Research for Sustainable Technologies

DECHEMA FORSCHUNGSINSTITUT
Stiftung bürgerlichen Rechts

Ali Soleimani Dorcheh, D. Fähsing, Mathias C. Galetz

High Temperature Corrosion by Molten Nitrates in Concentrated Solar Power Plants

Ferrostaal RAISELIFE

Materials
Chemical Engineering
Biotechnology

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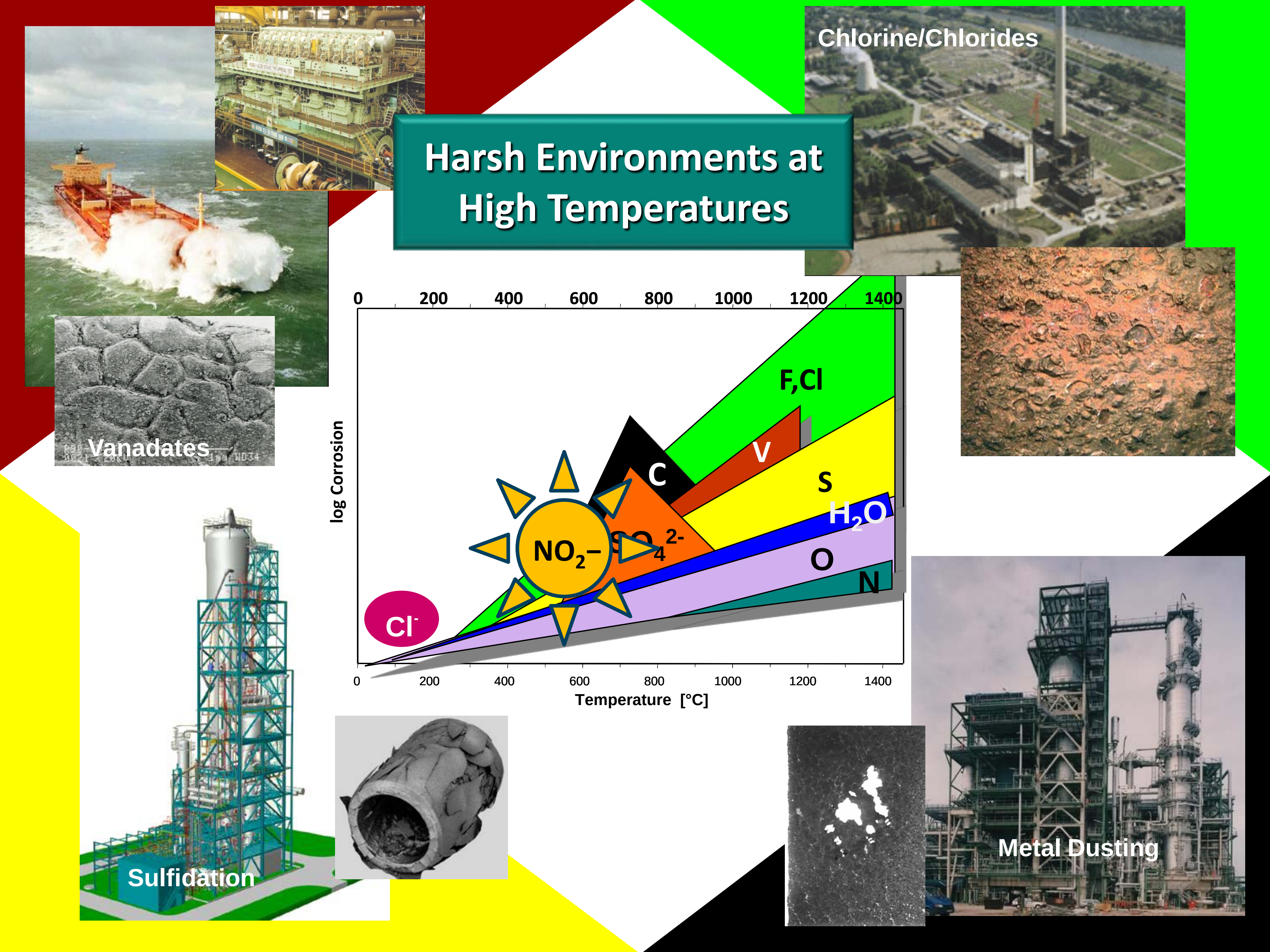
Interdisciplinary Research for Sustainable Technologies

Aim: Competitive, ressources conserving and environmentally friendly industrial society

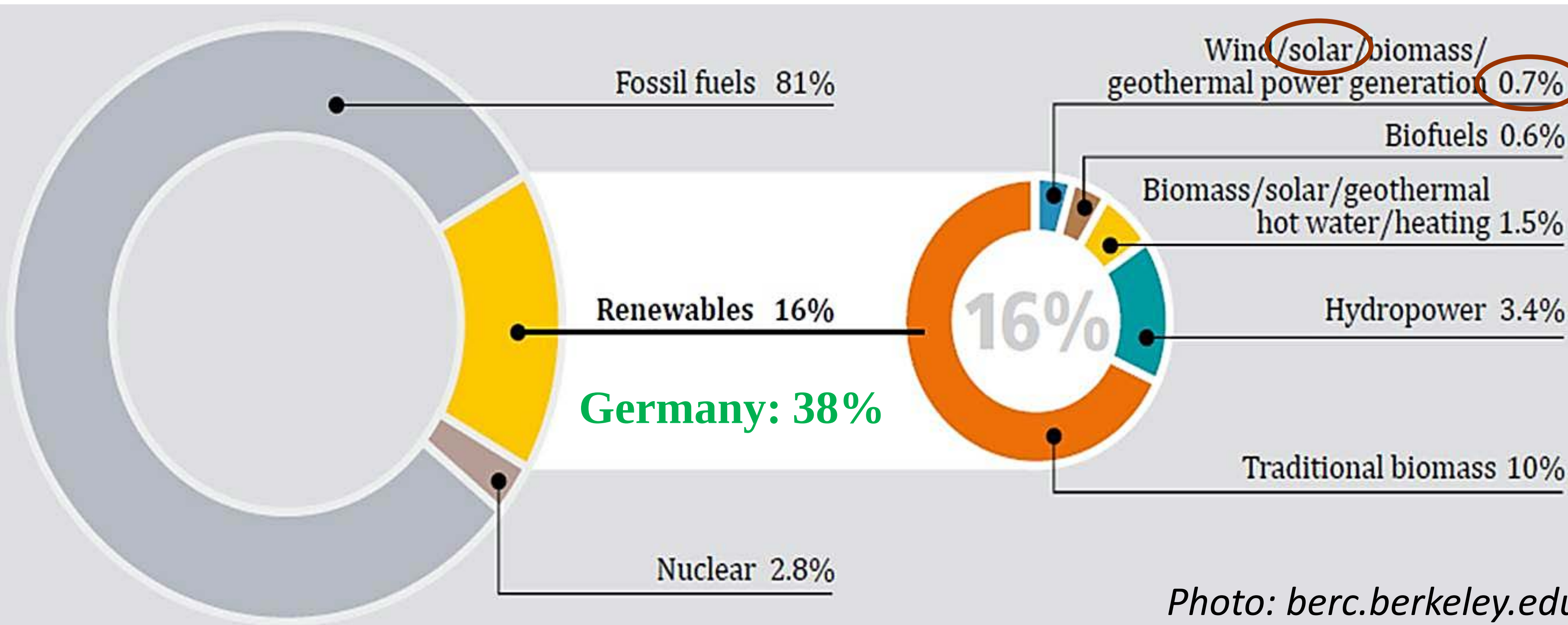
- Non-Profit Foundation under public law
- Ca. 75 employees
- Annual budget ca. 8 Mio €
  (2/3 from projects, 1/3 from donations and investment)

- Research groups:

– Biotechnology
– Chemical Engineering
– Electro Chemistry
– Aqueous Corrosion
– **High Temperature Materials**


Harsh Environments at High Temperatures
Chlorine/Chlorides
Vanadates
Sulfidation
Metal Dusting
0 200 400 600 800 1000 1200 1400
log Corrosion
Temperature [°C]
F,Cl
V
C
S
H_2O
O
N
SO_4^{2-}
NO_2^-
Cl^-

The share of renewable energy in global energy matrix



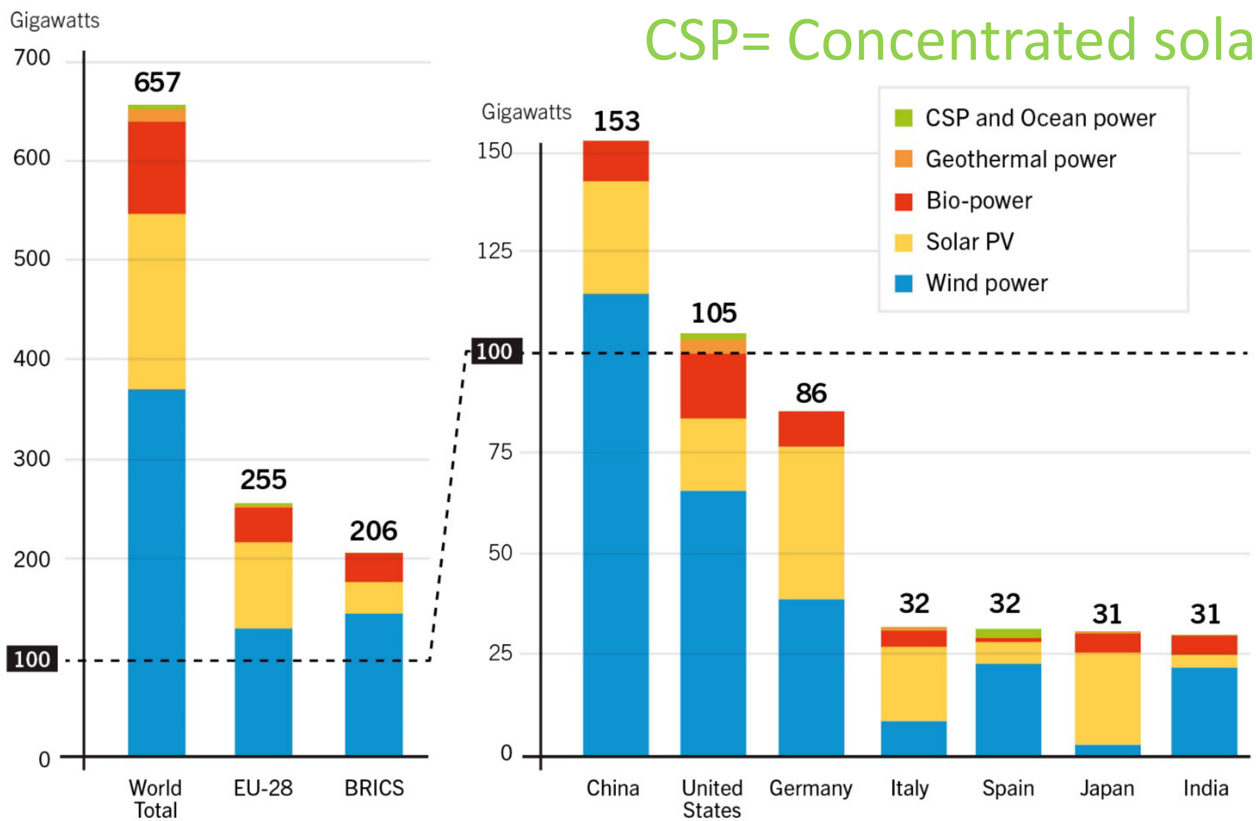
Germany: 38%

Photo: berc.berkeley.edu

The share of solar energy

Renewable Power Capacities* in World, EU-28, BRICS, and Top Seven Countries, 2014

CSP= Concentrated solar power

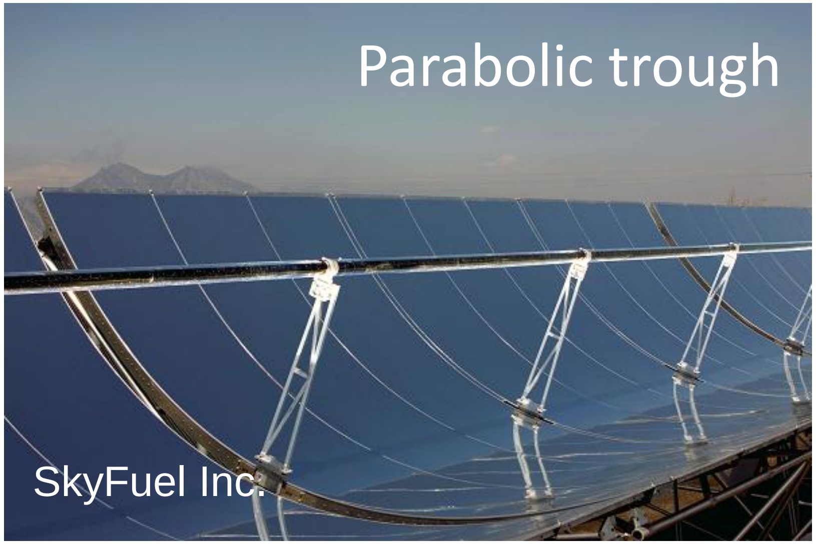


*not including hydropower

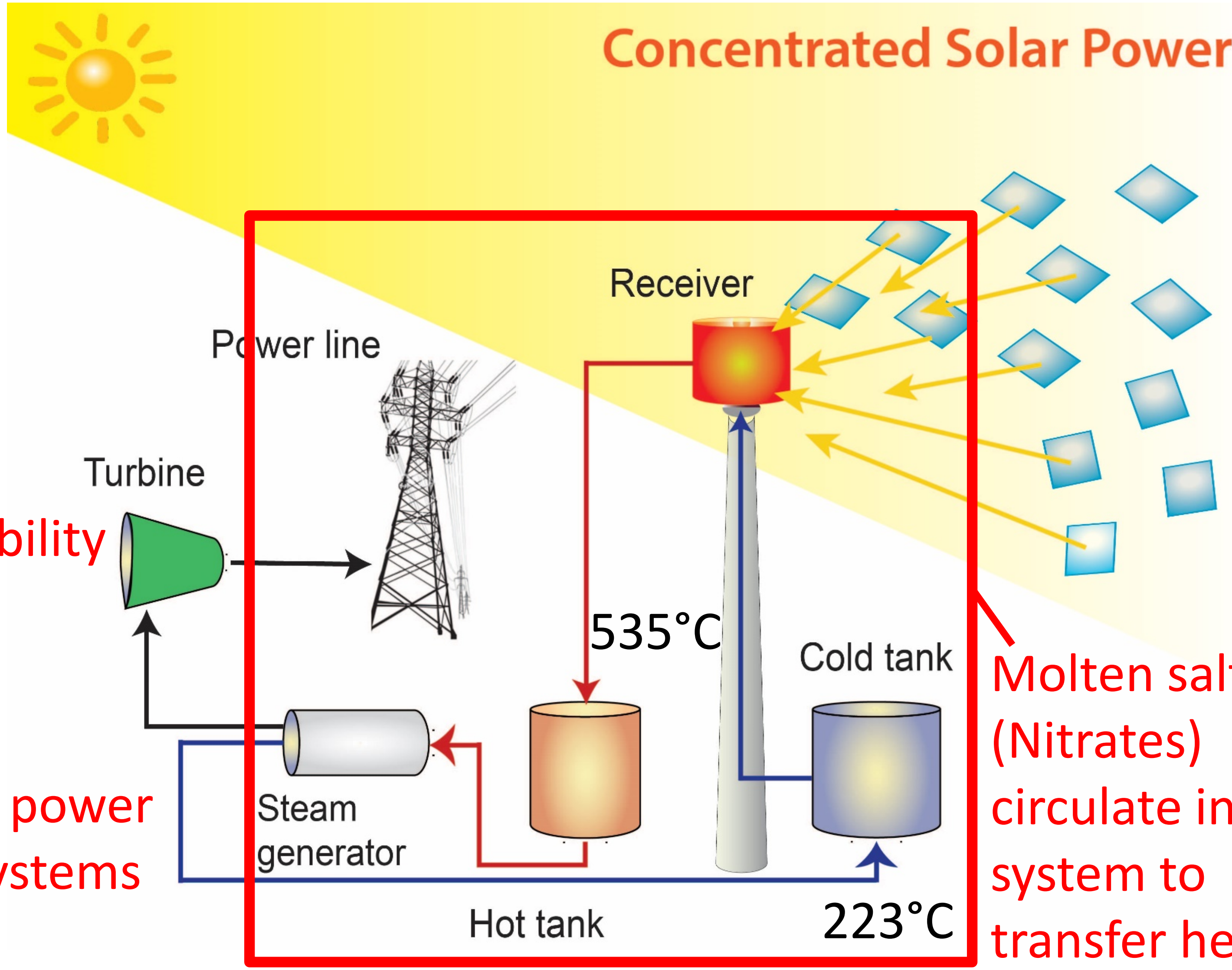
REN21 *Renewables 2015 Global Status Report*

REN21 Renewable Energy Policy Network for the 21st Century

Concentrated Solar Power (CSP)



Principles of Power Generation in a Solar Tower



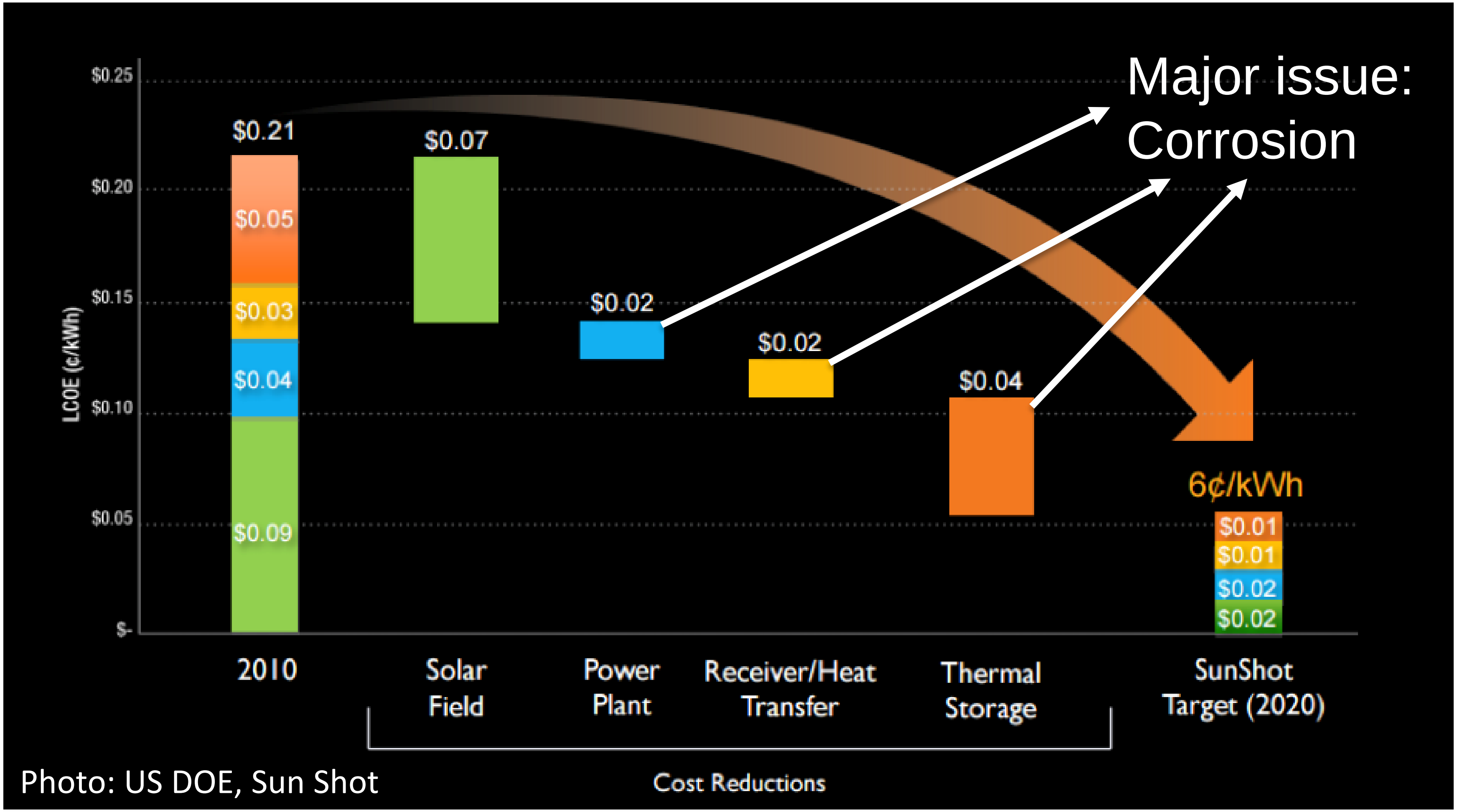
Storage capability (up to 16hrs)

Adapted for conventional power generation systems

Molten salts (Nitrates) circulate in the system to transfer heat

AS Dorcheh, MC Galetz, Solar Energy Materials and Solar Cells 146, 2016

Challenging the cost



levelized cost of energy

Objective of research

- Screening of high temperature corrosion behavior of steels and Ni-base alloys in molten salt environment
- Influence of salt impurity on corrosion behavior
- Development of solar salt corrosion resistant coatings

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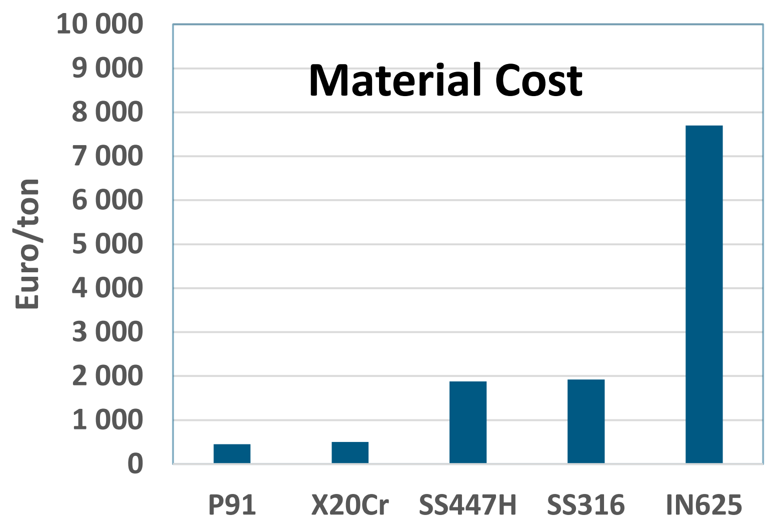
Studied materials

Alloy	P91	X20CrMoV 11-1	347HSS	316SS	IN625
Alloy type	Low-Cr Steels (ferritic-Mart.)		Stainless steel (austenitic)		Ni base alloy
Mn	0.412	0.58	1.24	1.79	0.089
Cr	**8.75**	**10.37**	**17.06**	**17.05**	**22.85**
Ni	**0.17**	**0.693**	**9.84**	**12.03**	**59.7**
Mo	0.944	0.852	0.341	2.37	8.6
Fe	88.7	86.5	70.1	65.8	3.41



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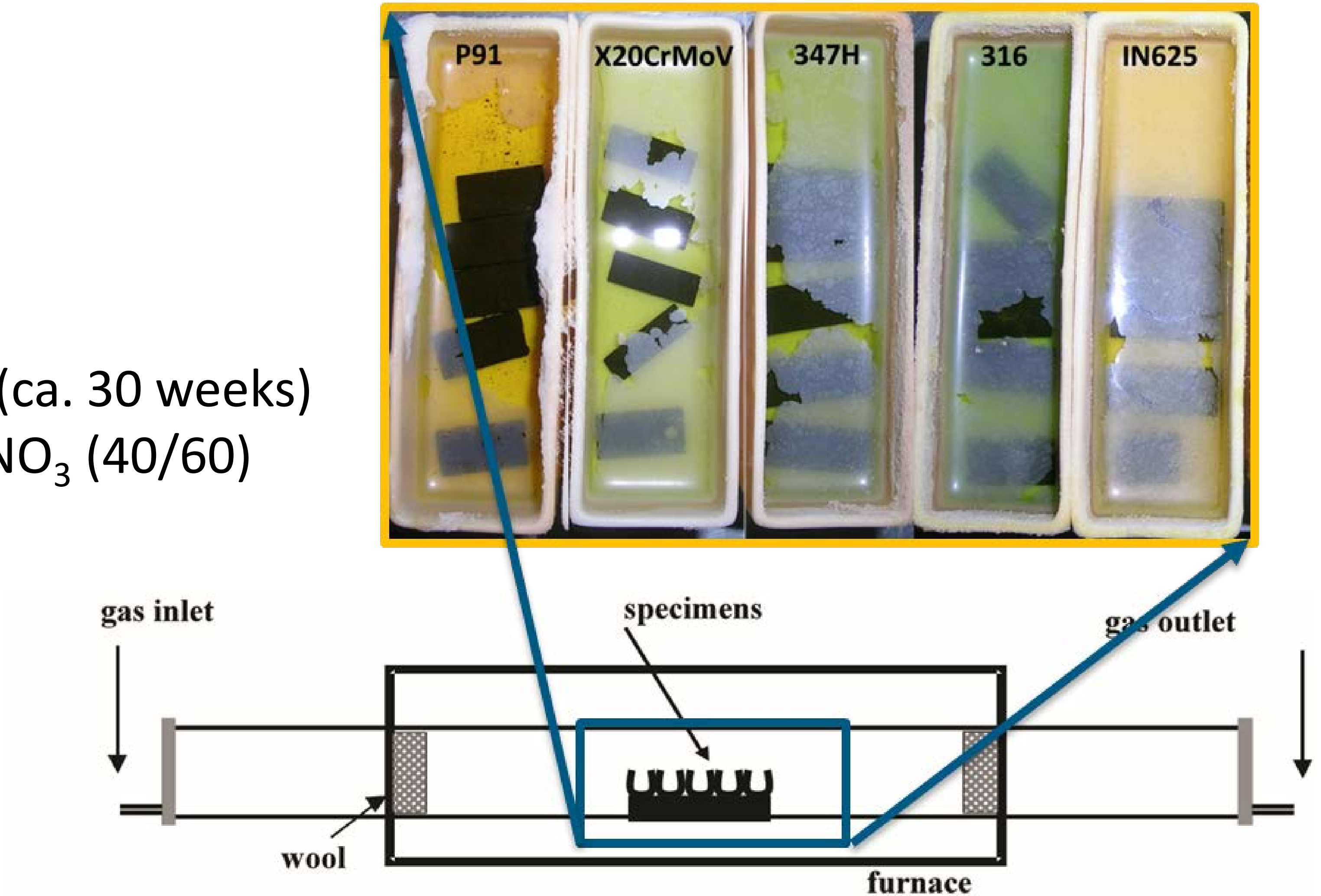
Corrosion test

T= 600°C

t= 5000h (ca. 30 weeks)

KNO_3-$NaNO_3$ (40/60)



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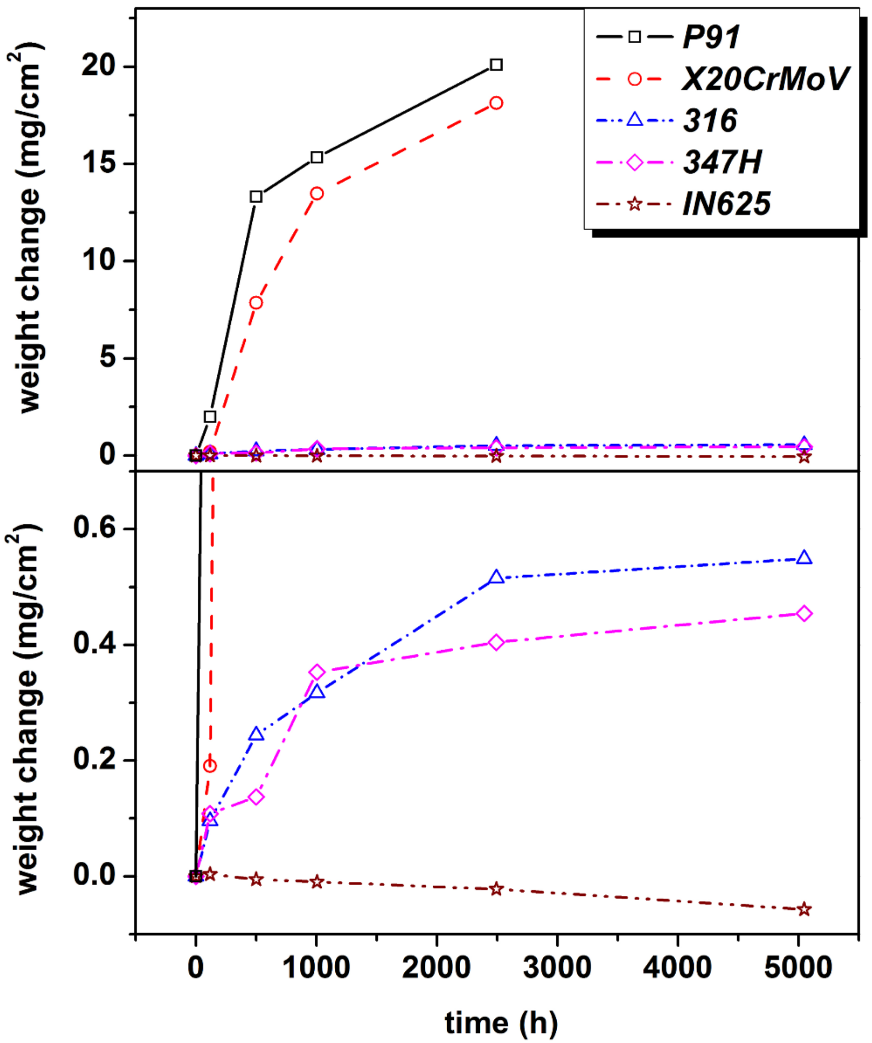
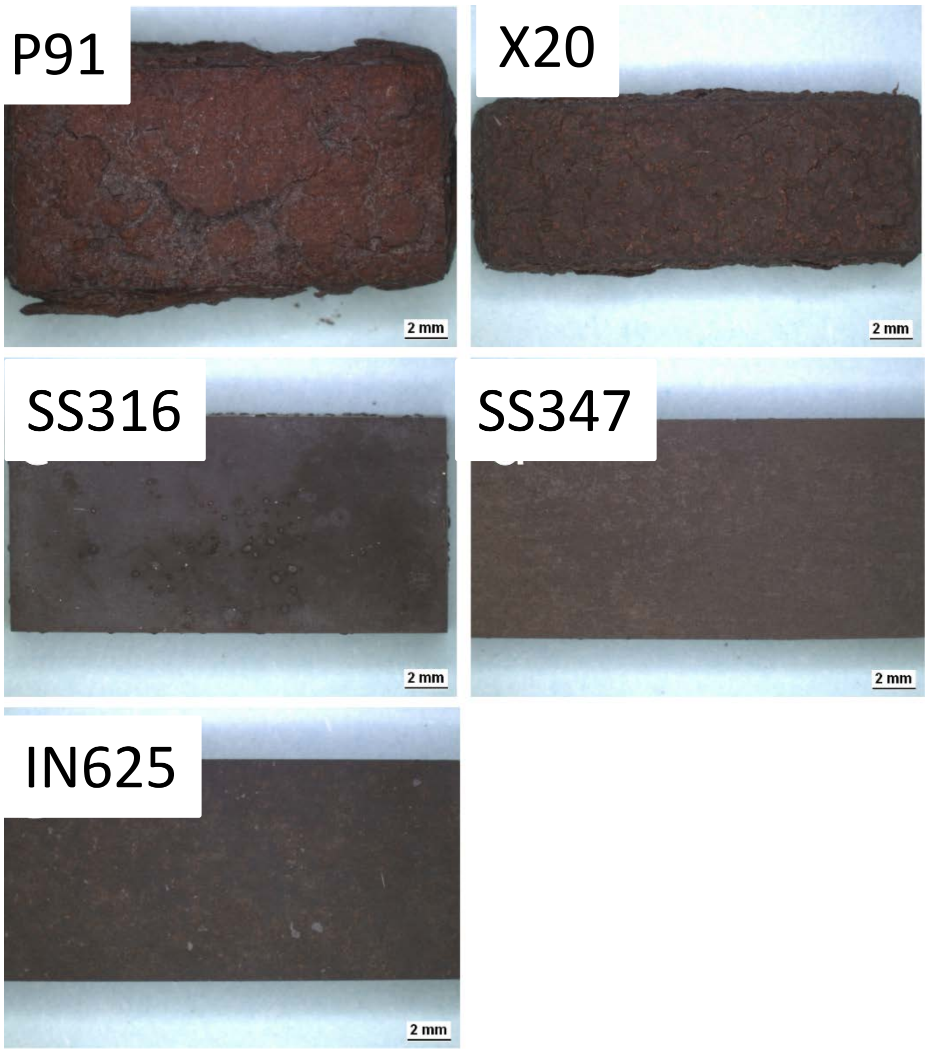
Thermogravimetry



After 2500h, 600°C, molten salt



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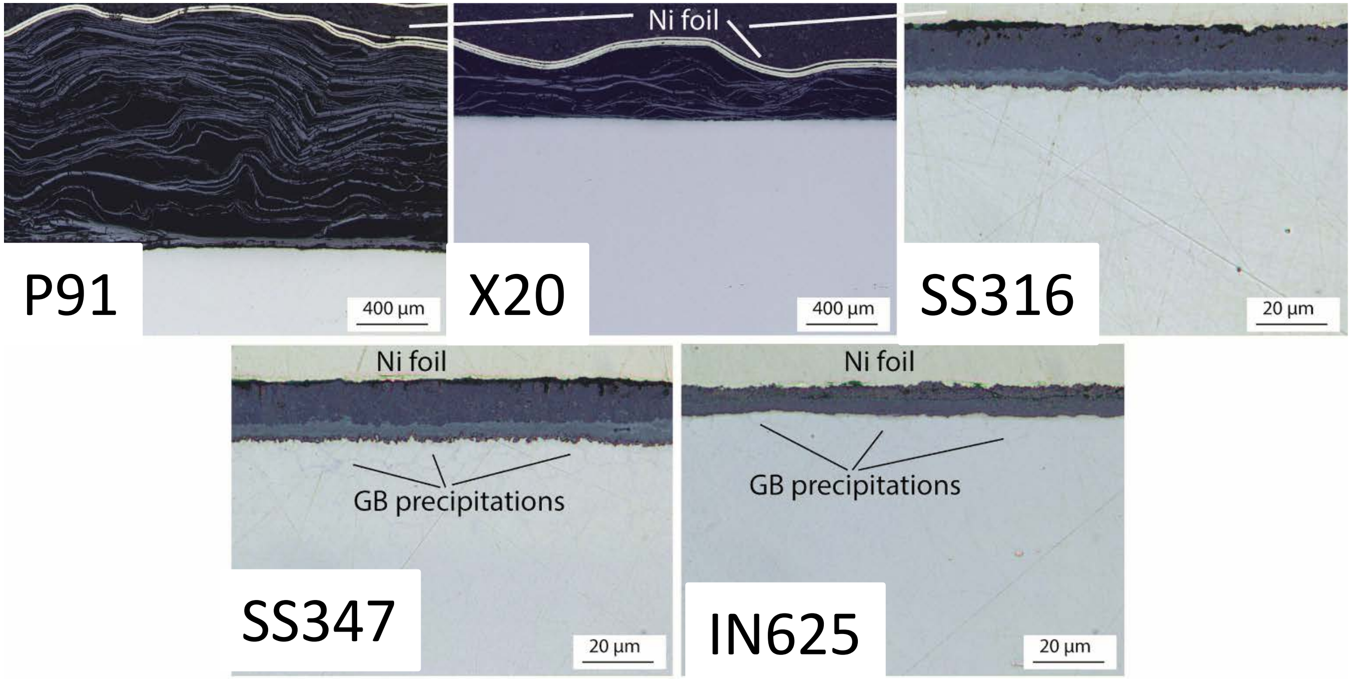
Cross-section investigation

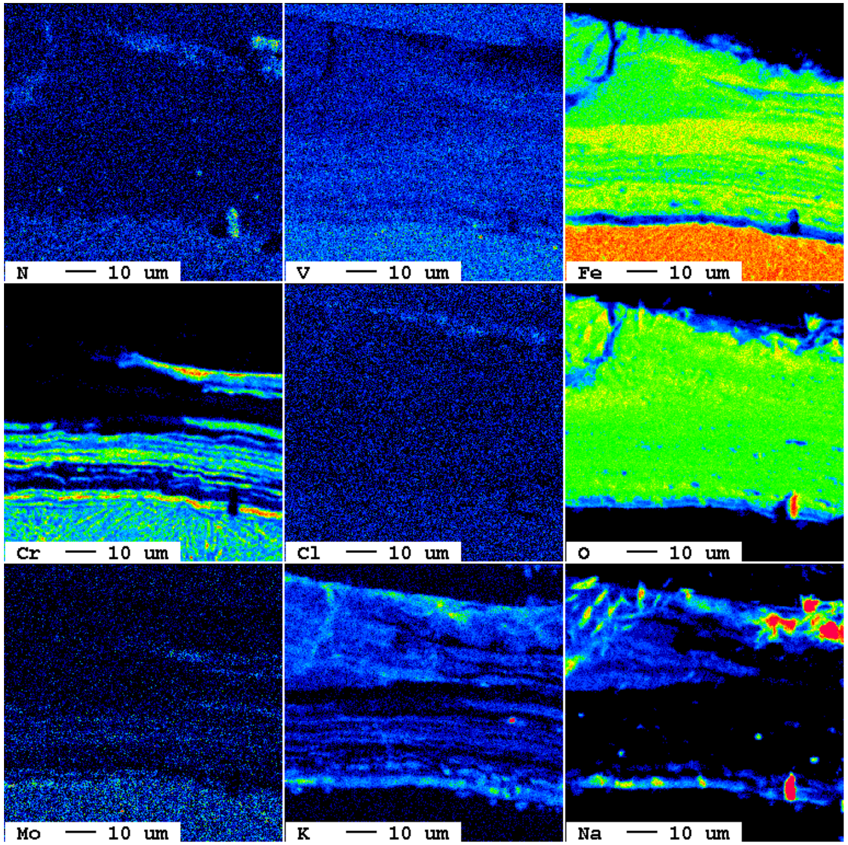


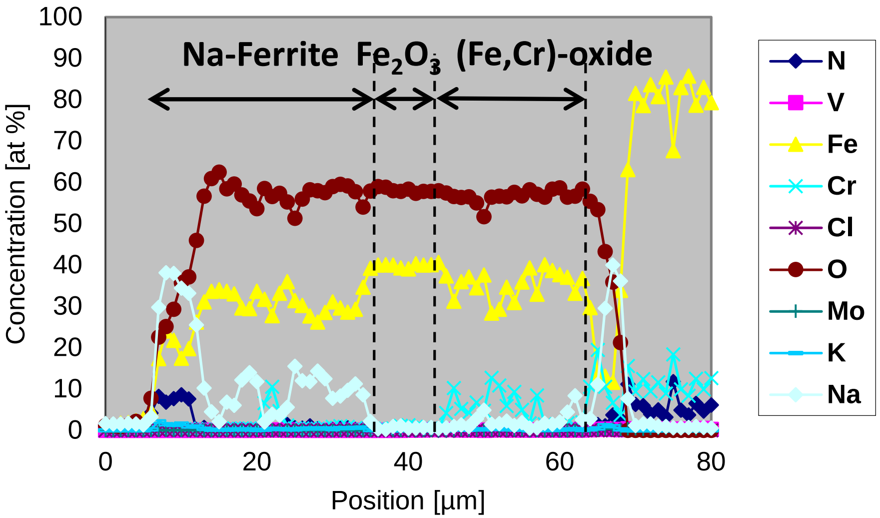
- Low-Cr steels (9, 11%) showed porous and multilayered scale morphologies showing a poor adherence to the metal surface

- Stainless steels and Ni-base alloy formed a thin, compact and well adhered oxide scales protective against molten salt corrosion for up to 5000h.

Corrosion products

Low Cr steel X20, After 1000h

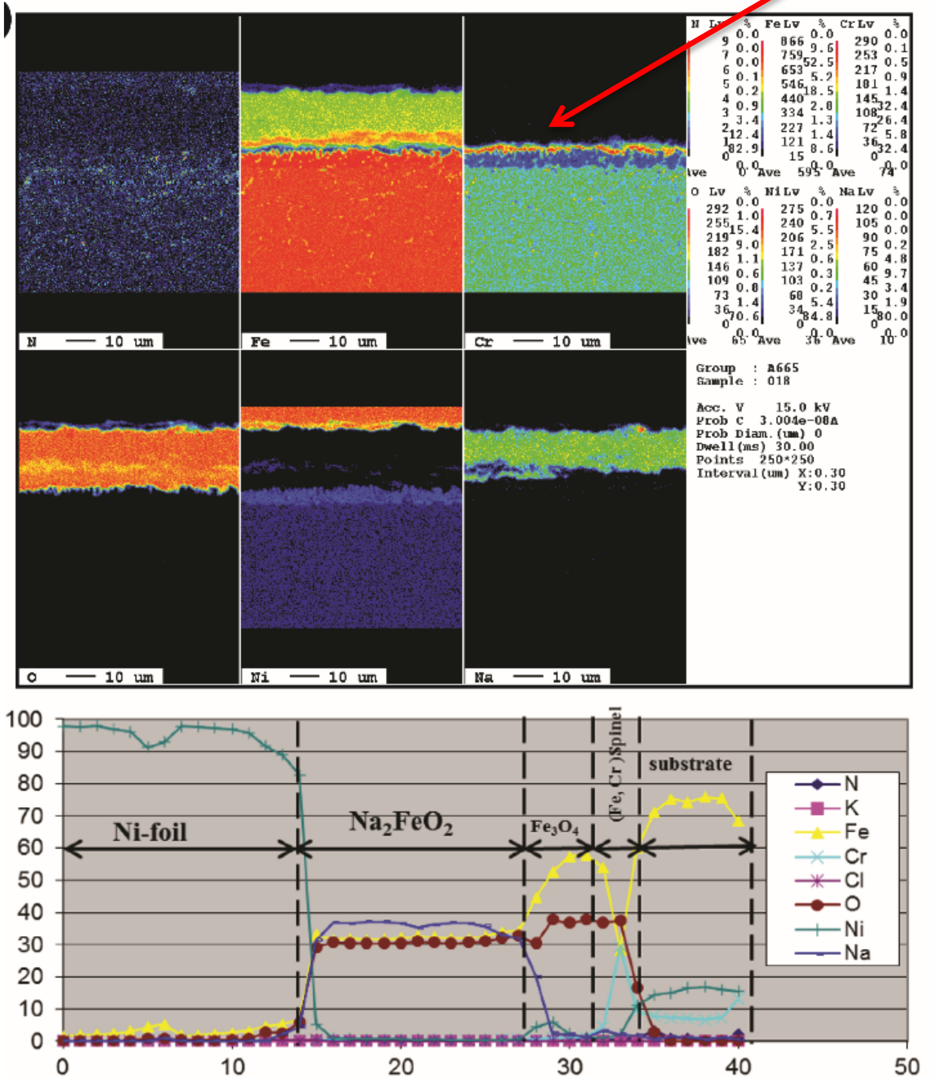




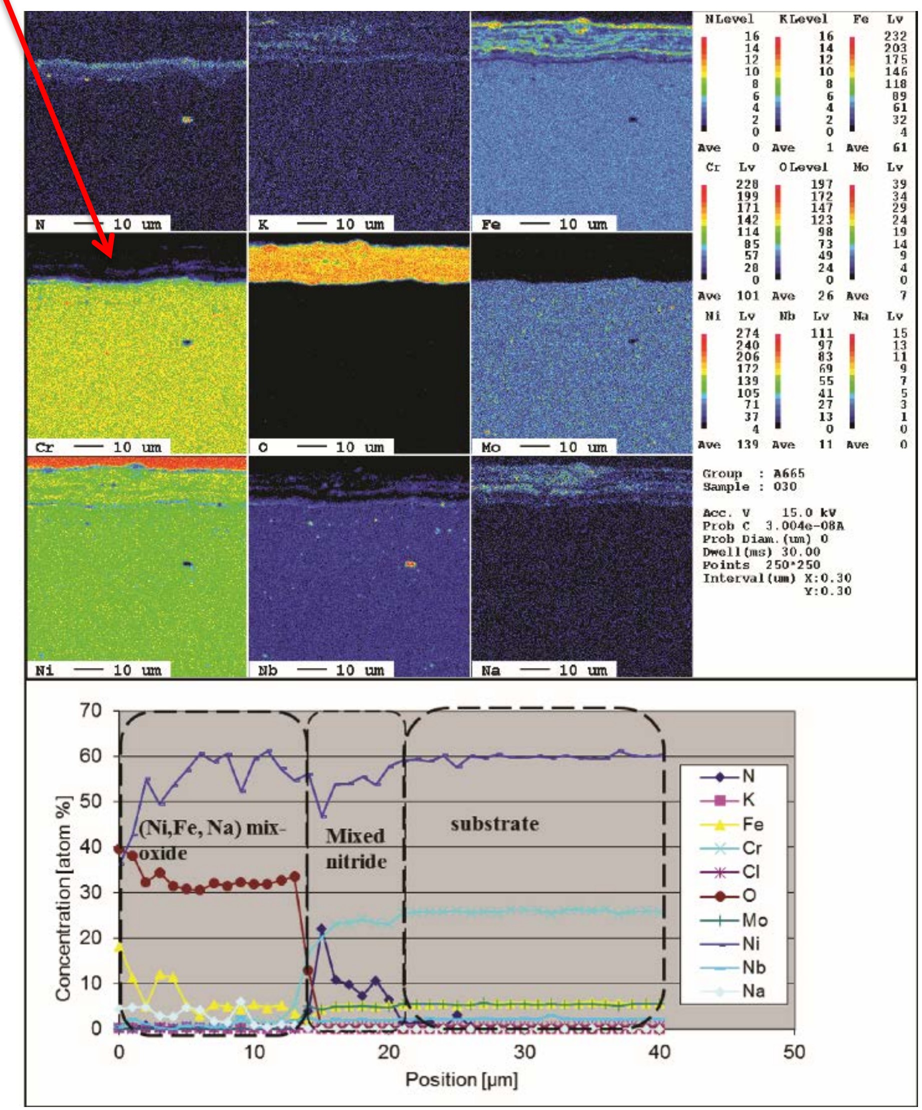
Corrosion products

Cr

Stainless steel 347H



Ni-base alloy, IN-625



† *trade name*

Objective of research

- Screening of high temperature corrosion behavior of steels and Ni-base alloys in molten salt environment
- Influence of salt impurity on corrosion behavior
- Development of a solar salt corrosion resistant coatings

The influence of chloride impurities

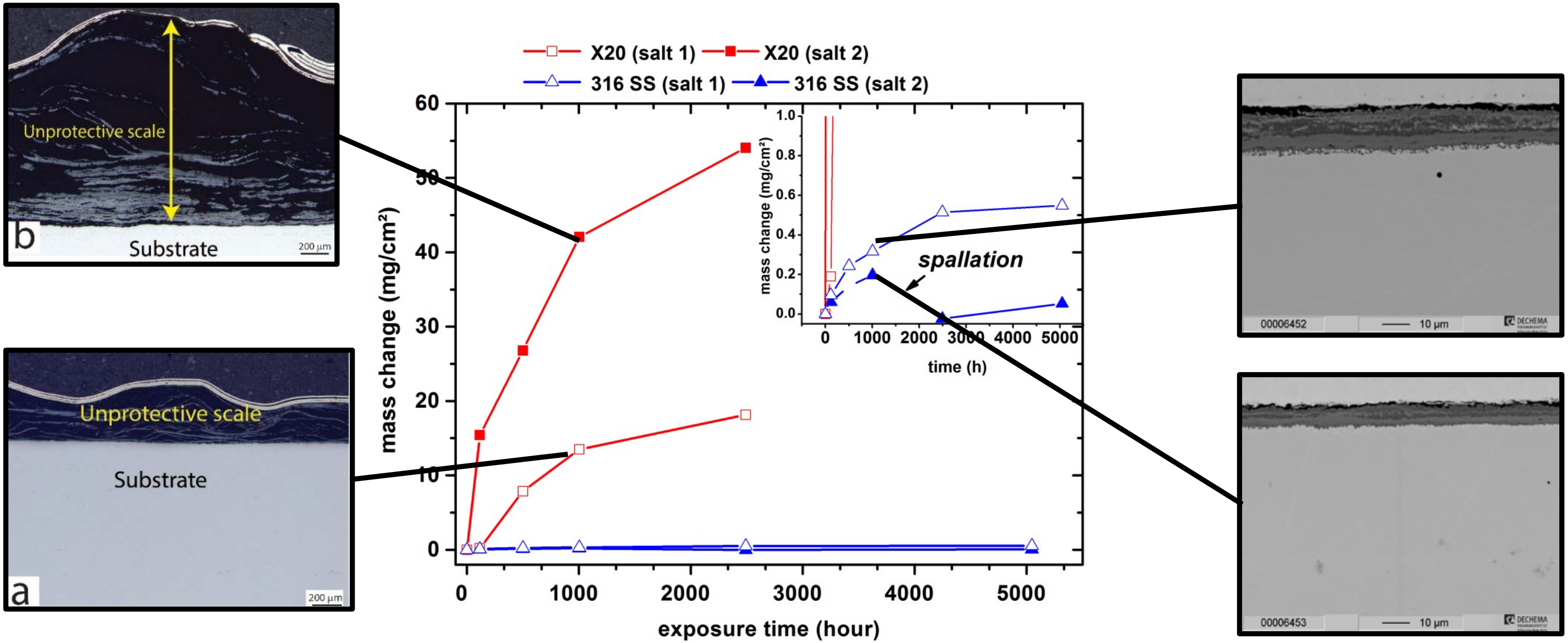
Studied materials

Alloy	X20CrMoV 11-1		316SS
Alloy type	Low-Cr Steels		Stainless steel
Mn	0.58	1.24	1.79
Cr	**10.37**	**17.06**	**17.05**
Ni	**0.693**	**9.84**	**12.03**
Mo	0.852	0.341	2.37
Fe	86.5	70.1	65.8

Salt impurities

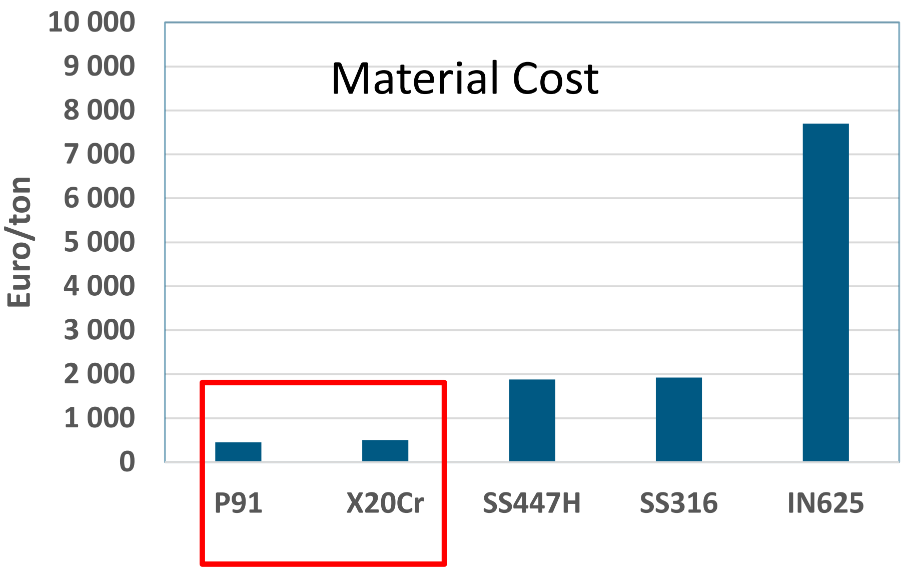
Impurity	Salt 1	Salt 2
	(wt %)	(wt %)
Nitrite (NO^{2-})	<0.01	<0.02
Chloride (Cl^{-})	<0.02	<0.25
Magnesium (Mg^{2+})	<0.0007	<0.05
Carbonate (CO_3^{2-})	<0.1	<0.1
Sulphate (SO_4^{2-})	<0.01	<0.1
Insolubles	<0.01	<0.05
Moisture	<0.2	<0.1

Corrosion rate vs. Impurities

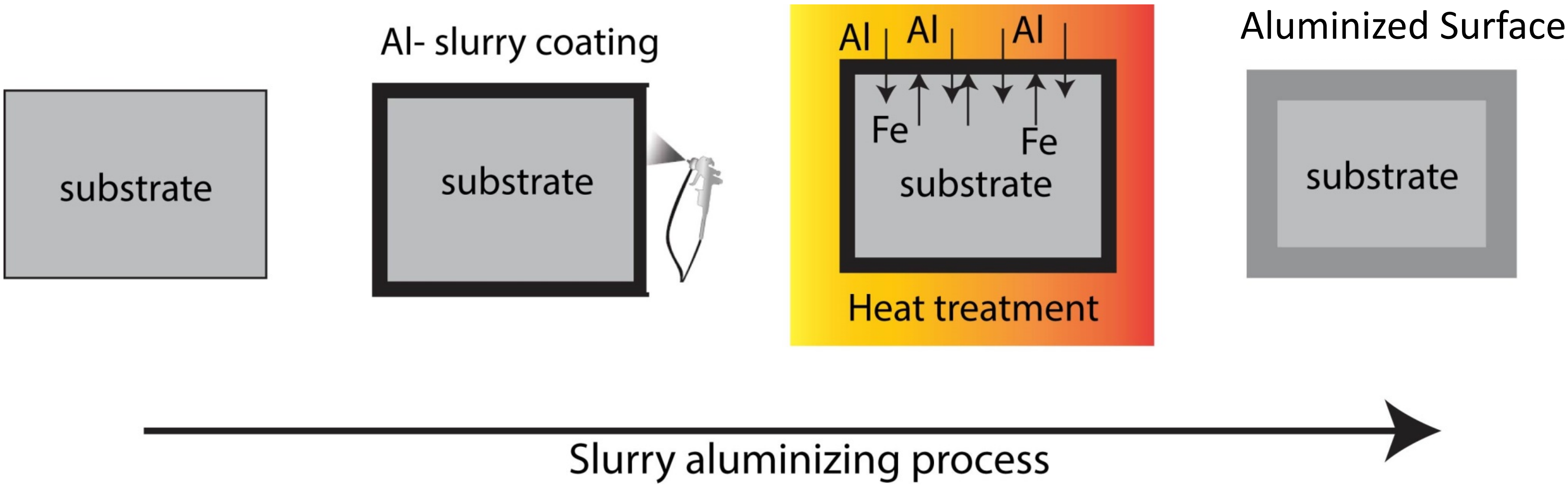


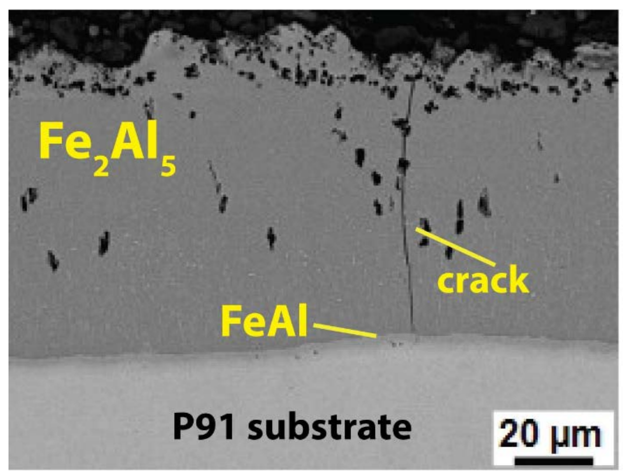
- Accelerated corrosion of X20 Steel in high chloride salt
- Significant resistance of 316SS vs. steel X20
- Lower weight gain of 316 SS in high chloride salt! (spallation/dissolution of the corrosion products? More adherent scale? Less Cr leached due to stable Chlorides?)

Can low-Cr steels be protected in molten nitrates?

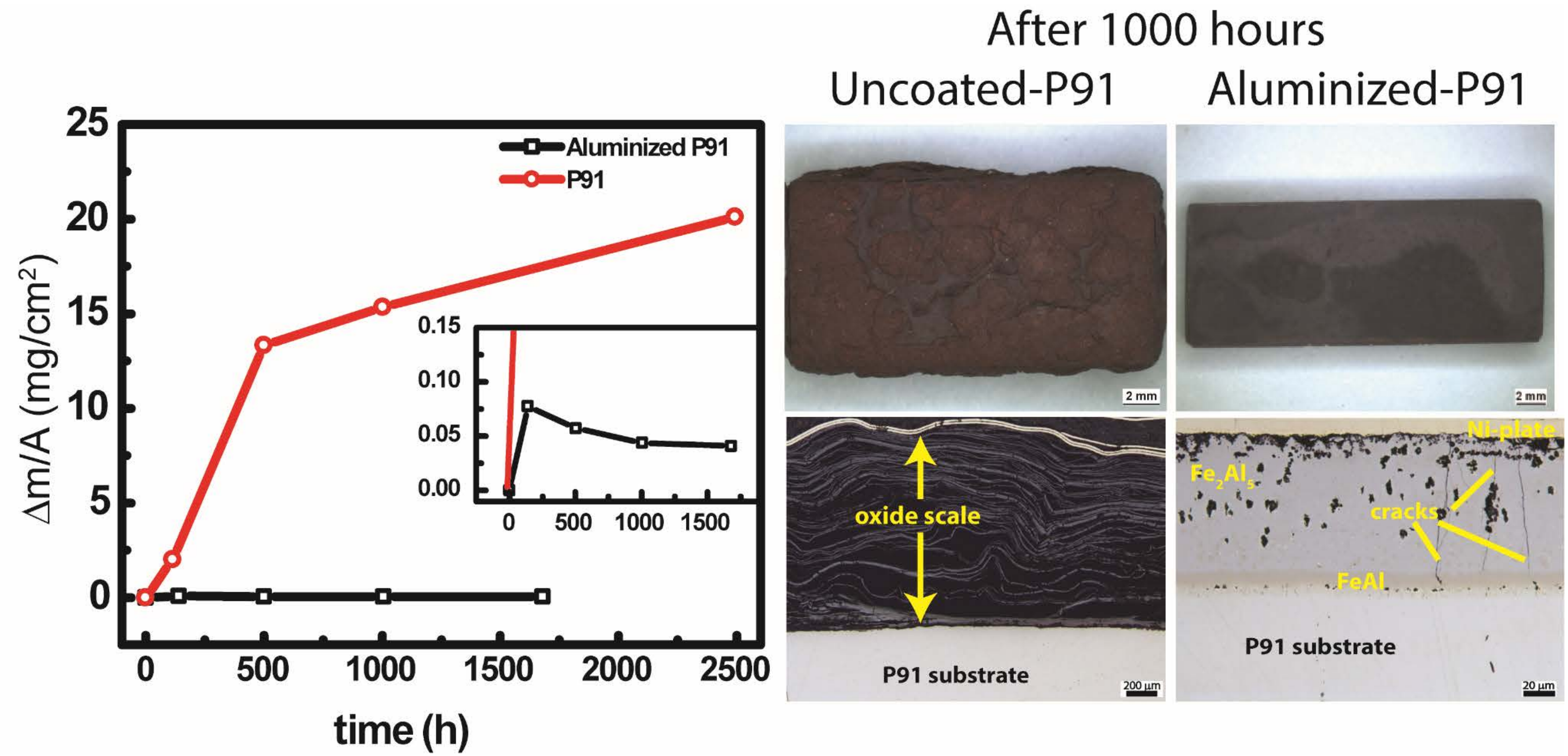


Aluminizing process





Corrosion performance



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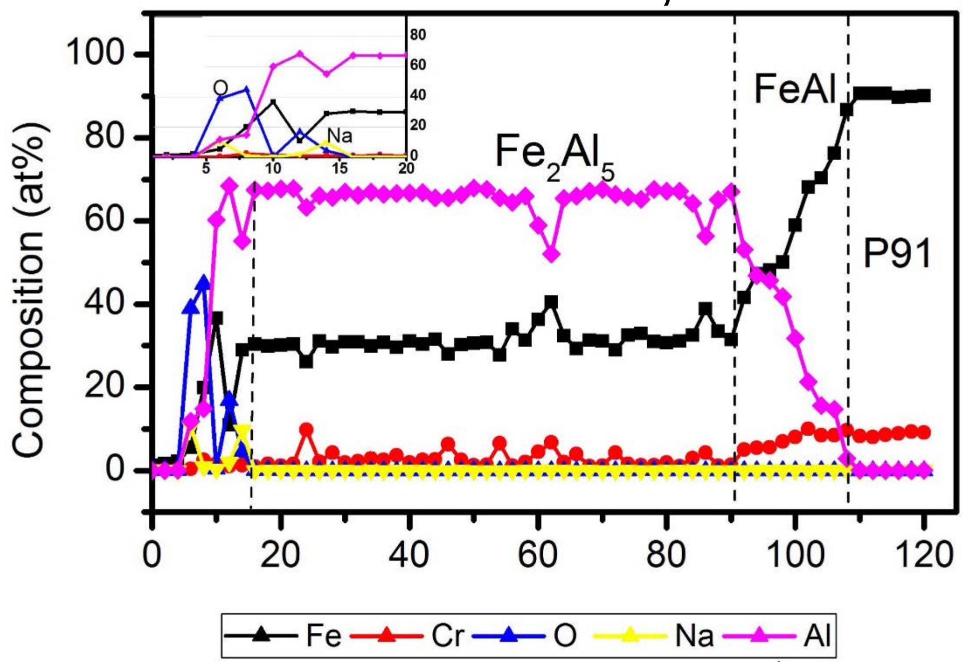
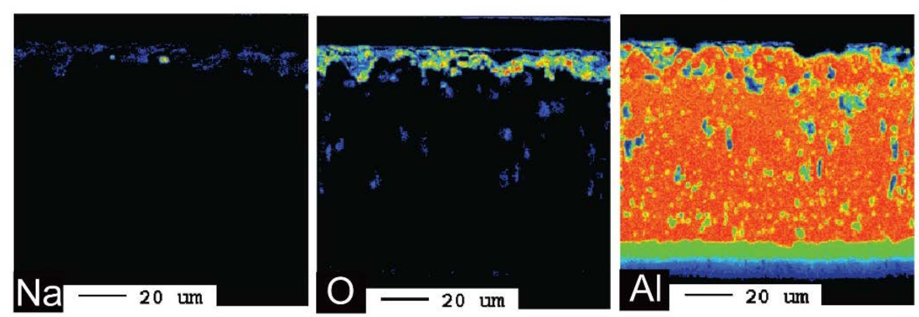
Corrosion performance –Aluminized P91

- The aluminide coating is in contact with the molten salt during the corrosion test
- A continuous thin Al-rich oxide formed on the surface
- No sign of salt attack is observed

After 1000h, 600°C





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Conclusion : Material selection

- ❑ Low chromium steels do not offer protection in molten salt environments – even worse with impurities
- ❑ Ni-base alloys perform best in molten salt environment and forms a Ni-rich oxide (price issue)
- ❑ Cr is leached from the scale – not protective in such salts!
- ❑ Stainless steels show protective behavior via formation of a slow growing, well adhered, compact sodium ferrite scale
- ❑ Aluminisation can offer an affordable protection

Outlook: Tripelpiont, outside of the tube: absorbtion, emittance, erosion

Thank you for your attention

For details please refer to:

A. Soleimani Dorcheh, R.N. Durham, and M.C. Galetz, Solar Energy Materials and Solar Cells, 144 (2016)

A. Soleimani Dorcheh and M.C. Galetz, Solar Energy Materials and Solar Cells, 146 (2016)

Ivanpah Solar Power Plant, CA, USA
173000 Mirrors
400 MW Capacity
Photo: Jamey Stillings, NY Times

SS316 in Salt 1 vs Salt 2