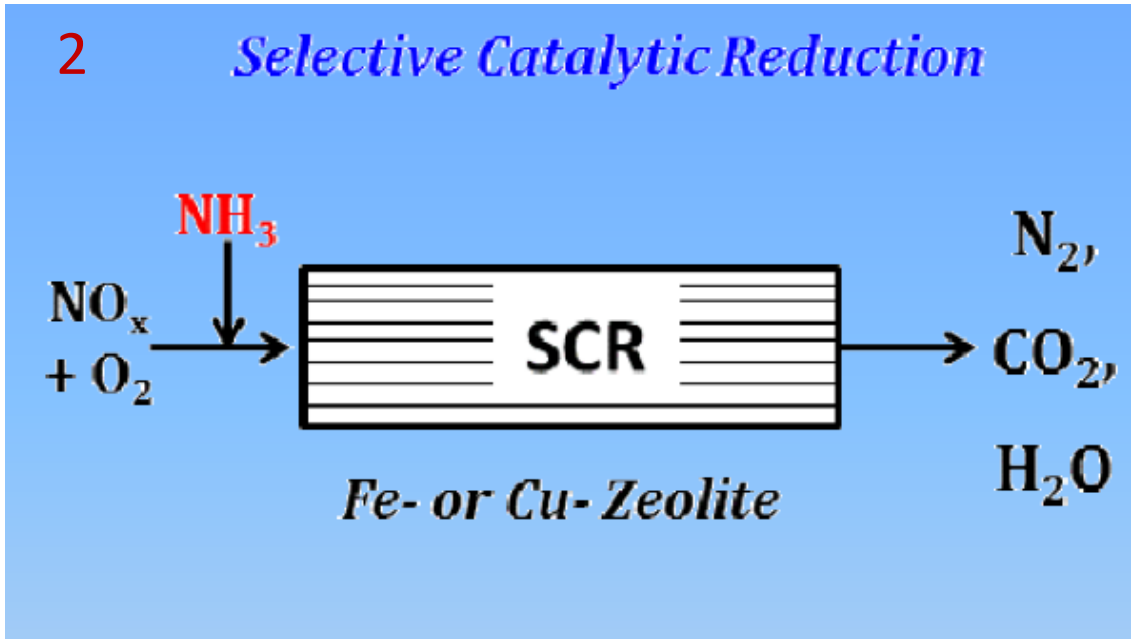
Removal of NO_x

Solutions known from other applications

TEKNOLOGISK INSTITUT

1. NO_X lean trap– storage and reduction
2. Selective catalytic reduction (SCR)





NO_x trap is not promissing in EURO6 real life tests

SCR promissing in tests

Selective catalytic reduction (SCR)

TEKNOLOGISK INSTITUT

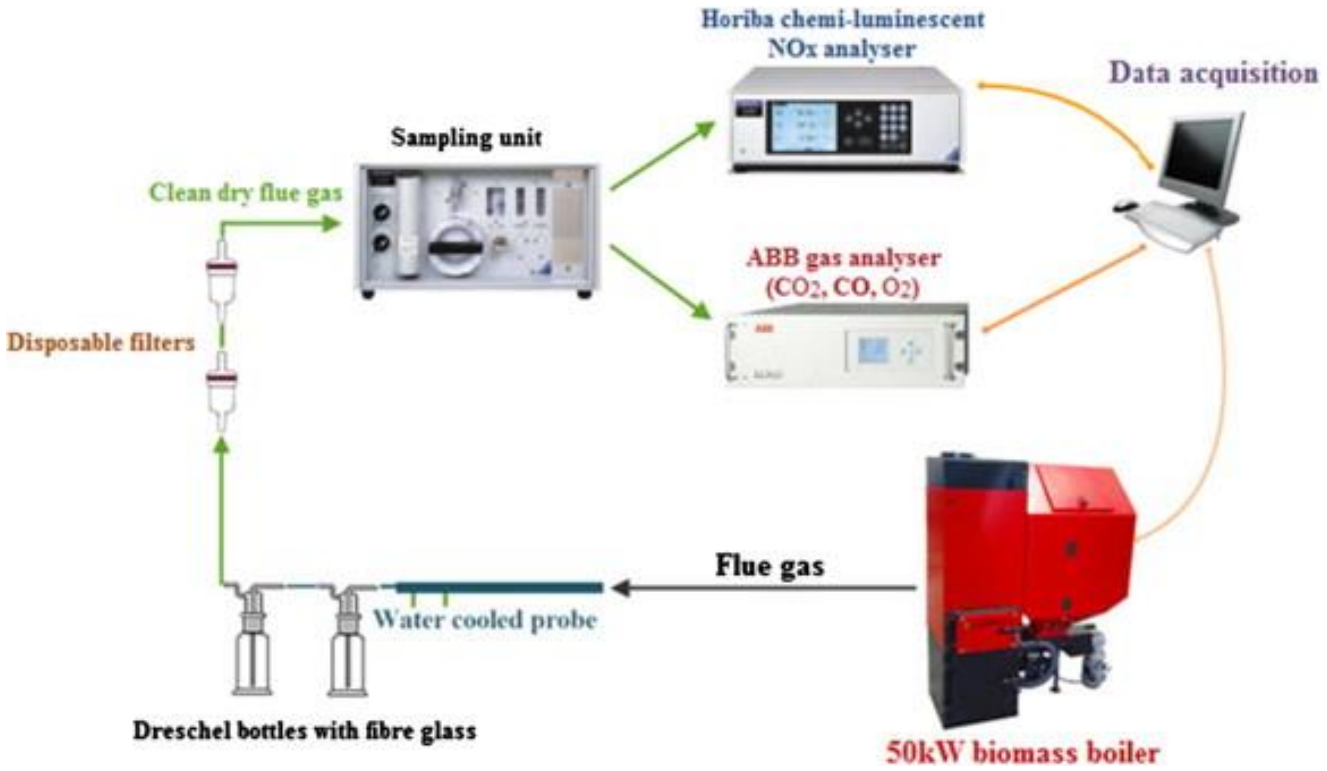
- The catalytic reduction is in the case using NH_3 as reductant

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$$
$$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O \quad \text{('fast SCR')}$$

NO_x measurements in biomass boilers

TEKNOLOGISK INSTITUT

- Set-up for measurements of NO_x from boilers



- By Measurements NO_x is normally found in the range 100-250ppm, dependent on the wood pellet (biomass) and combustion temperature

Hao Liu et al, Control of NOx emission of a domestic/small scale biomass pellet boiler by air staging, Fuel, 103, 792, 2013

Optimization of SCR to cars and small combustion units

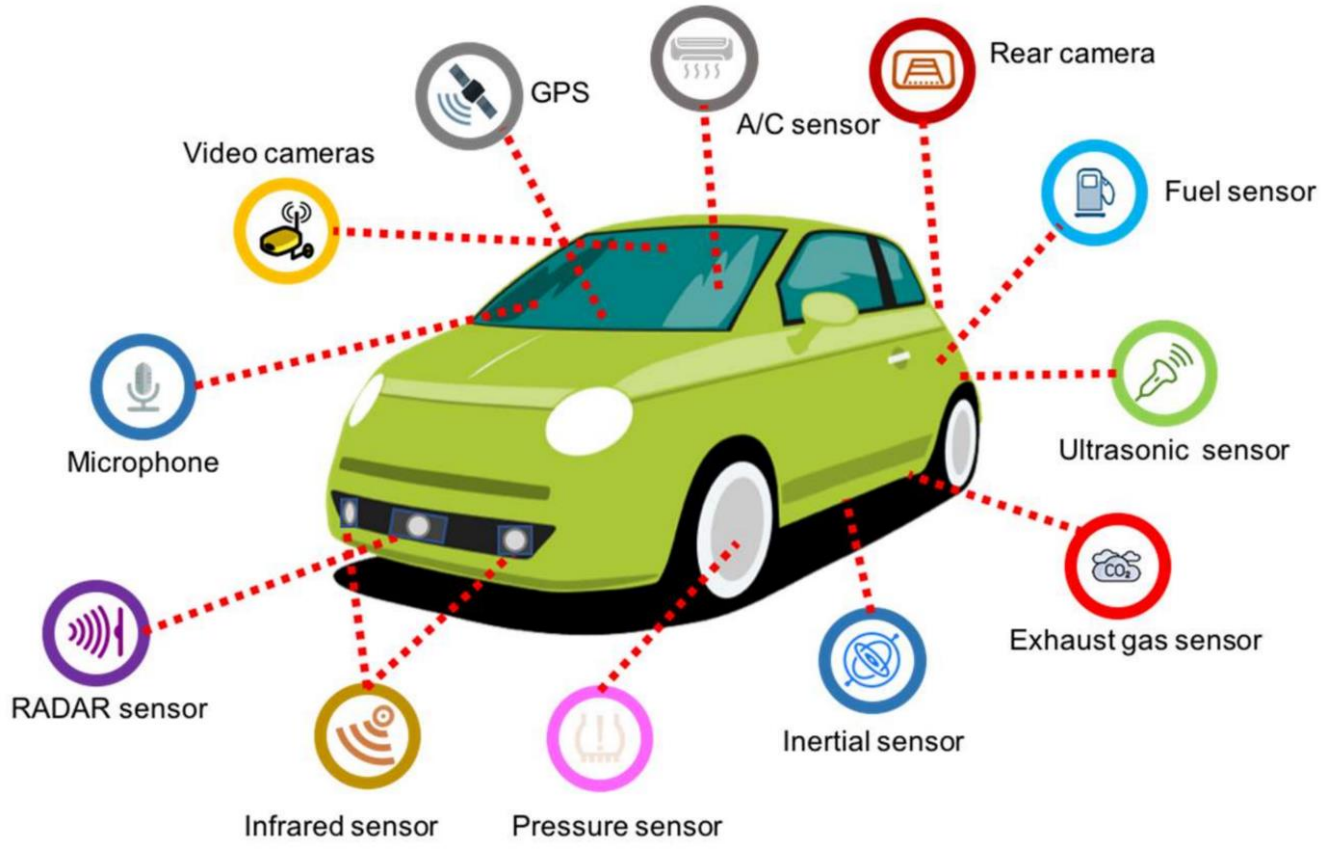
TEKNOLOGISK INSTITUT

- Optimization of the catalyst
  - More efficient
  - Cheaper
  - Environmental better

- Optimization of the reductant
  - Ammonia based systems seems most promising
  - Saftety and handling should be considered

Combustion improvement by use of sensors

Sensors from automobile industry

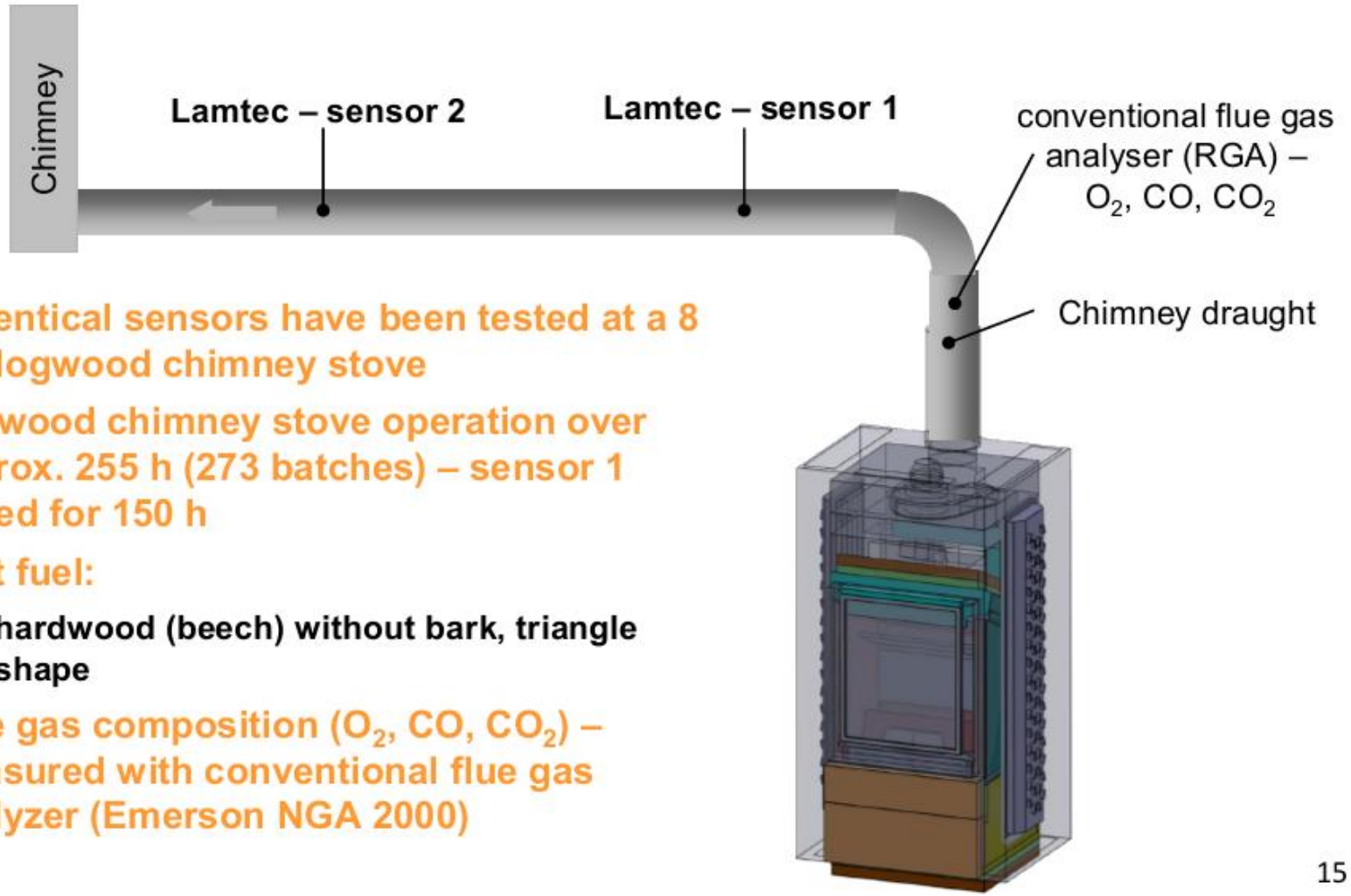


Sensor Technologies for Intelligent Transportation Systems Juan Guerrero-Ibáñez , Sherali Zeadally and Juan Contreras-Castillo

Sensor technology

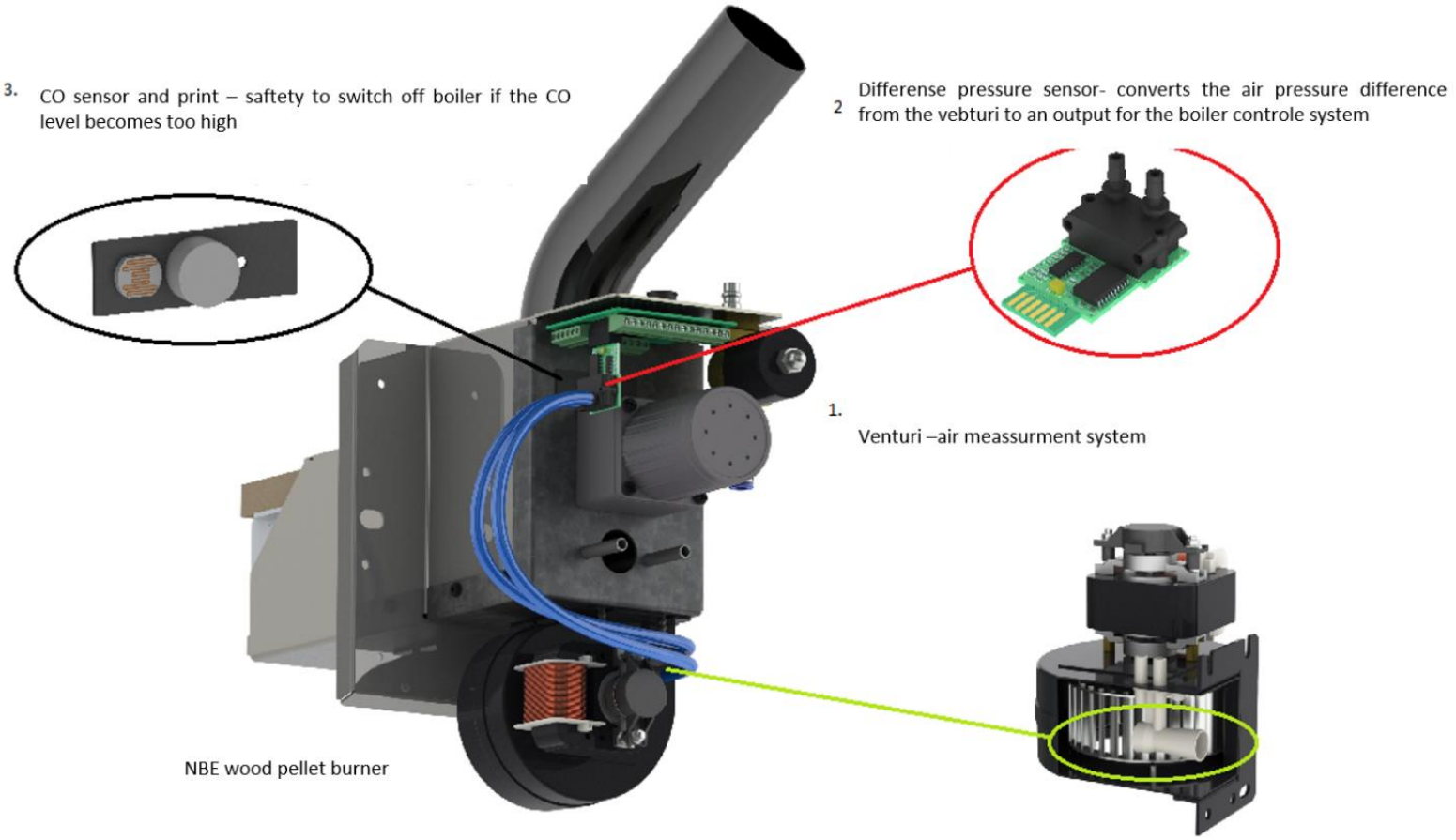
- **Limited (but growing) number of available sensors**
  - **O_2 sensors usually based on solid electrolyte principle (e.g. from NGK Spark Plug, Bosch, LogiDataTech, Scantronic, Heraeus)**
  - **CO & combination sensors (O_2 & CO) based on solid electrolyte or semiconductor principle (e.g. LAMTEC, FIGARO, Scantronic, SenSiC)**
- **Long development & implementation time span for new sensors**
- **Oxygen sensors**
  - **In general god accuracy, little cross sensitivity, good long term stability**
- **Sensors for CO & unburned gases**
  - **Combined signal for all unburned components (still rather poor selectivity for single components)**
  - **Noticeable cross sensitivities (oxygen, moisture, temperature)**
  - **Improvable accuracy & long term stability, but reliable trends & ranges**

Test on wood stoves



- 2 identical sensors have been tested at a 8 kW logwood chimney stove
- Logwood chimney stove operation over approx. 255 h (273 batches) – sensor 1 tested for 150 h
- Test fuel:
  - hardwood (beech) without bark, triangle shape
- Flue gas composition (O_2, CO, CO_2) – measured with conventional flue gas analyzer (Emerson NGA 2000)

Sensors in boilers



- Efficiency increased to 92% (5%points)
- CO is reduced with 69%
- OGC is reduced with 58%

EUDP, Intelligent brænder

Conclusions

TEKNOLOGISK INSTITUT

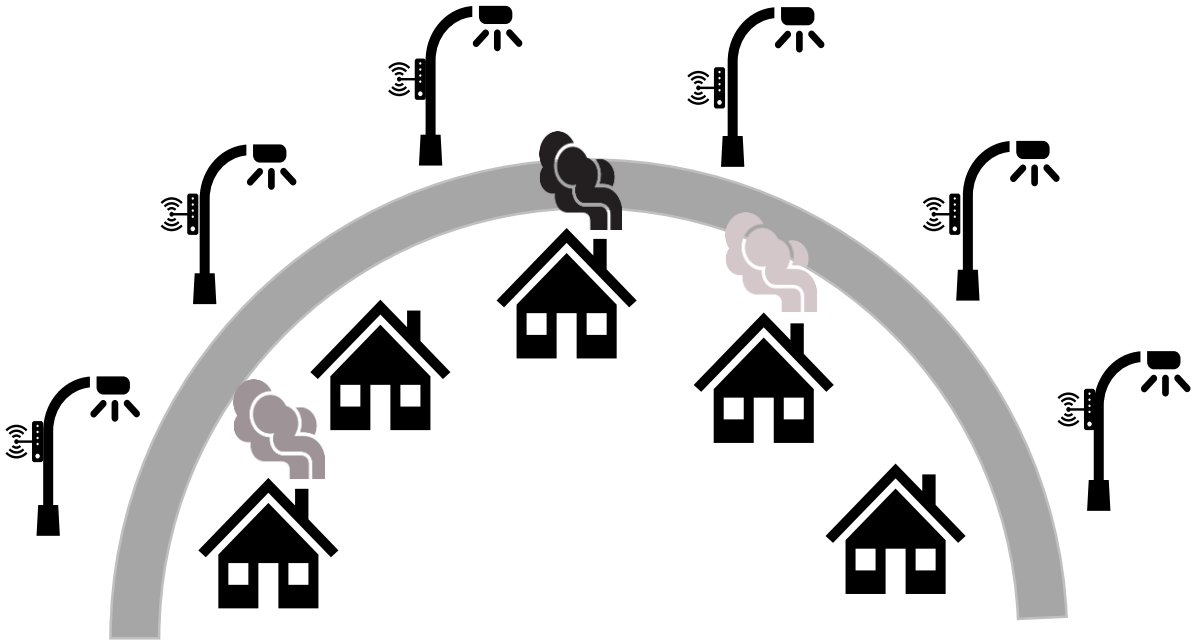
- Technology transfer is an obvious road to explore
  - Catalysts
  - Filters
  - Sensors
  - …..
- Considerations:
  - Cost
  - Differences in combustion (e.g. Lambda, temperature, pressure/draft etc)
  - Lifetime om secondary technology

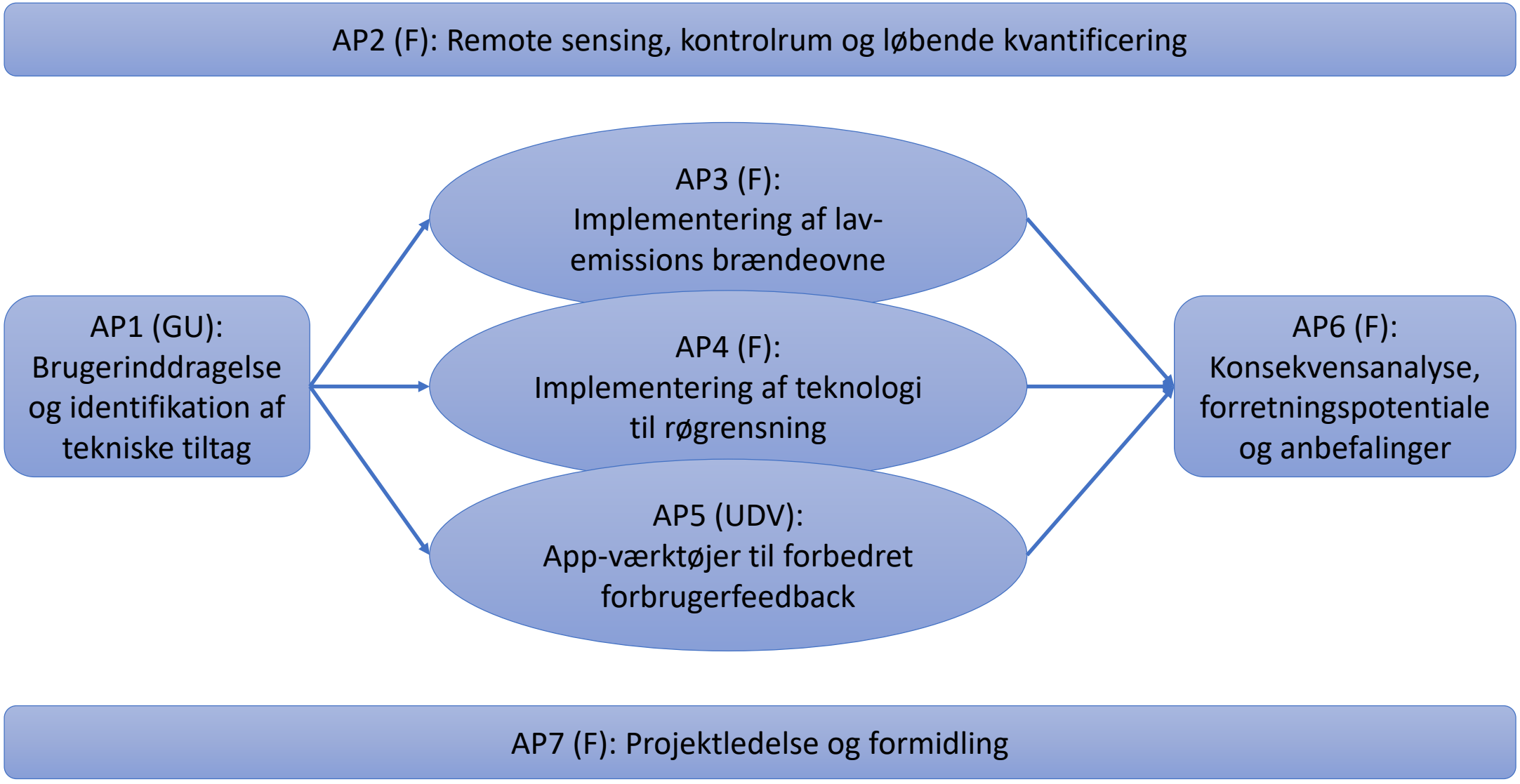
TEKNOLOGISK
INSTITUT

NYT FYRTÅRNSPROJEKT:

Testzone

- Karakterisering af real-life effekter af emissionsreducerende tiltag
  - Teknologi
  - Adfærd




AP2 (F): Remote sensing, kontrolrum og løbende kvantificering
AP1 (GU): Brugerinddragelse og identifikation af tekniske tiltag
AP3 (F): Implementering af lav-emissions brændeovne
AP4 (F): Implementering af teknologi til røgrensning
AP5 (UDV): App-værktøjer til forbedret forbrugerfeedback
AP6 (F): Konsekvensanalyse, forretningspotentiale og anbefalinger
AP7 (F): Projektledelse og formidling

TEKNOLOGISK
INSTITUT

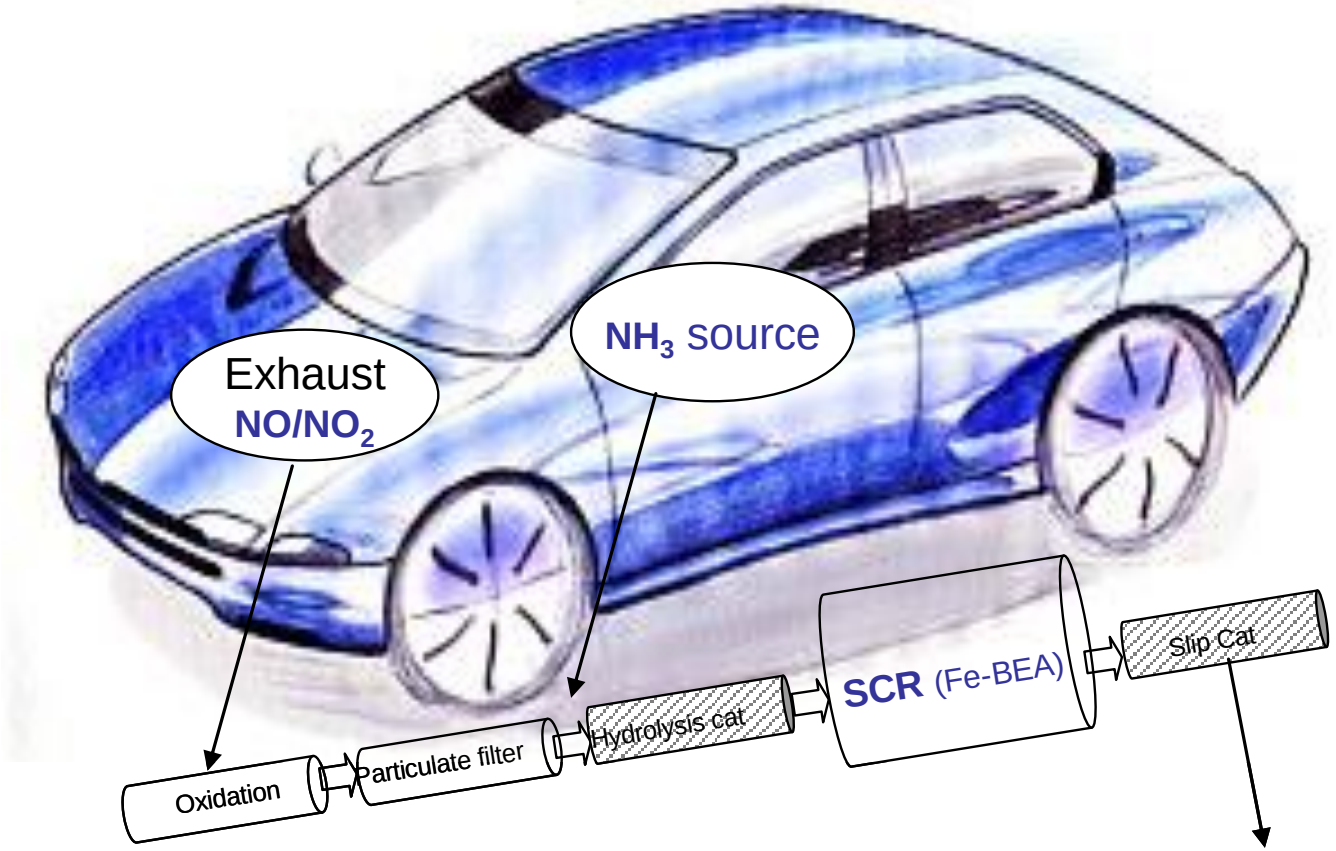
Thank you for your attention

Questions?

Optimization of reductant

TEKNOLOGISK INSTITUT

- Solutions of urea, $(NH_2)_2CO$, is often used as NH_3 source (AdBlue):
  - Urea → NH_3 + HNCO (t > 160°C)
  - HNCO + H_2O → NH_3 + CO_2 (hydrolysis catalyst t > 200°)



P. Hauck et al., Appl. Cat. B, 70, 91, (2007)

Evaluation of sensor technology

- **Overall**
  - **Reliable determination of current combustion condition at all times during whole evaluation period**
- **O_2 & CO determination**
  - **The sensor can well reproduce the O_2 trend over the entire range of operation of a wood stove (relative deviation: -6 to +7 %)**
  - **Slightly higher deviation could be observed for O_2 values lower than 5 vol% d.b. and higher than 14 vol% d.b.**
  - **The sensor supplies stable CO signals and can reproduce the CO trend over the entire measurement range.**
  - **For CO values higher than 1,500 ppmv the relative deviation increases up to 80%**

Project ERA-NET Bioenergy "Wood Stoves 2020"