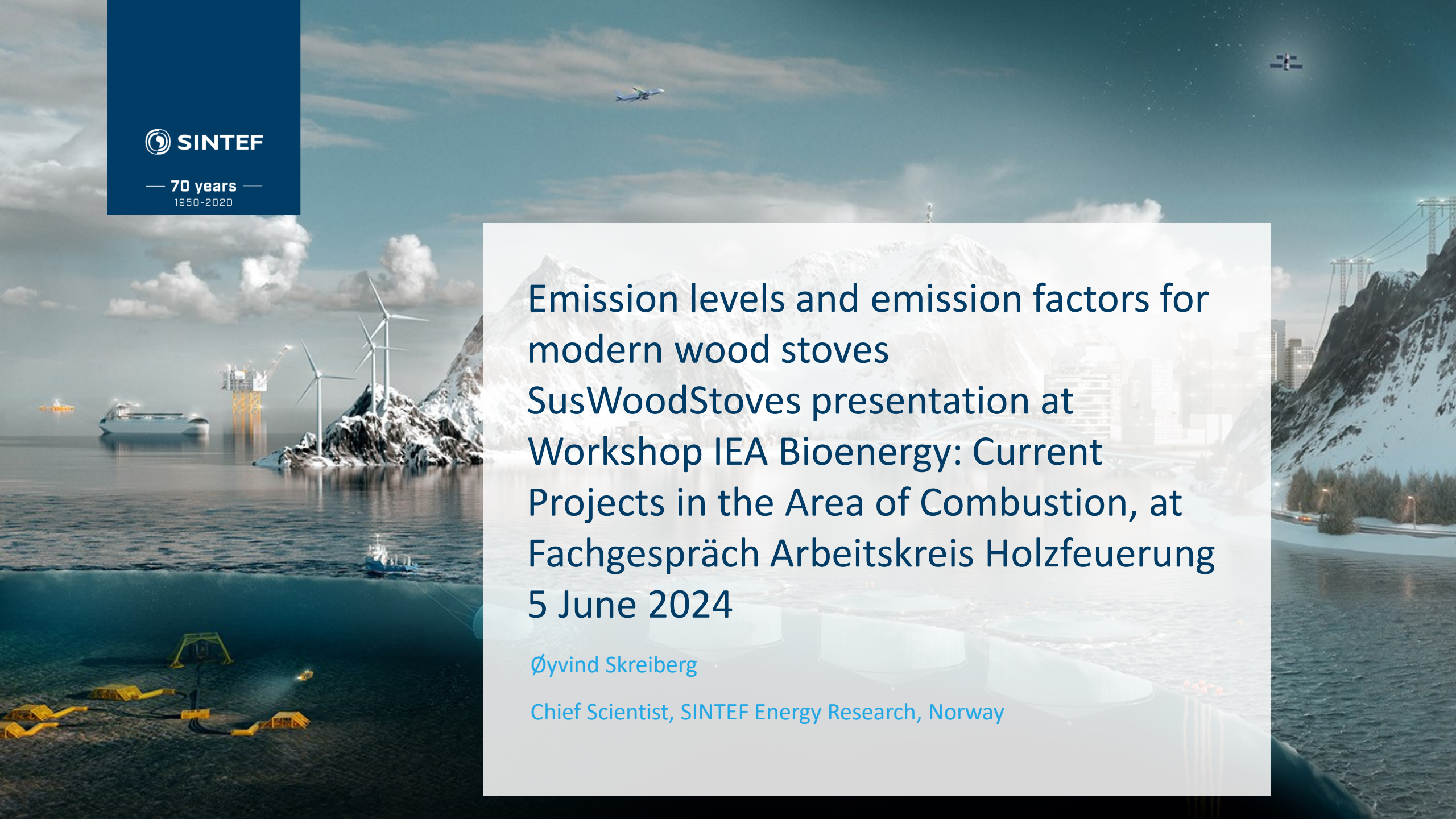

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70 years
1950-2020

Emission levels and emission factors for modern wood stoves SusWoodStoves presentation at Workshop IEA Bioenergy: Current Projects in the Area of Combustion, at Fachgespräch Arbeitskreis Holzfeuerung 5 June 2024

Øyvind Skreiberg

Chief Scientist, SINTEF Energy Research, Norway

SusWoodStoves

Increased sustainability for the wood stove value chain

Background

Wood log combustion is important in and for Norway and contributes much to residential space heating and relieves the pressure on the electricity grid, as well as provides energy security when the electricity grid goes down. However, wood log combustion contributes also to air pollution, and there is a need to increase the sustainability through stove, building integration and value chain optimization, which is the main project focus.

Goals

1) Speciation and quantification of particulate and gaseous emission levels from wood stoves for representative stove technologies and operating conditions,
2) Reduction of climate and health related emission levels through emission reduction and energy efficiency measures,
3) Optimum building integration of stoves,
4) Assessment of value chain performance of existing and improved stove technologies and connected systems for different stove-building configurations in Norway,
5) Techno- and socio-economic assessments of the current and future role of wood stoves in the Norwegian energy market,
6) Development of a roadmap for sustainable wood stoves in Norway,
7) Education of highly skilled candidates within this area and training of industry partners,
8) Monitoring of activities and state-of-the-art within this area and dissemination of knowledge to the industry partners, and other interested parties when applicable.

Project title: Sustainable wood stoves through stove, building integration and value chain optimization (SusWoodStoves)

Project leader: SINTEF Energy Research

Partners: NTNU, Jøtul AS, Nordpeis AS, Norsk Kleber AS, Norsk Varme

Project period: 2021-2024 (26)

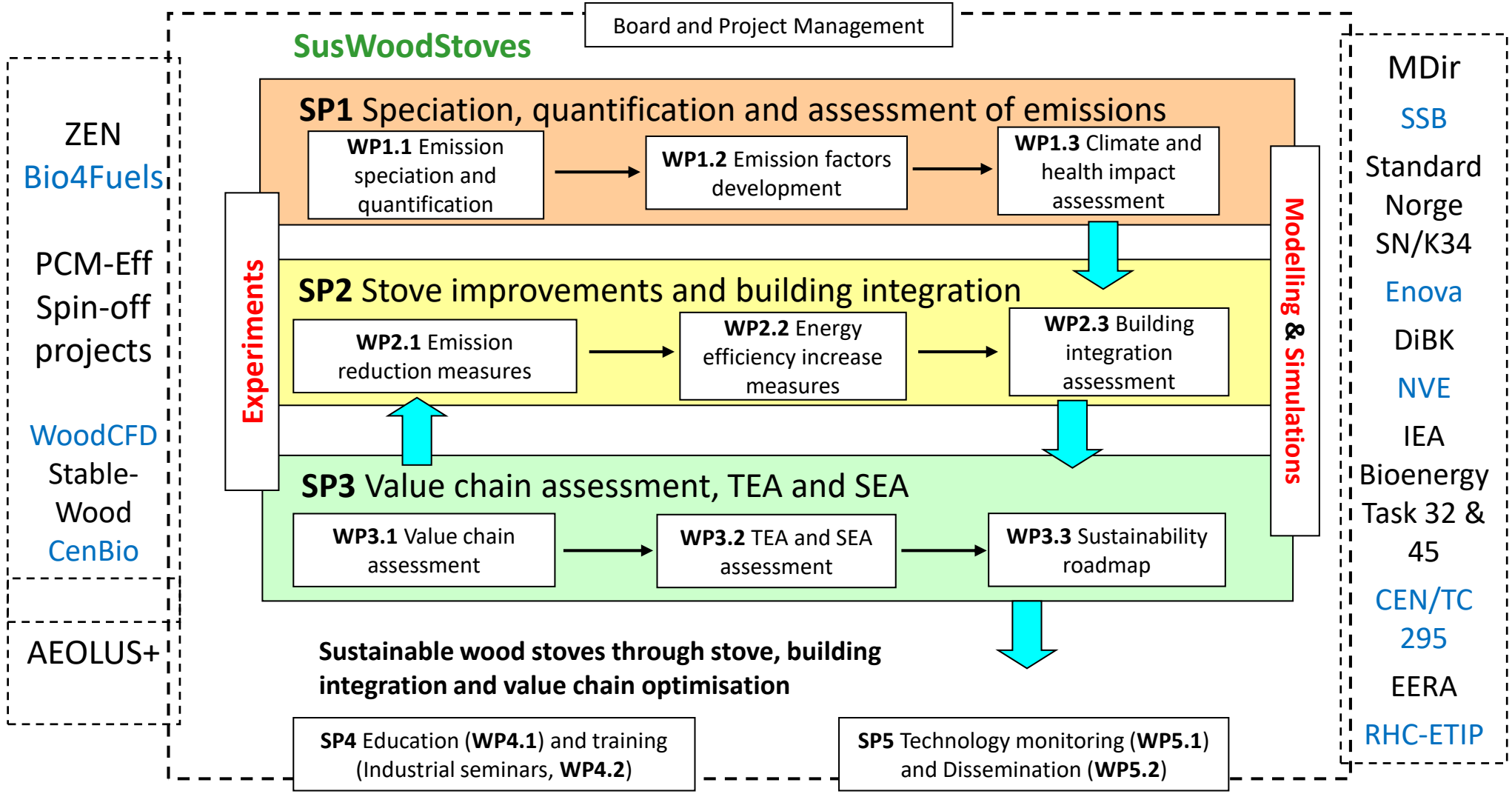
Type: Knowledge building project for the industry

Financing: 18.6 mill. NOK (15.1 from Research Council of Norway)

Project number: 319600

SusWoodStoves - Project structure

More info on the project homepage



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SusWoodStoves - SP1

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CHEMICAL ENGINEERING TRANSACTIONS

VOL. 92, 2022

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Rubens Maciel Filho, Eliseo Ranzi, Leonardo Tognotti

ISBN 978-88-95608-90-7; **ISSN** 2283-9216

DOI: 10.3303/CET2292040

A Critical Review and Discussion on Emission Factors for Wood Stoves

Øyvind Skreiberg*, Morten Seljeskog, Franziska Kausch

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oyvind.skreiberg@sintef.no

Link

Large variations exist in emission factors used in national emission inventories in the Nordic countries as well as when comparing with EMEP/EEA 2019 emission factors

There is a real need to derive more representative emission factors for wood stoves and to align these for inclusion in national emission inventories

Note: When using particulate emission factors for wood stoves derived using the Norwegian type approval standard in an atmospheric modelling tool, together with emission factors from other emission sources (e.g. traffic), and comparing with measurements, it is comparable (i.e. "real life").

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SusWoodStoves - SP1

CHEMICAL ENGINEERING TRANSACTIONS
VOL. 105, 2023

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: David Bogle, Flavio Manenti, Piero Salatino

ISBN 979-12-81206-04-5; **ISSN** 2283-9216

DOI: 10.3303/CET23105041

Emission Levels and Emission Factors for Modern Wood Stoves

Øyvind Skreiberg*, Morten Seljeskog, Franziska Kausch, Roger Khalil

Thermal Energy Department, SINTEF Energy Research, Trondheim, Norway
oyvind.skreiberg@sintef.no

How much has the modern wood stoves improved since 1998?

(from when only clean-burning stoves could be sold in the Norwegian market)

Link

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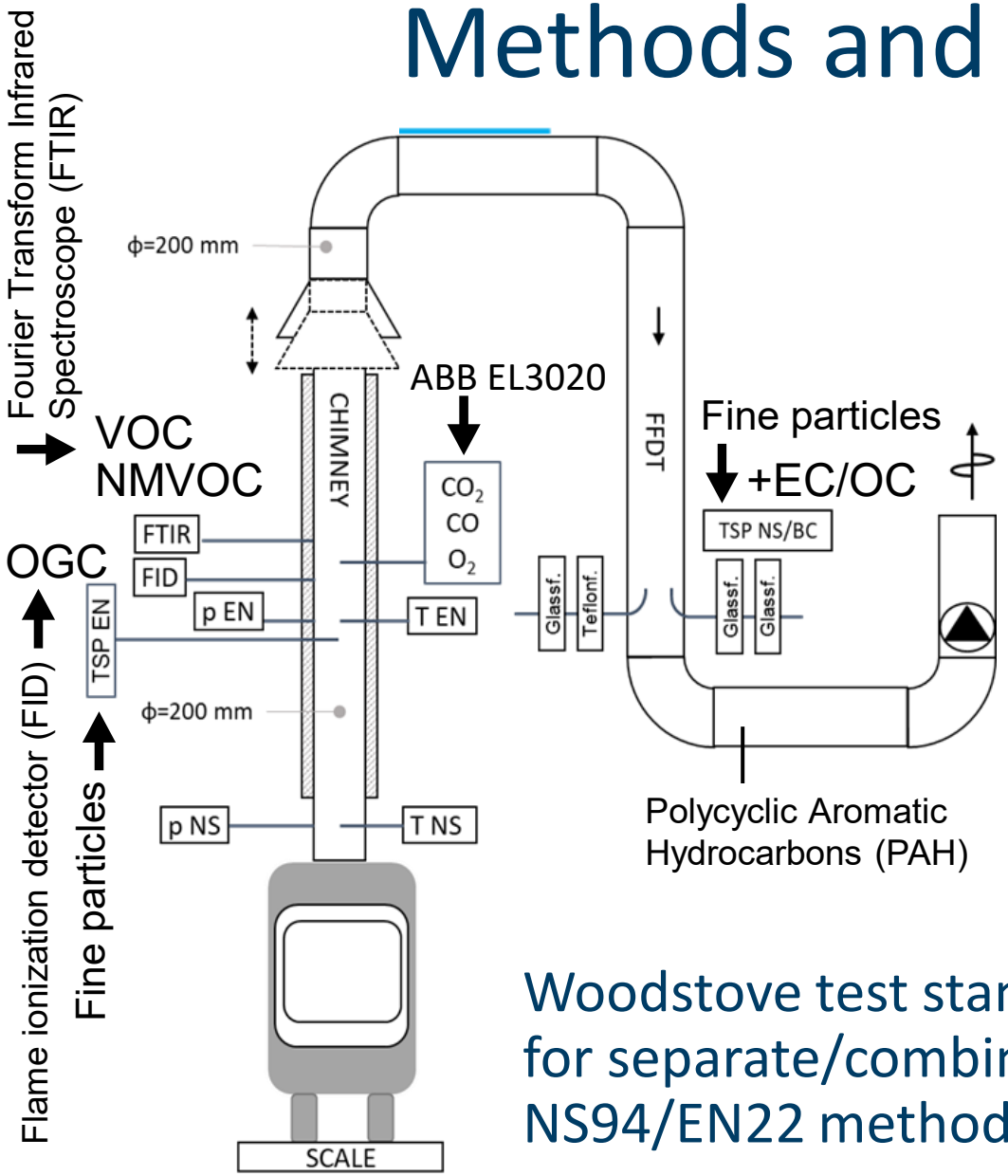
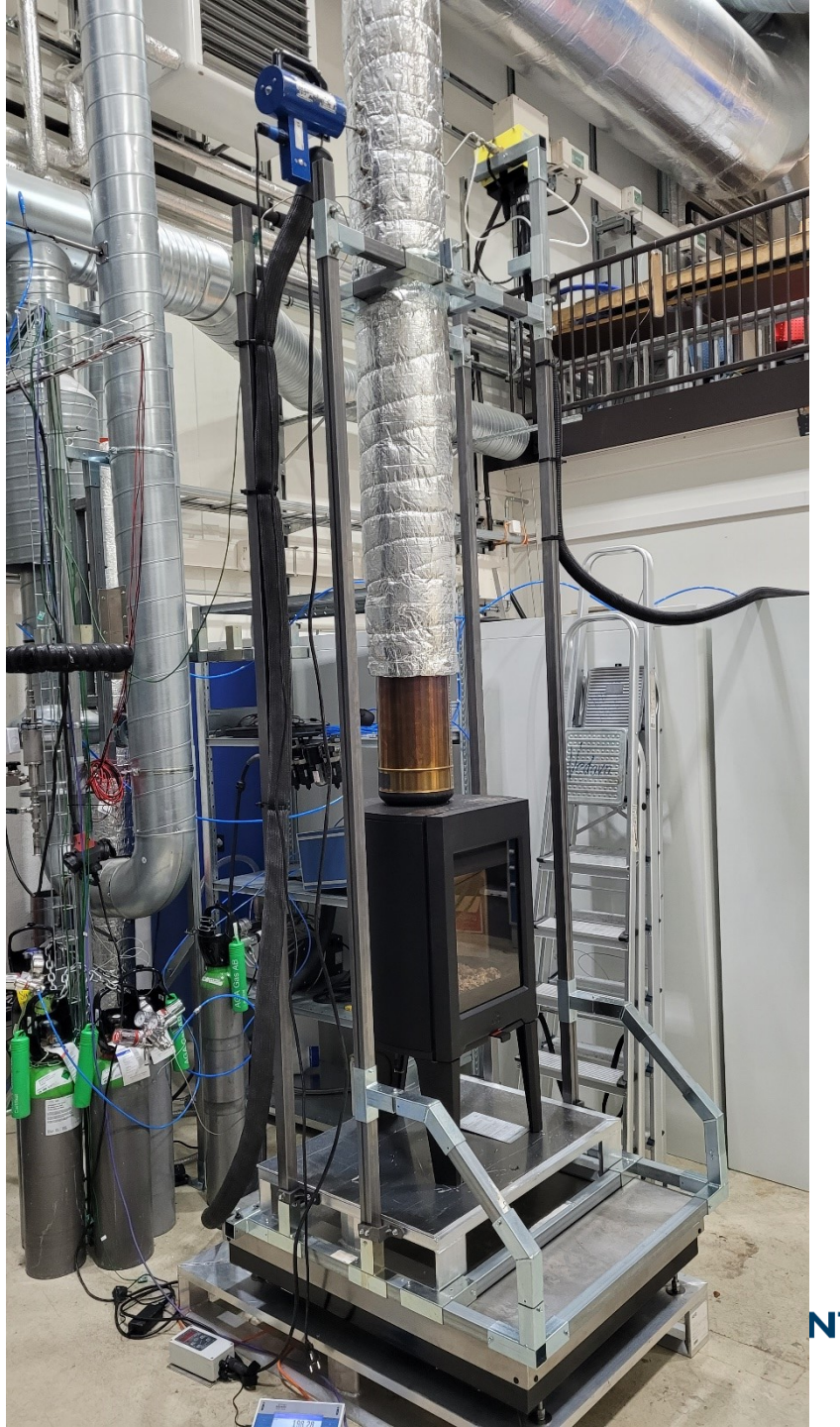
Primary emission reduction measures

Methods and materials



Woodstove test stand for separate/combined NS94/EN22 methods



NTEF

Primary emission reduction measures

Results

Current and recommended new emission factors for modern wood stoves, in g/kg dry fuel

	"Old" new stove	New new stove	Part load	Nominal load	Reduction	Part load / nominal load
TSP	8.44	3.84	5.44	2.39	55%	2.27
PM_{10}	8.30	3.81	5.40	2.38	54%	2.27
$PM_{2.5}$	7.85	3.78	5.34	2.34	52%	2.28
CO	85.73	23.89	35.21	15.59	72%	2.26
NMVOC	15.22	3.54	6.10	2.32	77%	2.63
CH_4	3.88	0.95	1.94	0.42	76%	4.59
EC	0.65	1.05	0.93	0.87	-61%	1.07
OC	4.50	1.33	2.53	0.79	70%	3.21
NO_x	0.69	0.66	0.67	0.68	4%	0.98
N_2O	0.02	0.02	0.02	0.01	31%	1.46
NH_3	0.05	0.05	0.05	0.04	0%	1.40
SO_2	0.30	0.14	0.13	0.15	54%	0.89
HCN		0.0013	0.0011	0.0014		0.80

- Emission factors about three times higher at part load vs. nominal load
- Carbonaceous particles are hard to remove even in new stoves
- NOx - no significant reduction

"Old" new stove - an average for stoves produced from 1998 to 2016
New new stove - an average for representative stoves of today (2022)

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Black carbon

- Stove dependent, large variation

Table 2 Weighted average emission levels, in g/kg dry fuel

	Stove 1					Stove 2				Stove 3			Stove 1	Stove 2	Stove 3	Stove 1-3
	Exp 1	Exp 2	Exp 11	Exp 3	Exp 4	Exp 12	Exp 5	Exp 6	Exp 7	Exp 8	Exp 9	Exp 10	Weighted	Weighted	Weighted	Mean
Load (kg/h)	1.98	1.79	1.65	1.27	1.25	1.24	1.20	2.17	1.70	2.55	0.95	1.31	1.59	1.65	1.73	1.66
TSP (g/kg)	4.39	3.08	2.48	2.01	11.84	6.98	2.87	2.29	2.41	5.20	5.42	2.82	4.82	3.26	4.13	4.07
PM10 (g/kg)	0.96	1.97	1.52	2.71	14.12	7.75	2.31	2.10	2.23	3.07	4.15	1.88	4.14	3.17	2.68	3.33
PM2.5 (g/kg)	0.96	1.92	1.49	2.70	14.10	7.54	2.28	2.07	2.19	3.01	4.03	1.80	4.12	3.11	2.60	3.27
EC (g/kg)	0.25	0.43	0.33	0.32	0.56	nm	0.93	0.76	0.96	2.52	1.29	1.58	0.37	0.90	1.89	1.05
OC (g/kg)	0.33	0.37	0.99	3.04	6.77	nm	0.33	0.63	0.74	1.66	1.99	0.53	2.23	0.57	1.18	1.33
CxHy-FID as C3H8 (g/kg)	3.22	5.33	nm	17.32	15.16	nm	3.25	1.10	2.72	1.34	3.39	1.04	9.45	2.49	1.51	4.48
CO (g/kg)	12.32	16.81	nm	50.30	47.85	nm	32.04	12.42	24.98	11.42	24.40	21.43	29.40	24.23	18.05	23.89
CH4 (g/kg)	0.42	0.86	nm	5.25	3.09	nm	0.62	0.14	0.53	0.16	0.59	0.14	2.16	0.46	0.21	0.94
NMVOC (g/kg)	2.80	4.47	nm	12.07	12.07	nm	2.63	0.97	2.19	1.18	2.80	0.90	7.29	2.03	1.29	3.54
SO2 - Spruce (g/kg)	0.11	0.08	nm	0.06	IF	nm	0.20	0.23	0.10	0.20	0.10	0.17	0.08	0.17	0.17	0.14
NOx - Spruce (g/kg)	0.79	0.76	nm	0.69	0.69	nm	0.64	0.65	0.58	0.60	0.68	0.62	0.74	0.62	0.62	0.66
N2O - Spruce (g/kg)	0.006	0.004	nm	0.022	IF	nm	0.007	0.006	0.001	0.047	0.029	0.015	0.012	0.004	0.029	0.015
NH3 - Spruce (g/kg)	0.024	0.019	nm	0.023	0.028	nm	0.029	0.036	0.028	0.080	0.103	0.079	0.023	0.030	0.083	0.045
HCN (g/kg)	0.0014	0.0014	nm	0.0010	0.0011	nm	0.0009	0.0019	0.0007	0.0016	0.0013	0.0014	0.0013	0.0011	0.0014	0.0013

Explanation: IF: too high interference in the FTIR to be determined; nm: not measured. Red numbers for TSP for Stove 1 are considered to have higher uncertainty due to a different filter type used. Red numbers for PM10 and PM2.5 for Stove 3 are considered to have higher uncertainty due to a detected leakage. These numbers have been discarded when calculating the recommended new emission factors for modern wood stoves.

- Hard to remove even in new stoves
- Needs special focus in the future

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Primary emission reduction measures

Summary

- Today`s modern wood stoves emits on average 50+% less particles and 70+% less harmful gaseous compounds, than the average of new stoves since 1998
- Fine particles as soot/black carbon is difficult to reduce even if the combustion conditions are much improved
- No NOx emission reduction, despite the staged-air combustion principle
- End-users should preferably operate their appliance at nominal loads
- Automated wood stoves would be necessary for minimum user interaction
- Radical design changes are necessary for abatement of some emission compounds
- National emission inventories should be updated according to the progress of any technology, including wood stoves, responsible for harmful emissions

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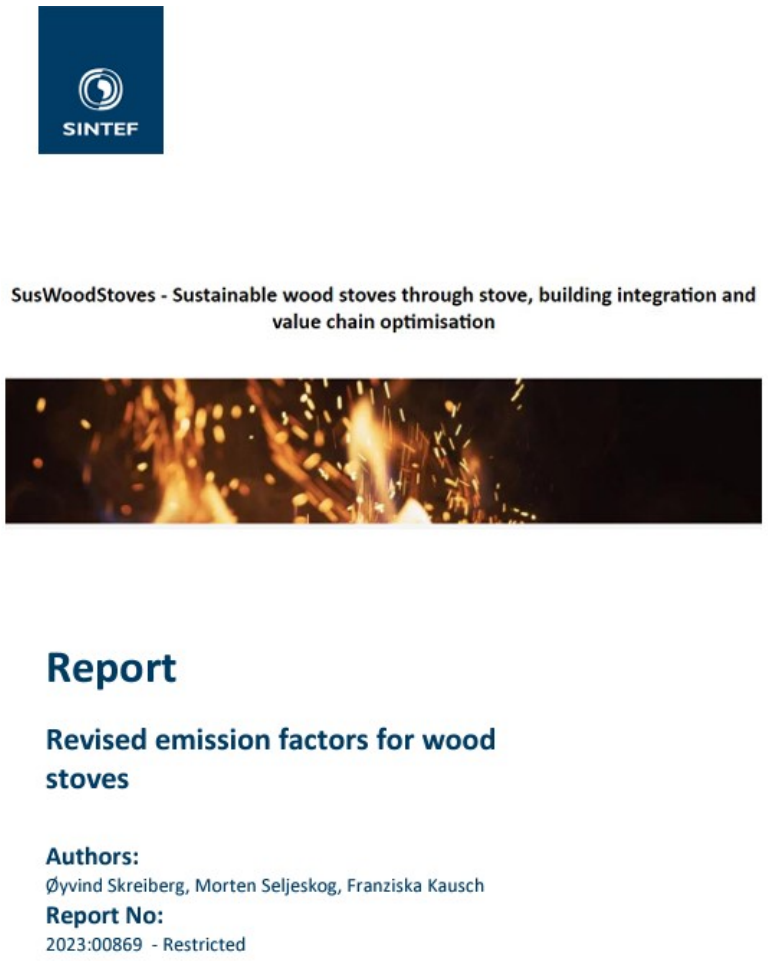
SusWoodStoves - SP1



Summary:
Today the best wood stoves outperform the staged air combustion wood stoves introduced in the 1990s, as further continuous improvements have been carried out and new and improved designs have been introduced. Hence, in national emission inventories this should be considered, so the mean emission factors used for the overall modern wood stove category reflect the continuous improvements over the last decades. The measurements carried out in this work made it possible to provide such emission factors for the modern wood stove category, for a wide range of emission compounds. The results show that most emissions of unburnt have been much reduced the last decades. However, for black carbon and for emissions due to minor and trace elements in the wood, this is not the case. Further targeted development and/or new combustion concepts are needed to significantly reduce both black carbon and NOx emissions.

The emission factors have been presented to the Norwegian authorities

SINTEF

Emissions from modern wood stoves

Link

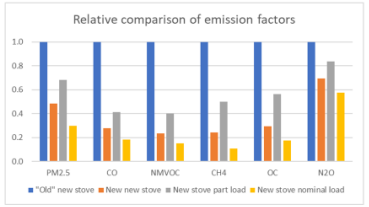
January 2024

Factsheet: Emissions from modern wood stoves

Emissions from wood burning are strongly reduced the last decades, thanks to continuous research and technology development. This is one of the results from the knowledge building project SusWoodStoves, supported by the Research Council of Norway and industry.

In SusWoodStoves we have compared the emission factors that today are used in the Norwegian national emission inventory for modern wood stoves with three modern wood stoves.
Then we found that the three modern wood stoves on average has:

- *52 % lower emissions for the smallest (and most dangerous) particles (PM2.5)*
- *72 % lower emissions for CO (carbon monoxide)*
- *76 % lower emissions for CH_4 (methane)*
- *77 % lower emissions for other relatively light gases (NMVOC)*
- *70 % lower emissions for the heaviest gas compounds that condense out as liquid particles in the atmosphere*



The emission inventory must be updated
The results are good news that also must be reflected in our national emission inventory. Updated emission factors (per kg dry wood) must be used when the total emissions from the wood stove fleet in Norway is calculated based on technology type (old stove: before 1998; modern stove: from 1998; and open fireplace) and the wood consumption in these.

Read more in the SINTEF blog Research and Development Reduce Emissions from Wood Burning.
And in the scientific publication Emission levels and emission factors for modern wood stoves.

At the same time the stove efficiency has been improved, being on average 80%, which gives further reduced emissions per kWh net heat output.

Want to know more? Contact:
Øyvind Skreiberg
Chief Scientist at SINTEF Energy Research

SINTEF Technology for a better society

Link

#ENERGY BIOENERGY

Research and Development Reduce Emissions from Wood Burning

BY ØYVIND SKREIBERG
FEBRUARY 8, 2024

COMMENTS 0

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SusWoodStoves - SP2

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CHEMICAL ENGINEERING TRANSACTIONS

VOL. 99, 2023

A publication of AIDIC

The Italian Association of Chemical Engineering

Online at www.cetjournal.it

Guest Editors: Sauro Pierucci, Flavio Manenti

ISBN 978-88-95608-98-3; **ISSN** 2283-9216

DOI: 10.3303/CET2399010

Energy Efficiency Increase by Improved Operation and Control in Wood Stoves

Øyvind Skreiberg*, Morten Seljeskog, Franziska Kausch

Thermal Energy Department, SINTEF Energy Research, Trondheim, Norway
oyvind.skreiberg@sintef.no

Link

Stove efficiencies of around **80%** was achieved for all three stoves, with the highest efficiency achieved for the stove with the highest heat storage capacity

The potential for further efficiency increases in wood stoves is significant, as during the combustion process the total efficiency in these modern wood stoves can approach **90%**

The efficiency used by Statistics Norway today is 75% for modern wood stoves. Old stoves: 50%. Open fireplaces: 15%.

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SusWoodStoves - SP2

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CHEMICAL ENGINEERING TRANSACTIONS

VOL. 99, 2023

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Sauro Pierucci, Flavio Manenti

ISBN 978-88-95608-98-3; **ISSN** 2283-9216

DOI: 10.3303/CET2399011

Reducing Emissions from Current Clean-Burn Wood Stove Technology by Automating the Combustion Air Supply and Improving the End-User Interaction – Two Important Primary Measures

Morten Seljeskog*, Franziska Kausch, Roger A. Khalil, Øyvind Skreiberg

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Morten.Seljeskog@sintef.no

Link

Automating the combustion air has a high potential to reduce emissions of PM, CO, and OGC, as well as increasing the efficiency

Good ignition is crucial to achieve low emissions

No significant differences in emissions were found when comparing birch, spruce and pine

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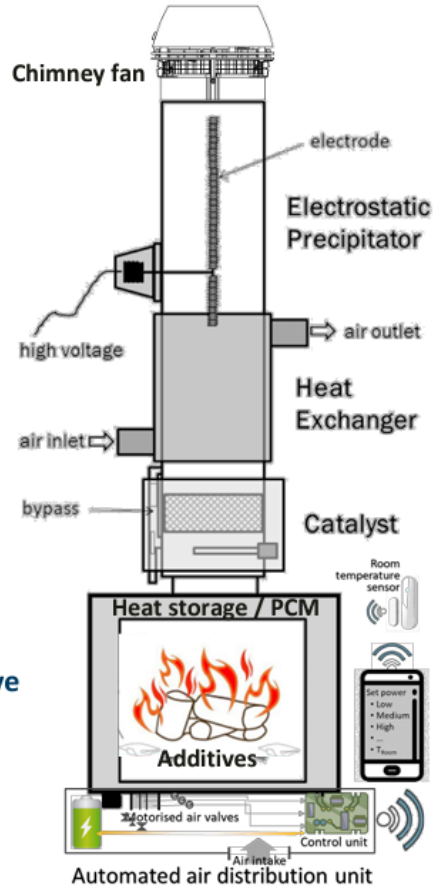
Summary

- Automating the combustion air has a high potential to reduce emissions of PM, CO, and OGC, as well as increasing the efficiency even at more realistic test conditions.
- The effect of end-user operation as for the ignition from cold stove, and use of fuel with varying properties, showed significant variation in emissions over the ignition period.
- Good ignition, when firing according to NS94, can be achieved repeatedly by assuring that the fuel catches fire before closing the door and/or reduce the primary/secondary air flows.
- **Bad ignition** due to **over-/under** firing and **dense stacking**, can produce at least **twice as much PM and CO** and **3-4 times the OGC**, compared to correct ignition.
- **No significant differences** in emissions were found when comparing **birch, spruce, and pine**, for wood with equal moisture content.
- However, **burning pine, showed higher** emissions of total carbon particles, as elemental and organic carbon, on the same level as with poor ignition.

SusWoodStoves - SP2



Report

Secondary Measures to mitigate wood stove emissions

D2.1.2

Author:
Morten Seljeskog

Report No:
2023:01381 - Restricted

Client (pos partner)
SusWoodStoves project consortium

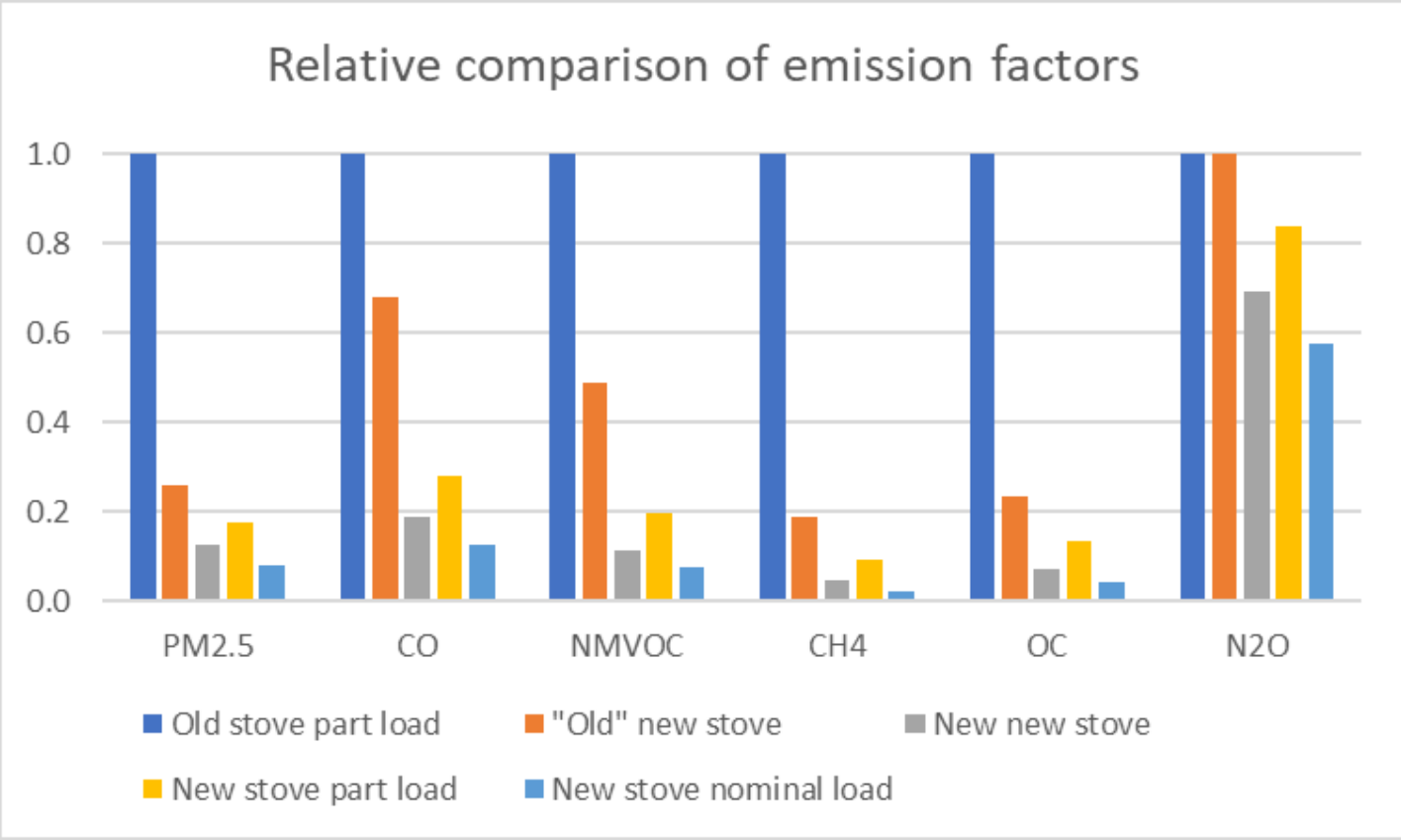
Secondary measures

The main recommendation from this report, is that the best solution in terms of emission reductions and efficiency increase, for old small-scale room heaters, is still to replace those for new ones

Most secondary measures referred to in this report, even commercial ones like ESPs or retrofit catalysts, still need more research/development before they constitute a real alternative regarding emission reductions

SusWoodStoves - SP2

PhD study - ongoing (first publication is in progress)



Climate impact of wood stove use

Health impact of wood stove use

Climate and health impacts are also reduced alongside environmental impacts

Different with respect to GWP factors, and geographical and seasonal dependent GWP for several compounds, and BC is important!

Different with respect to health influence, and PM is important!

Old stove - an average for stoves produced before 1998
"Old" new stove - an average for stoves produced from 1998 to 2016
New new stove - an average for representative stoves of today (2022)

The picture is improving further when including stove efficiency

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SusWoodStoves - SP3

Measurement of the Wood Stove Impact on the Electric Power Consumption of a Norwegian Detached House

Abolfazl Mohammadabadi[1](✉), Øyvind Skreiberg[2], and Laurent Georges[1]

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[2] SINTEF Energy Research, Sem Sælands vei 11, 7034 Trondheim, Norway

PhD study - ongoing (first publication is published)

The study underscores the potential of wood stoves to reduce electric power consumption during mornings and evenings, thus reducing the stress on the electricity grid

PhD study - Building integration and electricity grid interaction

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SusWoodStoves - SP4

2 PhD

Master and summer students

Workshops

SusWoodStoves - SP5

https://www.sintef.no/en/projects/2021/suswoodstoves-sustainable-wood-stoves-through-stove-building-integration-and-value-chain-optimisation/publications/#menu

Numerous dissemination efforts towards the public, and some also in English language

#ENERGY BIOENERGY

The 10 commandments of wood burning stoves

BY ØYVIND SKREIBERG
NOVEMBER 13, 2023

COMMENTS
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Take home messages

- Modern wood stoves have much improved during the last 25 years, resulting in large reductions in most emissions of unburnt, and increased energy efficiency
- Environmental, climate and health impacts are reduced accordingly
- Still, proper operation and wood quality is key
- Automation of the air supply contributes to automatic proper operation
- End-users should preferably operate their appliance at nominal load
- Different wood species give mostly similar emissions of unburnt
- National emission inventories should be updated according to the progress of any technology, including wood stoves, responsible for harmful emissions
- However, too large variations in emission factors for most species can be seen when comparing national emission inventories today

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70 years

1950-2020

Technology for a better society