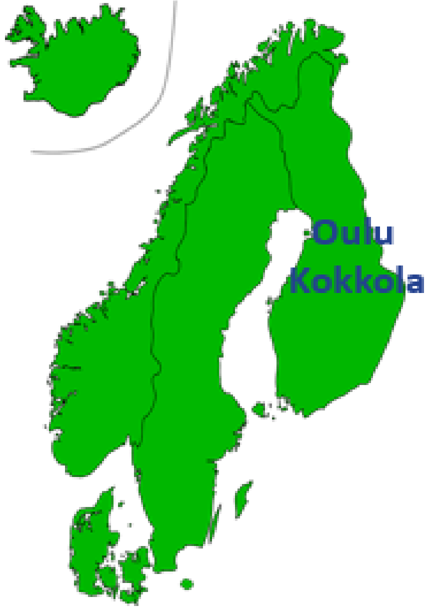
Methane pyrolysis
(Thermocatalytic decomposition of methane)

Prof. Ulla Lassi, University of Oulu, Finland
29.3.2023

Sustainable Chemistry Research Unit

FACTS (2020):

Staff: 47
3 Full professor, 3 docents, 17 post docs
Degrees: 15 M.Sc., 3 Ph.D.
14 research projects (BF, AF, EU funded)
32 international publications, 2 pending patents
Close company collaboration
Several disciplines in chemistry

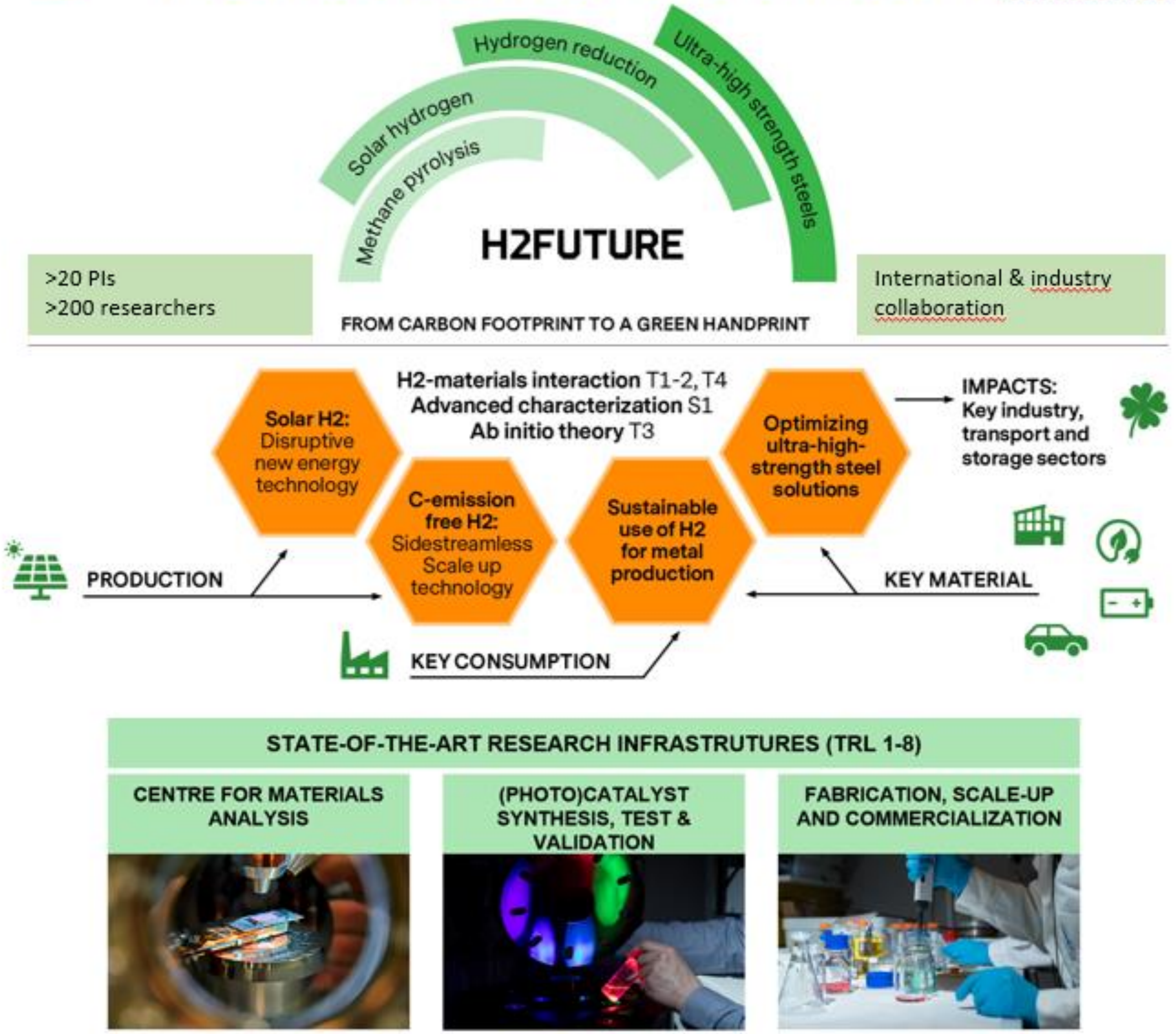


RESEARCH FOCUS AREAS IN APPLIED CHEMISTRY **(Scientific results during past years)**

I.	Lithium-ion battery chemicals Metals recovery, leaching, and precipitation	(3 PhD, 6 PhD students, 20 M.Sc., publ.,)
II.	**New water treatment chemicals and solutions**	(6 PhD, 6 PhD students, 10 M.Sc., 30 publ)
III.	**Catalysis in biomass conversion**	(5 PhD, 4 PhD students, 6 M.Sc., 15 publ.)
IV.	**Technical carbons and applications**	(3 PhD, 3 M.Sc., 20 publ.)

www.oulu.fi/sustainablechemistry

H2FUTURE - Multidisciplinary Research and Education as a Foundation of the Green Transition



- National profilation project **H2FUTURE** 2023-2028
- CO_2 free and energy efficient H2 production methods: ***solar H2 and (bio)methane pyrolysis***
- Energy materials research: electroceramics
- Solar panels and nanocoatings
- Coordination of Hydrogen Research Forum Finland (9 research organization members): Research based view on hydrogen transition
- **National graduate school on H2 transition under construction**
- I4WORLD EU-Horizon MSCA docotoral program focusing on UN SDG themes
- Offering courses on energy technology and systems, **minor** on sustainable development
- Open university and continuous learning, **education on H2 transition** (FiTech) and UNIC collaboration

I4WORLD UNIVERSITY OF OULU

Co-funded by the European Union

erc

BUSINESS FINLAND

SUOMEN AKATEMIA

Hydrogen roadmap – Sustainable chemistry

2008-2015

FT synthesis
Catalytic conversion of biomass-derived synthesis gas to olefins/FT diesel

Collaboration with LTU & NTNU

PhD thesis Romar 2015
PhD thesis Tuomikoski 2014

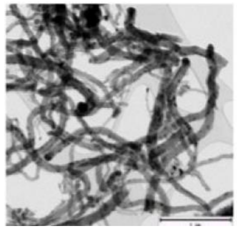
2015-2021

Methane pyrolysis to hydrogen and carbon

Carbon applications (activated carbon, carbon foams, carbon catalysis)

Carbon use in batteries

Hydrogen reduction (with MET)

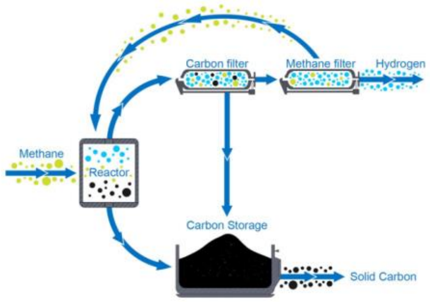


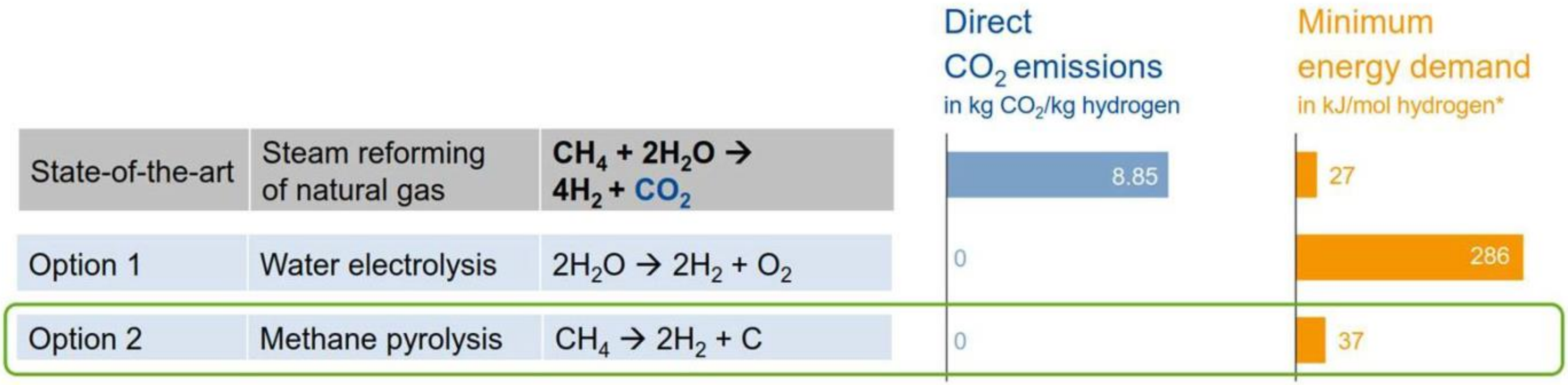
PhD thesis Bergna 2019
PhD thesis Kupila 2021
PhD thesis Varila 2020

2022-

Improved material efficiency for **methane pyrolysis** (use of secondary materials)

Hydrogen reduction in metallurgical industry (with MET)

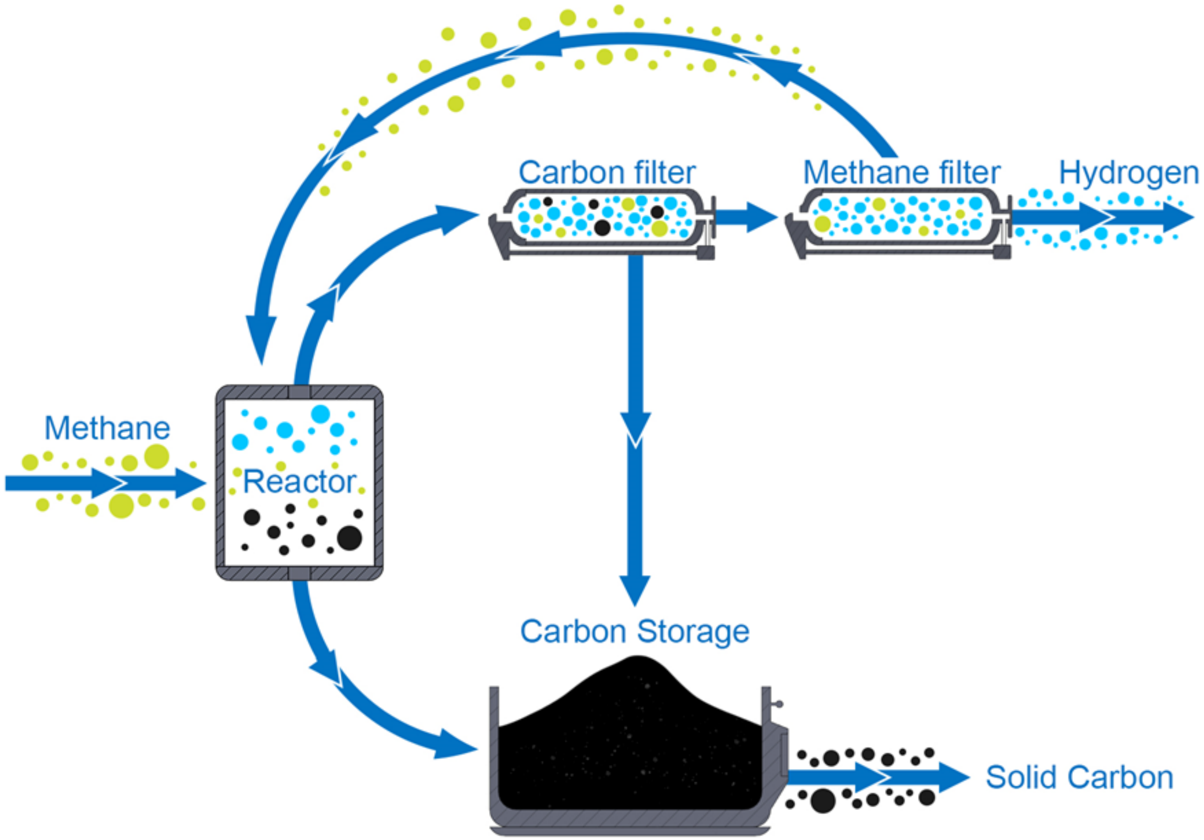




Production of hydrogen (options)

- Daloz, W., Frederik Scheiff, Kai Ehrhardt, Dieter Flick and Andreas Bode,The quest for CO2 -free hydrogen – methane pyrolysis at scale, ARPA-E Methane Cohort Kickoff, Houston (US), Dec 10, 2019.

Methane pyrolysis



TRL3 -> TRL7

Several innovations behind this:

1) Use of CO_2/CO free technology
2) Catalyst
3) Reactor set-up
4) Solid carbon for energy storage applications

TCD of (bio)methane

Table 1. Chemical reactions for hydrogen production from methane and corresponding reaction enthalpies. In the first three reactions (SMR, DRM, and PO), carbon is emitted as CO_2 or CO, whereas in TDM and TCD, solid deposits of carbon are formed.

Production Method	Chemical Equation	Reaction Enthalpies	Equation Number
Steam methane reforming (SMR)	$CH_4 + H_2O \rightarrow CO + 3H_2$	$\Delta H_{298K} = 206$ kJ/mol	(1)
Water gas shift reaction (WGS)	$CO + H_2O \rightarrow CO_2 + H_2$	$\Delta H_{298K} = -41$ kJ/mol	(2)
Dry reforming of methane (DRM)	$CH_4 + CO_2 \rightarrow 2CO + 2H_2$	$\Delta H_{298K} = 247$ kJ/mol	(3)
Partial oxidation (PO)	$CH_4 + 0.5O_2 \rightarrow CO + 2H_2$	$\Delta H_{298K} = -23$ kJ/mol	(4)
Thermal decomposition of methane (TDM) Thermocatalytic decomposition of methane (TCD)	$CH_4 \rightarrow C + 2H_2$	$\Delta H_{298K} = 75$ kJ/mol	(5)

Välimäki, Emmi; Yli-Varo, Lasse; Romar, Henrik; Lassi, Ulla (2021) Carbons Formed in Methane Thermal and Thermocatalytic Decomposition Processes: Properties and Applications., C. 7 (3), 50 . http://dx.doi.org/10.3390/c7030050

Catalysts

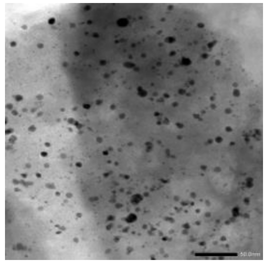
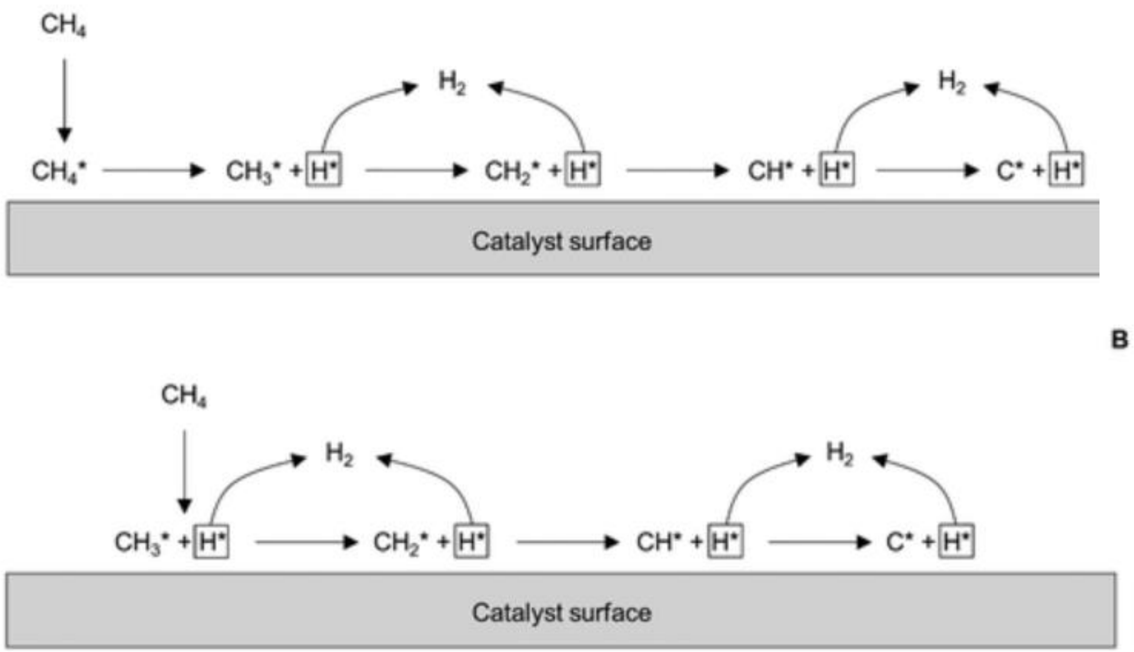


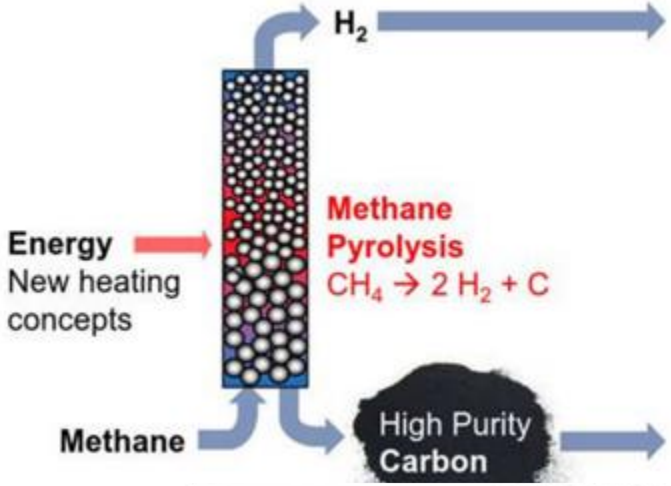
Table 2. Initial Activity of Nickel, Iron, and Cobalt Catalysts in the Decomposition of Methane for Hydrogen Production

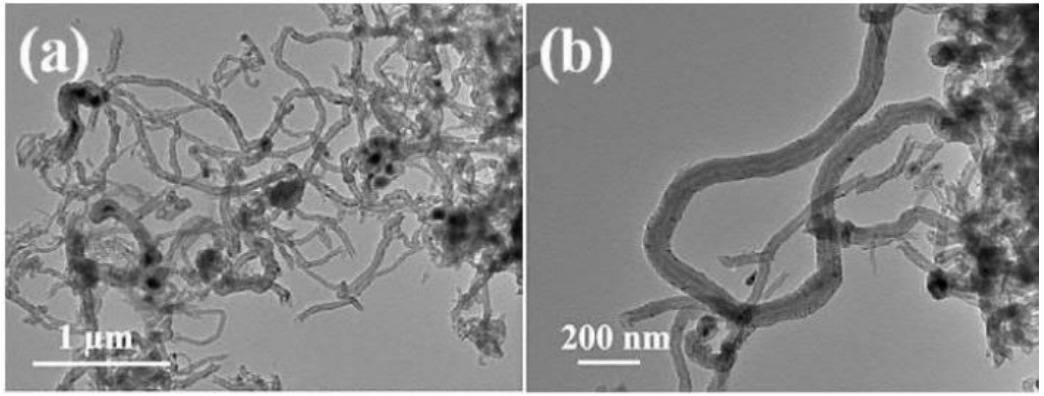
catalyst	T [°C]	P [atm]	CH_4/N_2 [vol vol^{-1}]	flow rate [mL min^{-1}]	space velocity [mL h^{-1} g_{cat}^{-1}]	H_2 yield [%]	ref
Ni/CeO_2	700	1	1/0	150	4500	53	139
Ni/La_2O_3	700	1	1/0	150	4500	60	139
Ni/SiO_2	700	1	1/0	60	7200	73	140
Fe/CeO_2	700	1	1/0	150	4500	51	141
Fe/La_2O_3	700	1	1/0	150	4500	40	141
Fe/SiO_2	700	1	3/7	70	42000	20	94
Ni/SiO_2	800	1	1/0	250	5000	74	134
Fe/SiO_2	800	1	1/0	250	5000	39	134
Co/SiO_2	800	1	1/0	250	5000	48	134

Ind. Eng. Chem. Res. 2021, 60, 32, 11855–11881

Catalysts







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Sustainable Carbon as a secondary product supplementing the sales

PRODUCTS

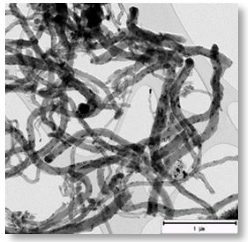
Carbon nanotubes (CNT)

Carbon nanofibers (CNF)

Amorphous carbon → activated carbon

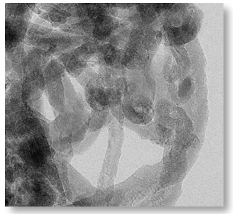
Graphite

CNT, CNF



- Battery industry
- Electric vehicles (supercapacitors)
- Catalysts

Graphite



- Battery industry
- Lightweight materials for automotive and aerospace industry

Activated carbon

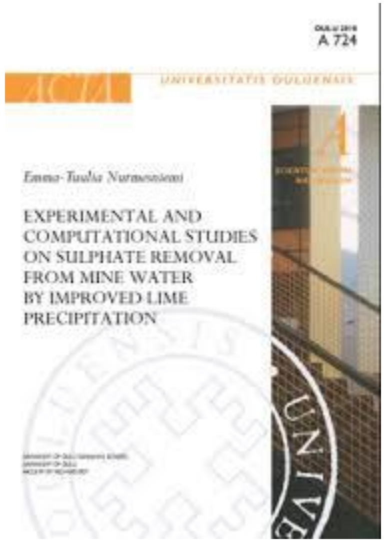
- Water treatment
- Pharmaceutical purification
- Industrial applications

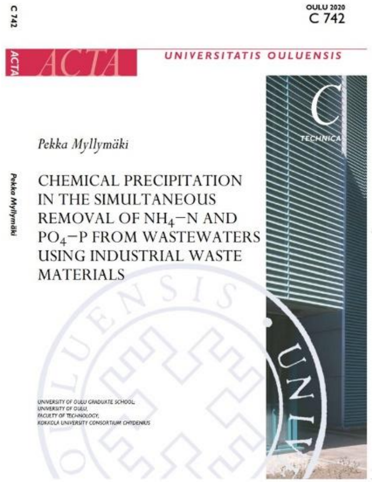
hycamite

Conclusions

- Methane pyrolysis feasible technology for (bio)methane conversion to hydrogen and solid carbon
- Currently under pre-commerzialization stage
- CO/CO_2 free technology
- Added-value from the utilization of carbon

Thanks for your attention!





Professor Ulla Lassi, University of Oulu
Head of Research Unit of Sustainable chemistry
eMail: ulla.lassi@oulu.fi,
tel: +358 400 294 090

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Battery chemistry research since 2007