Electrochemical characterisation speeds up prediction of corrosion behaviour

E.W. Schuring
J.W. Hooijmans

April 2013
ECN-L--13-034

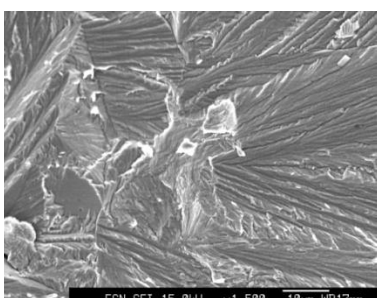
Electrochemical characterisation speeds up prediction of corrosion behaviour

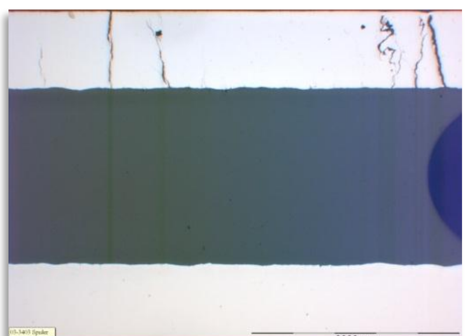
E.W. Schuring
J.W. Hooijmans

Environment and Energy Engineering;
Stand 48

Content

- Introduction
- Corrosion in real life
- Why Electrochemical characterisation of corrosion
- Applications
  - corrosion resistance coatings
  - corrosion behaviour (brazed) joints
- Available electrochemical corrosion techniques
- Standards
- Conclusions

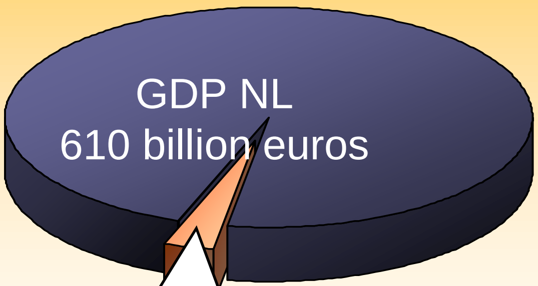




Corrosion in real life

Current status

- Unplanned failures due to corrosion damage



Direct annual costs due to corrosion: 18.3 Billion Euros (3%)

Early detection of corrosion phenomena

Barrier quality

Knowledge processes

Materials selection

Knowledge development:

Degradation processes

Monitoring

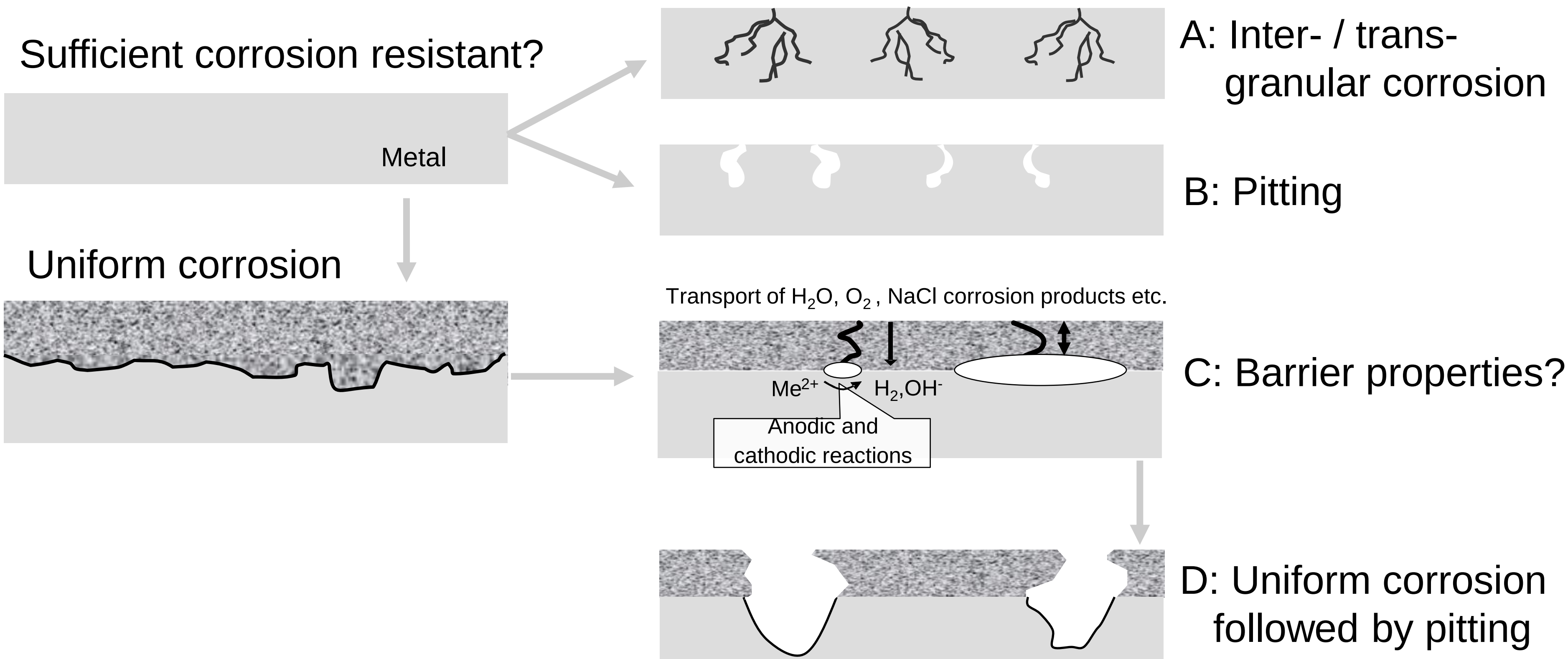
Materials

Safety
+
Environment

*20-30% reduction could be achieved using existing knowledge. New technologies enable further reduction.

Corrosion in real life

Corrosion mechanisms



Why electrochemicl characterisation?

- Standard test methods like salt spray testing are expensive and need long exposition times
- Standard characterisation can lead to unrightfull acceptance

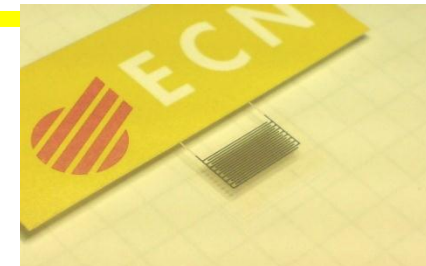
NEED FOR FAST & REALIABLE CORROSION CHARACTERISATION

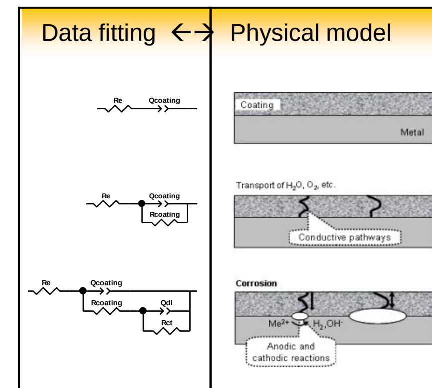
- Failure prediction for end-users (more sensitive than other methods)
- On-site electrochemical characterisation measurements in tanks and on pipeline coatings
- Determine time dependent quality and barrier properties of coatings
- Reduce testing time
- Get insight in acting corrosion mechanisms

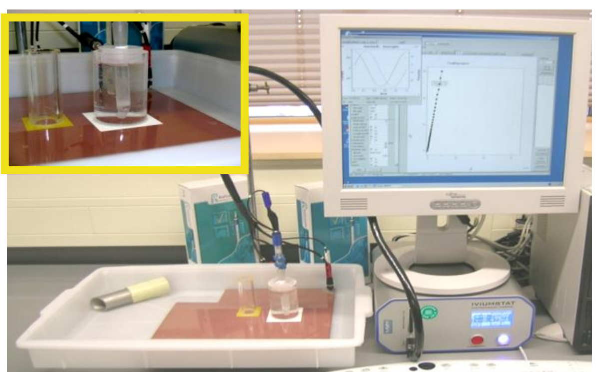
Methods for corrosion testing

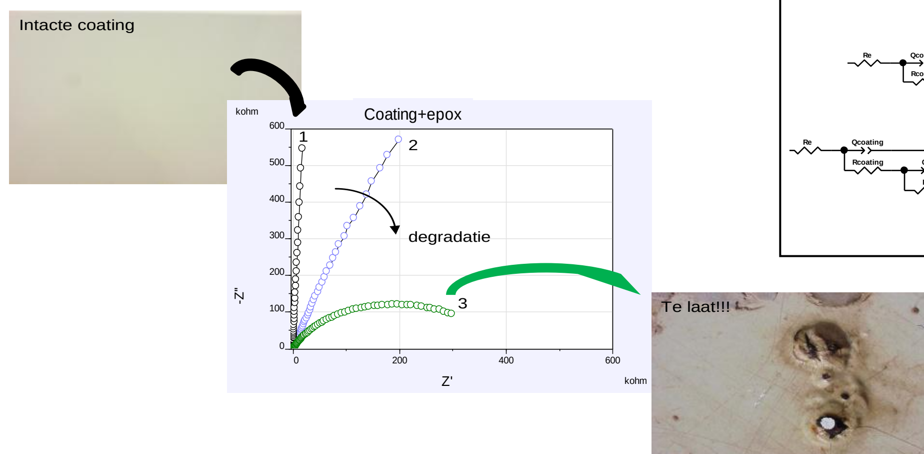
Electrochemical Corrosion testing

- Barrier properties
- Corrosion rate
- Time-to-failure prediction
- Sensors
- Development accelerated corrosion test methods



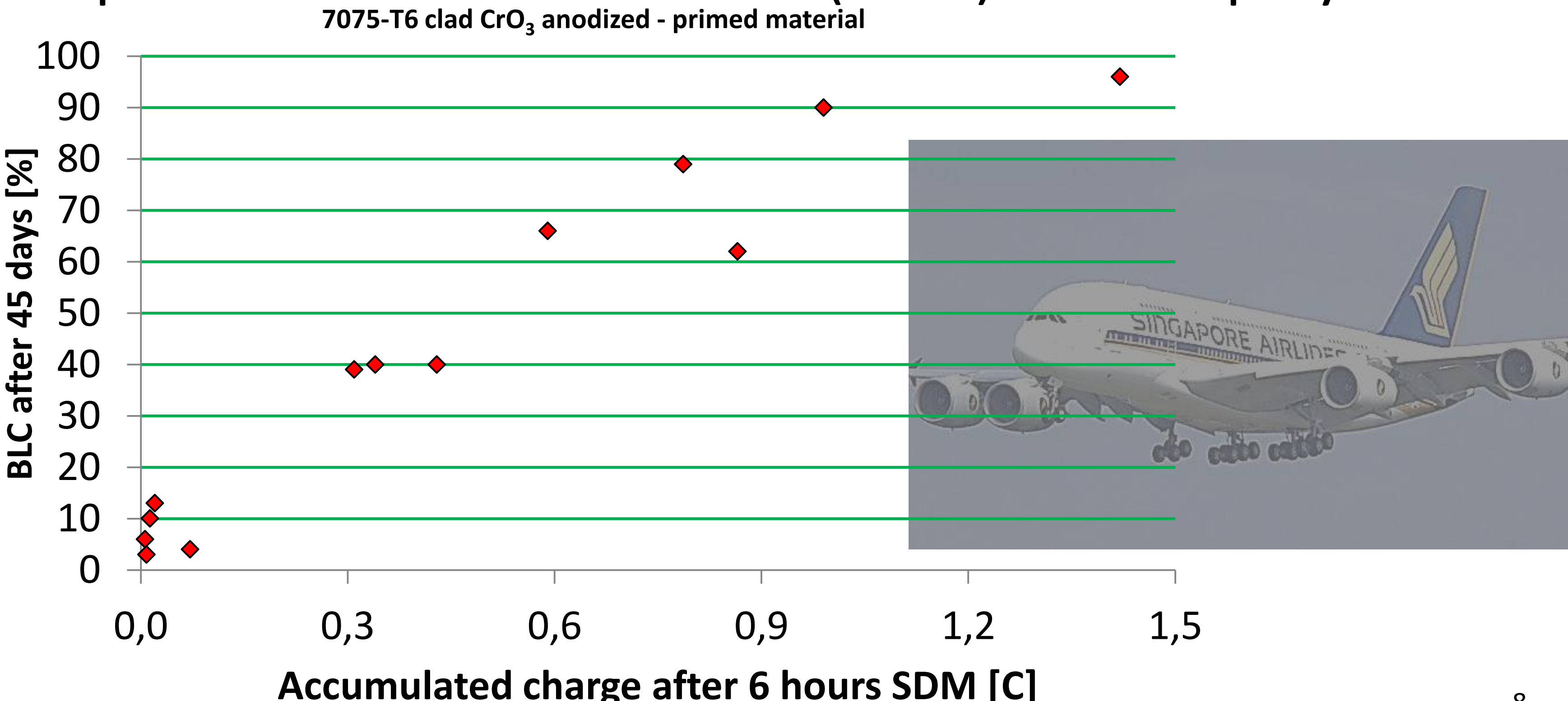






Application (SDM): Accelerated Corrosion resistance test coatings

Stepwise Dissolution Method (SDM) vs Salt spray-BLC



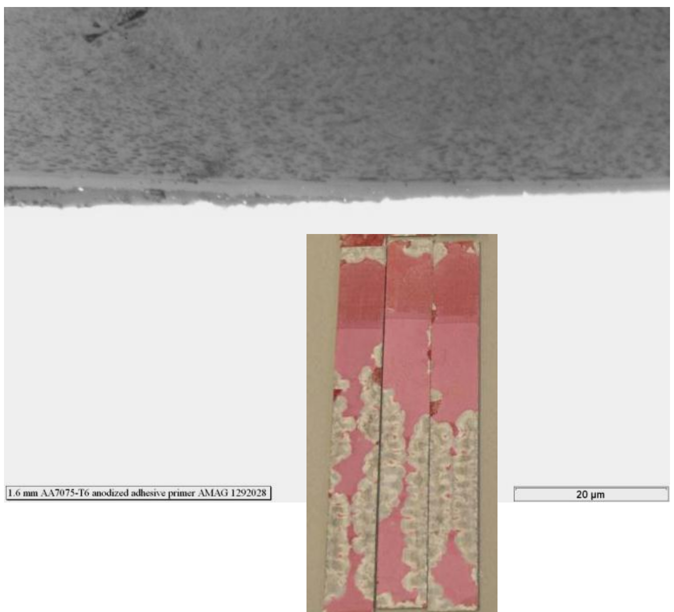
Application (SDM): Accelerated Corrosion resistance test coatings

Comparison between BLC and SDM – Both show wedging of anodic coating

BLC (45 days)

SDM (6 hours)

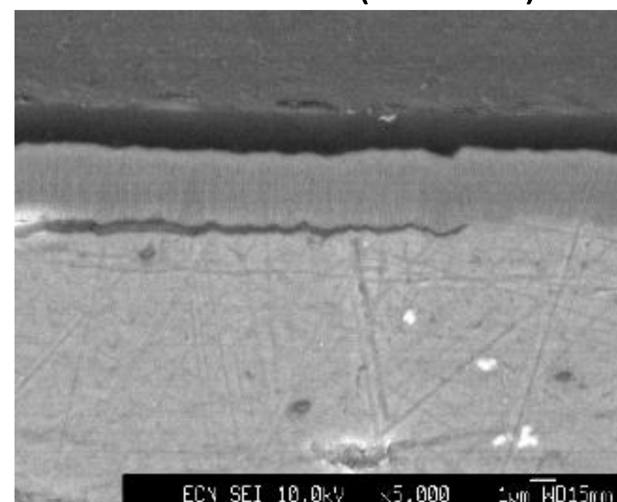
Exposure side



Embedding mass

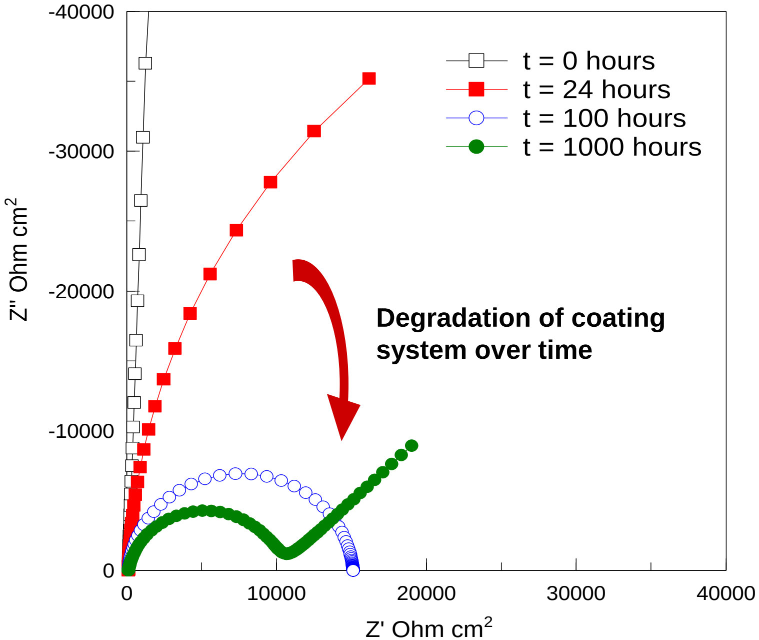
Anodic coating

Aluminum substrate



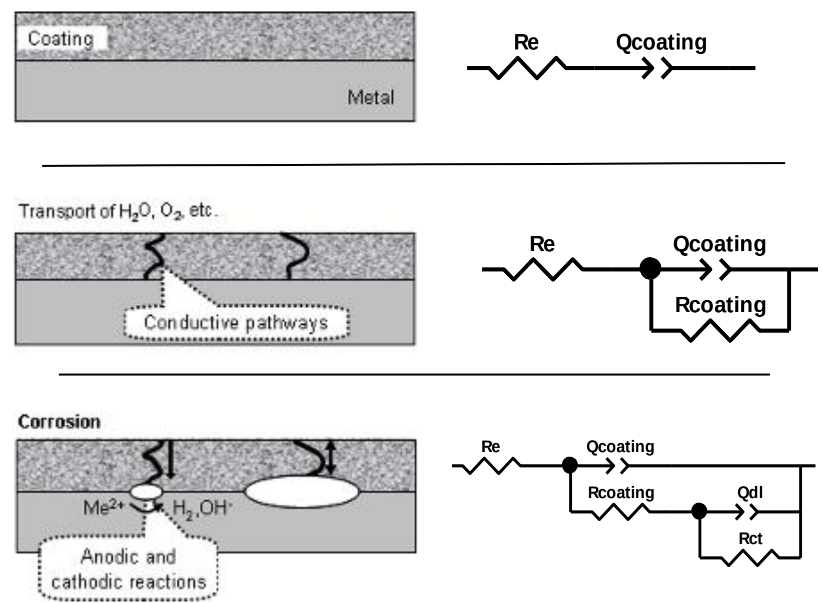
Application (EIS):
Corrosion resistance coatings

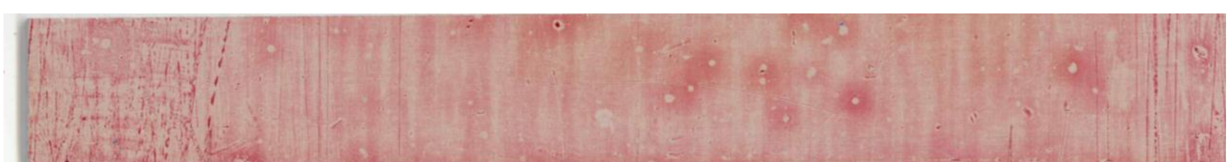
EIS measurements of organic coating



Physical interpretation

Equivalent circuits





Application (PC, OCP, SDM): Corrosion resistance brazed joints

Problem:

Acceptance of brazed joints in heating appliances

Experience:

Brazed joints were accepted after standard corrosion testing, Salt spray testing.

Catastrophic failure in surface due to ‘knife line’-type attack which was not recognised in standard acceptance tests

Result:

User rejects brazed joints in his application(s), although wrong material combinations were originally applied

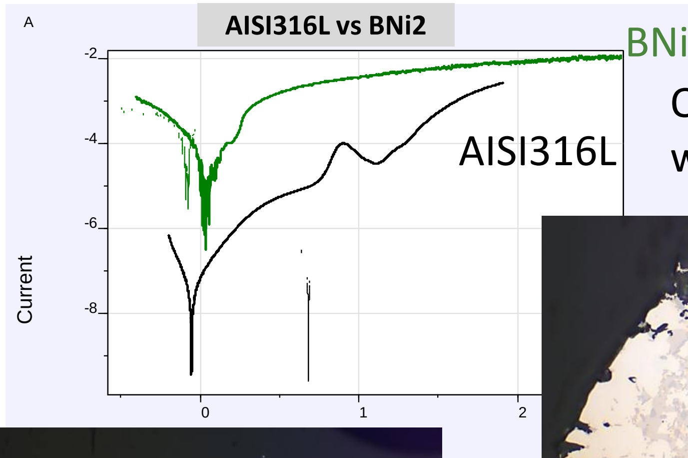
Consequence:

Limitations in design and optimisation

Solution:

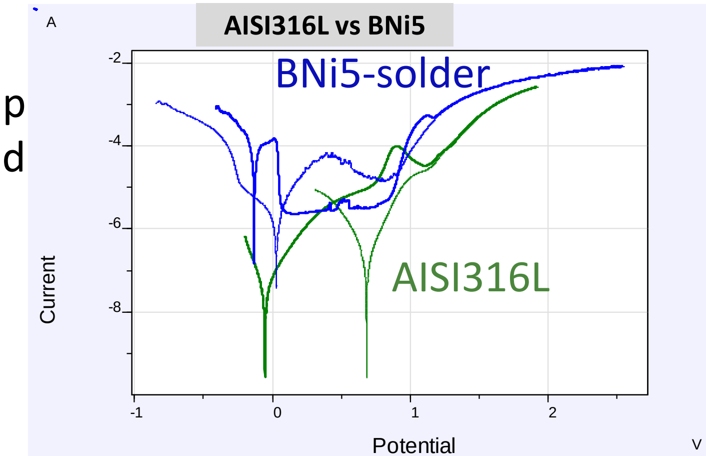
Determine corrosion mechanisms and apply accelerated tests in applicable environments comparing accepted concept and new (brazed) concept

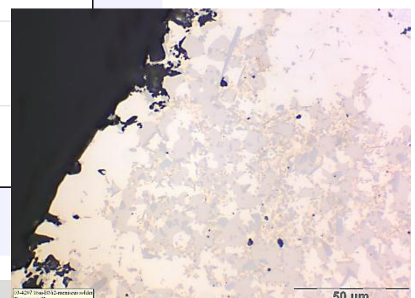
Application (PC, OCP, SDM): Corrosion resistance brazed joints

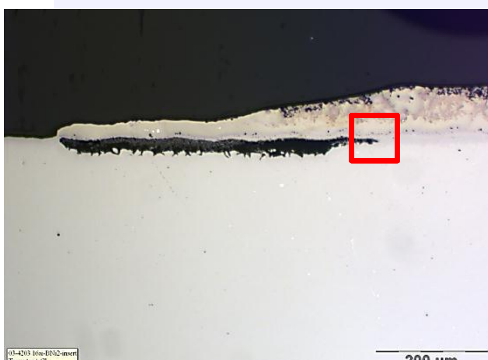


BNi2-solder

OCP in Chlorinated tap water @ 60°C, aerated



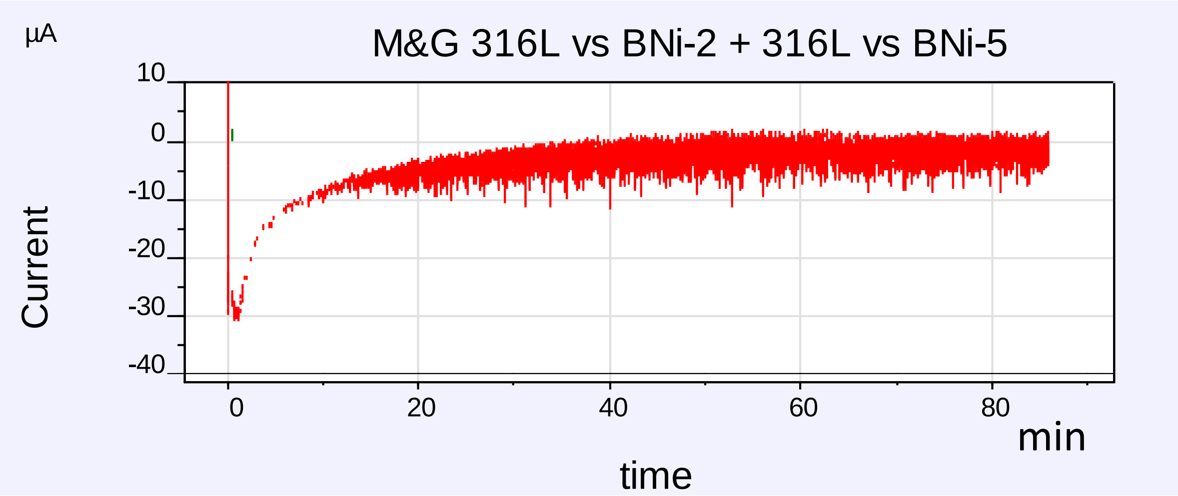




Not recognised in Salt Spray test

Application (PC, OCP, SDM): Corrosion resistance brazed joints

Coupling tests 316L vs B-Ni 5: Highly electrochemically stressed



------: B-Ni 2

------: B-Ni 5

Artificial condensate

Aerated @ 60 °C

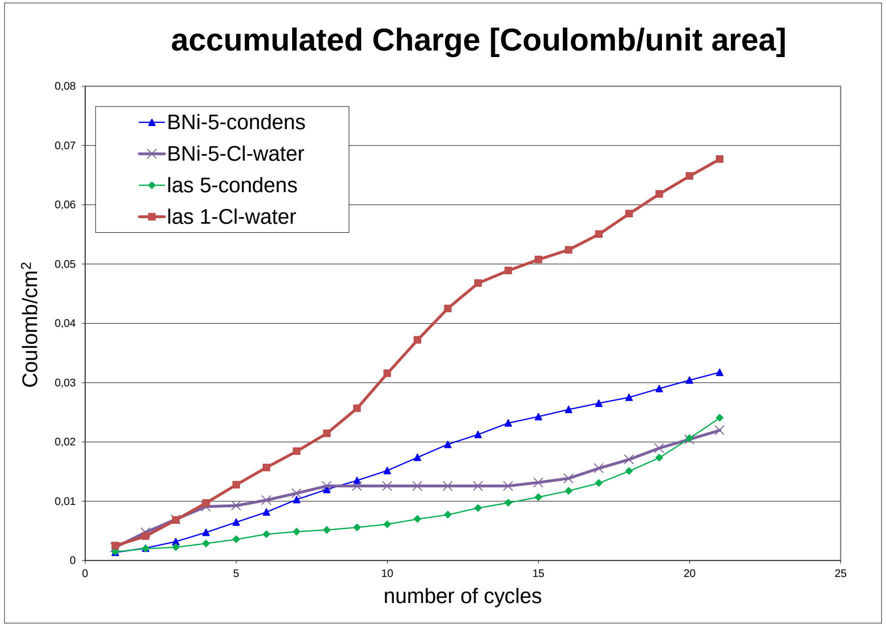
B-Ni 2 high coupling current

B-Ni 5 very low coupling current

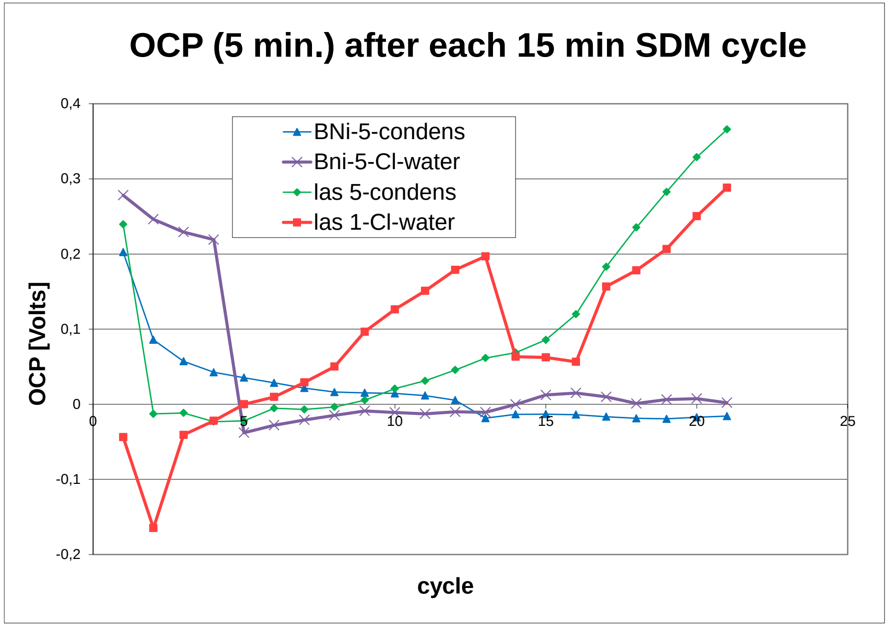
Active behaviour of BNi2 → corrosion

Application (PC, OCP, SDM): Corrosion resistance brazed joints

Stepwise Dissolution Measurement (SDM)



Open Corrosion Potential (OCP)



Test conditions of BNi5 brazed and laser welded joint in AISI316L:

- Artificial condensate: Cl-30mg/l; NO_3-300mg/l; SO_4-50mg/l (@ 85°C, (5.5h)
- Chlorinated tap water: 250ppm Cl @60°C (5.5h)

Methods for corrosion testing

Various method Corrosion measurements:

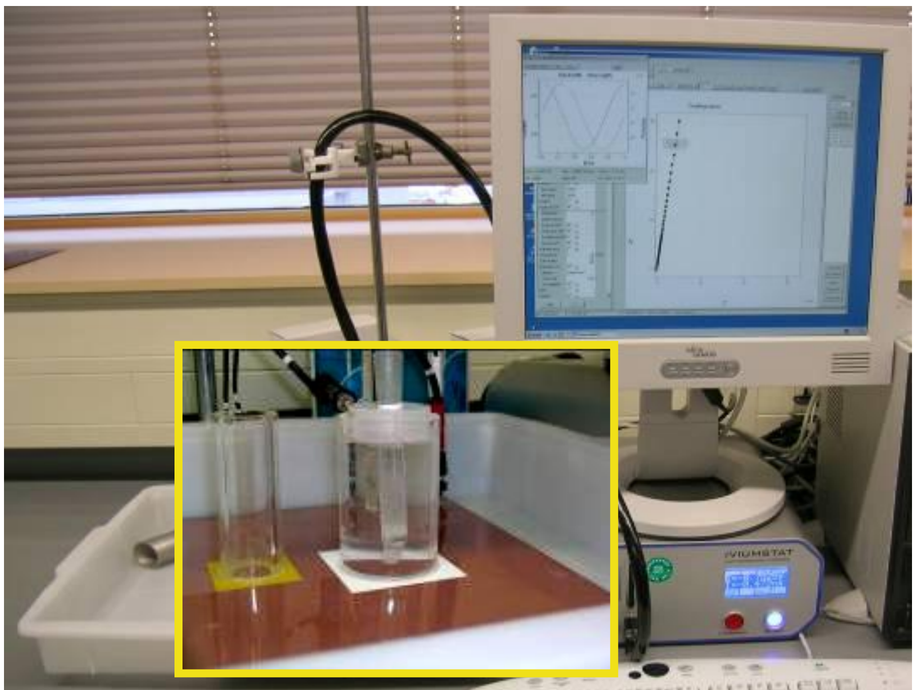
- Corrosion tests to standards (ASTM, ISO; Salt Spray, Stress Corrosion, Pitting) normally long term testing

- Electrochemical techniques (various conditions):
  Screening
  - EIS (Electrochemical Impedance Spectrometry)
  - ECN (Electro Chemical Noise)
  - PC (Polarisation Curve)
  - Couple test

  Accelerated testing
  - AAD (Accelarated Anodic Dissolution)
  - SDM (Step Wise Dissolution Measurement)

Methods for corrosion testing

Corrosion measurements: EIS



Corrosion measurement technique

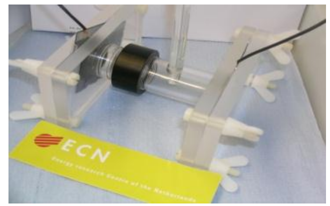
EIS = Electrochemical Impedance Spectroscopy

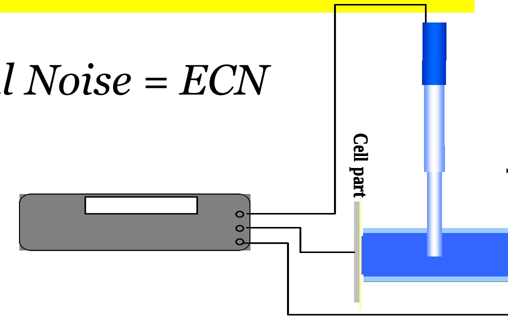
- Sensitive measurement technique
- Data analysis by equivalent circuit modeling
- Determining underlying physical behaviour
- Determine barrier quality in time
- Quick measurement technique (hours)
- Online monitoring possible

Typical for coating systems

Methods for corrosion testing

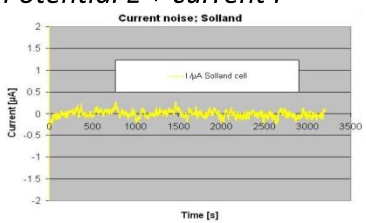
Corrosion resistance screening: *Electro Chemical Noise = ECN*

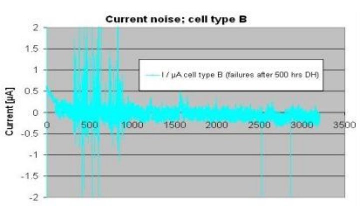




Measurement data;	Data analysis	Environmental resistance

Potential E + current I





E

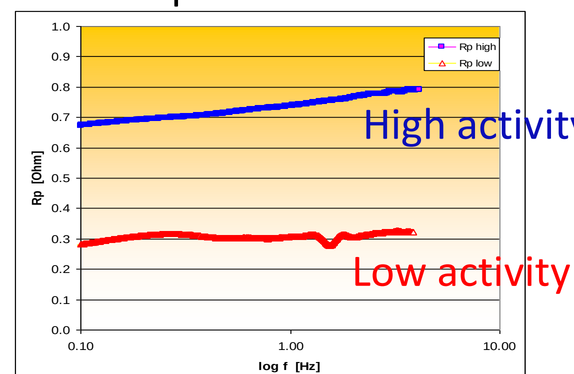
I

detrending

time or freq. domain transformation

FFT / MEM

Comparison method



Methods for corrosion testing

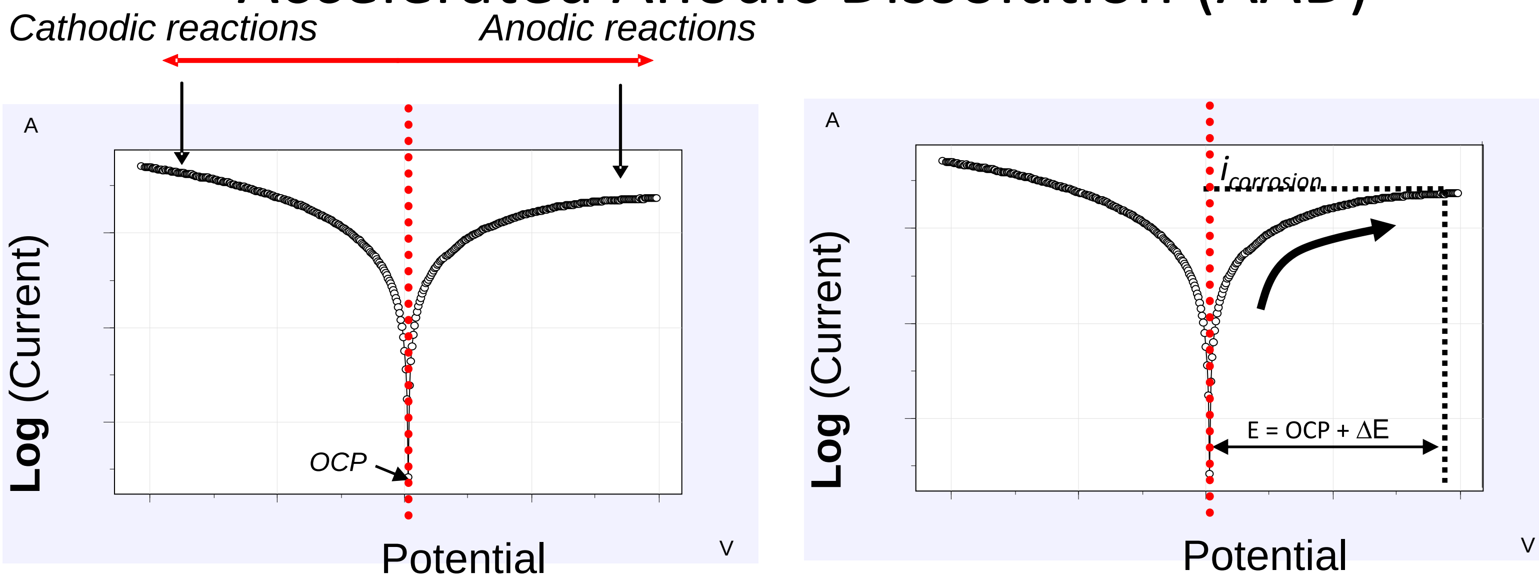
Electro Chemical Noise = ECN

- ECN: *potential (=E) and / or current (=I) fluctuations spontaneously generated by corrosion reactions*
- Current flow: *magnitude indicates amount of metal loss per unit time*
- Data detrending → transformation to freq. or time domain
- Calculation of polarization resistance Rp
- Rp indicator for environmental resistance (the higher the better)

Typical: Comparison materials and material batches → Ranking

Methods for corrosion testing

Accelerated Anodic Dissolution (AAD)



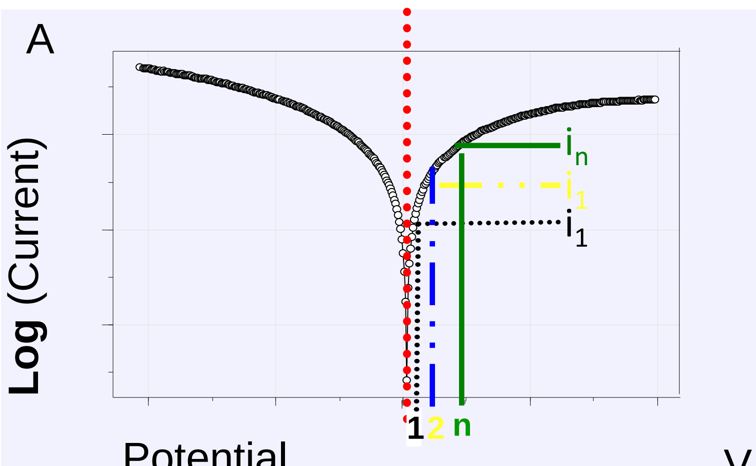
Polarization curve; corrosion rate behaviour

Classic accelerating corrosion

- extremely high current →too aggressive acceleration
- impossible discriminate between subtle corrosion differences
- no correlation with real corrosion mechanism(s)

Methods for corrosion testing

Stepwise Dissolution Method (SDM)



SDM	Stepwise Dissolution Measurement
cycle 1 n-th cycle	Method: OCP monitoring Potentiostatic polarization; E = OCP + ΔE ΔE = 10 mV to 30 mV OCP monitoring Potentiostatic polarization
• Stepwise→ all relevant corrosion phenomena accelerated • No change in mechanism → only acceleration	
Time	Results in 7-8 hours Longer exposure times of days possible

Standards

- Currently no accepted standards, ISO, CEN, ASTM or NEN, are available on electrochemical characterisation
- General applicable standards are:
  - ASTM G5 - 13 Standard Reference Test Method for Making Potentiodynamic Anodic Polarization Measurements
  - ASTM G61 - 86(2009) Standard Test Method for Conducting Cyclic Potentiodynamic Polarization Measurements for Localized Corrosion Susceptibility of Iron-, Nickel-, or Cobalt-Based Alloys
- Standards are under construction/discussion in ISO group TC156 workgroup 11
- NEN workgroup 330040 corrosion revitalised May 2013. Acts as mirror commission for ISO TC156
- No European TC on corrosion operational

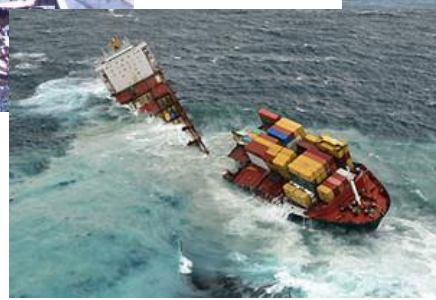
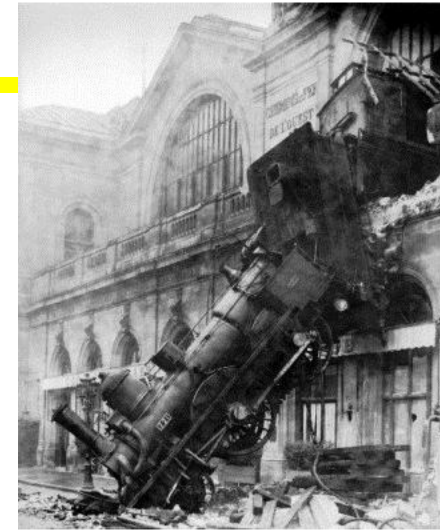
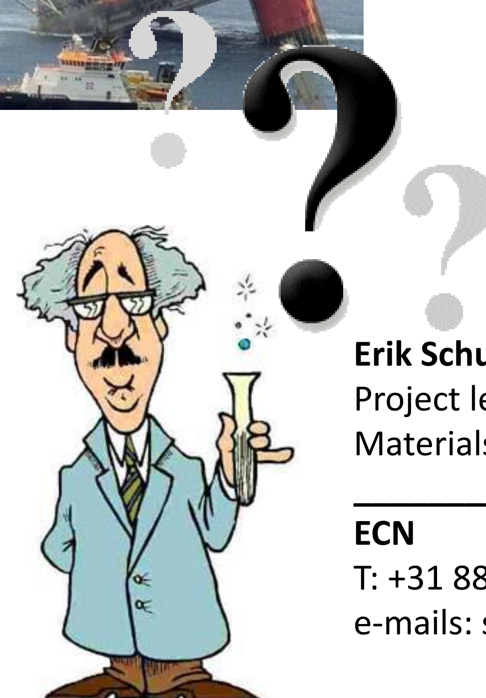
Conclusions

Summary corrosion screening method

- ECN method fast; within 1h -1 week results depending on test method!
- Fast pre-selection of promising materials/combinations → cost savings
- Determining of corrosion initiation
- Determination of corrosion mechanisms and propagation
- Life time predictions possible
- Strong combination with metallographic post-investigation
- Ranking materials / constructions for corrosion performance

Thanks for your attention &
Please Visit our Stand #48



ECN
Westerduinweg 3
1755 LE Petten
The Netherlands

P.O. Box 1
1755 ZG Petten
The Netherlands

T +31 88 515 49 49
F +31 88 515 44 80

info@ecn.nl
www.ecn.nl

Erik Schuring, IWE & Jaap Hooijmans
Project leader
Materials Testing & Analysis

ECN
T: +31 88 515 4877 | M: +31 6 23455488
e-mails: schuring@ecn.nl, hooijmans@ecn.nl

Energy-research Centre of the Netherlands

Locations

ECN
Petten

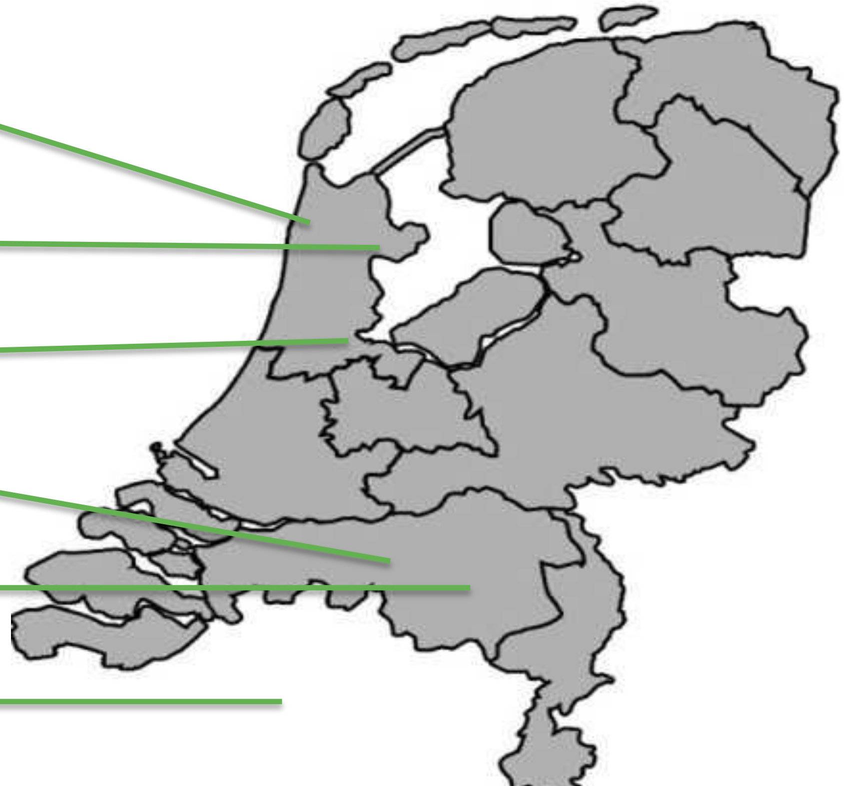
ECN
Wieringerwerf

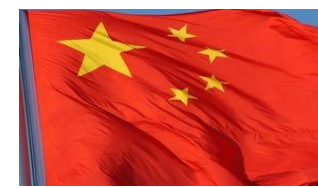
ECN
Amsterdam

ECN
Goirle

ECN
Eindhoven

ECN
Brussels





ECN
Beijing

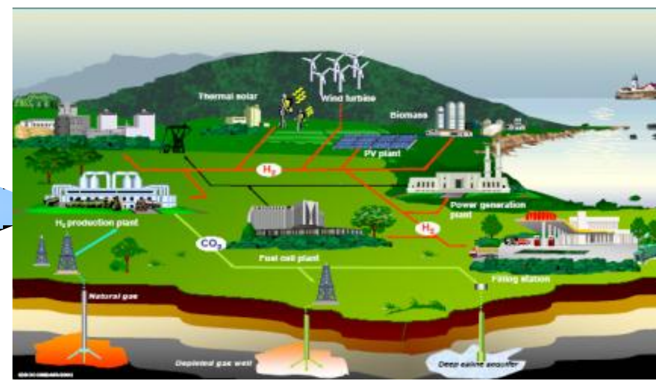
TRIAS ENERGETICA

Supply issues

Energy savings

Heat technology

Industry

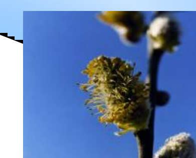


System innovations

Solar

Wind

Biomass



CO_2 technology

H_2&BC's

Renewables

ECN

Westerduinweg 3
1755 LE Petten

Postbus 1
1755 LG Petten

T 088 515 4949
F 088 515 8338
info@ecn.nl
www.ecn.nl