LABORELEC

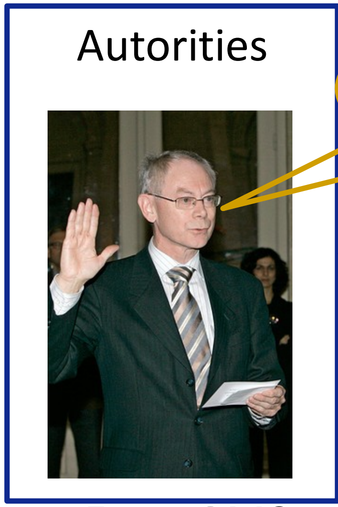
Predictive Emission Monitoring System (PEMS) as back-up for the monitoring of emissions in case of AMS failure

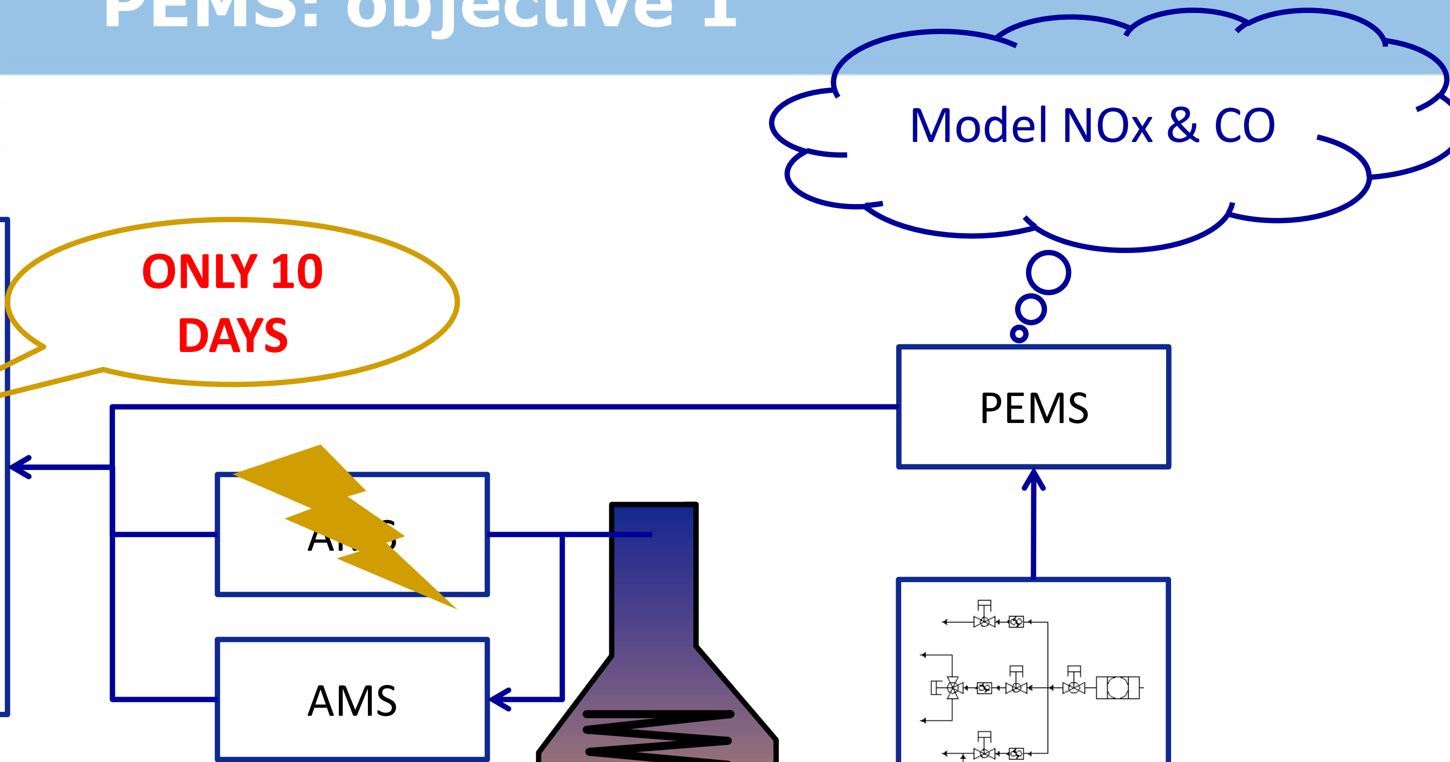
jan.mertens@laborelec.com

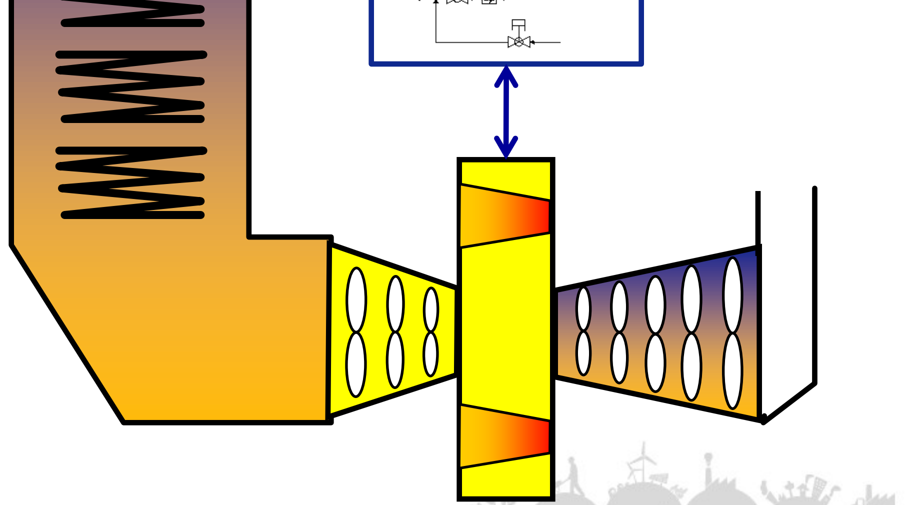
Contents

- Objective
- NO_x & CO modelling
  - Model set-up?
  - Modelling
  - Implementation
  - Results & Follow-up
- Quality Assurance
- Conclusion

PEMS: objective 1

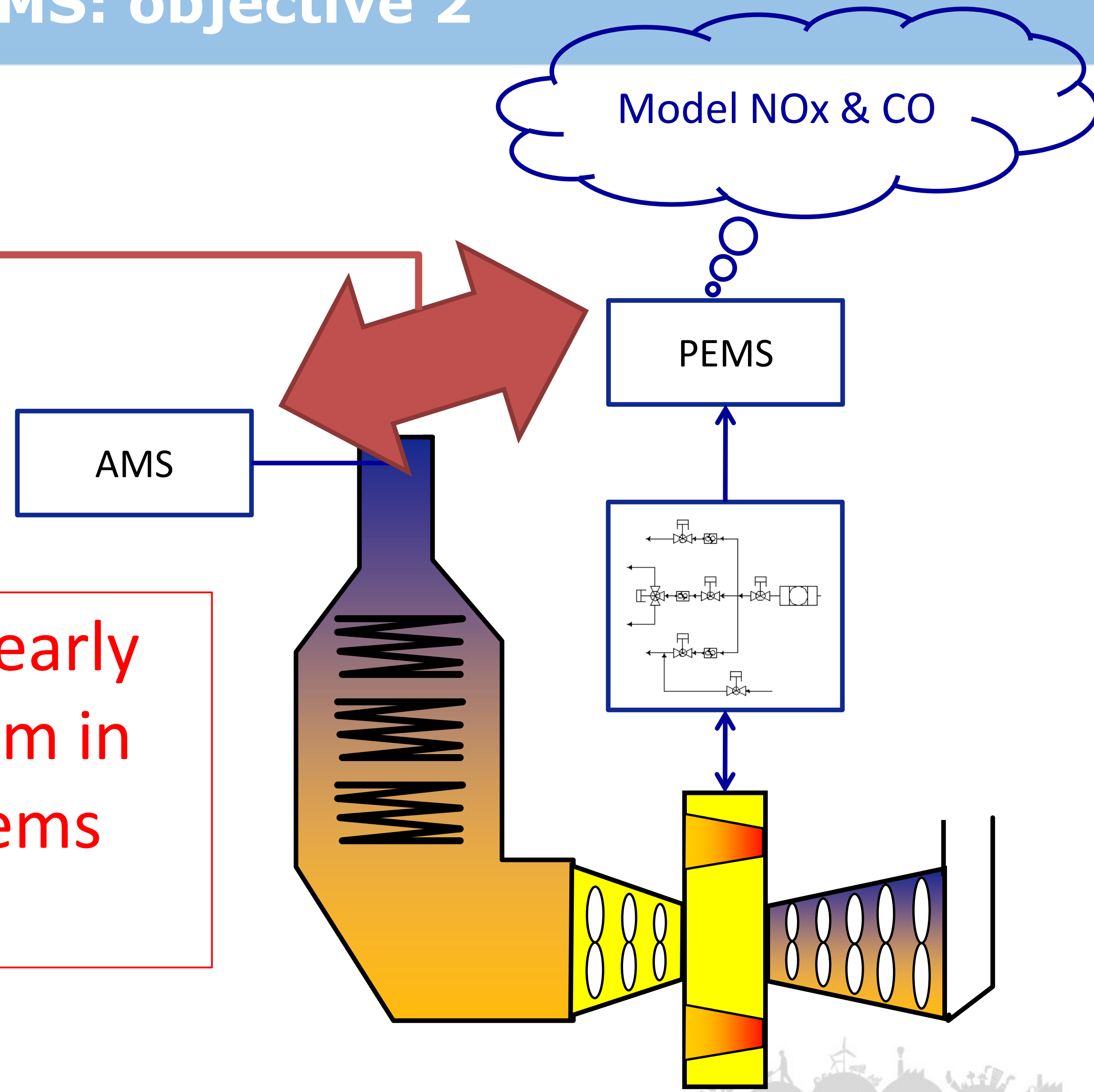






- **Extra AMS**
  - EXPENSIVE
  - Extra Maintenance
  - Current status: Accepted
- **PEMS**
  - CHEAP
  - Little maintenance
  - Current status: not accepted in BE, accepted in NL, US, parts of UK, …

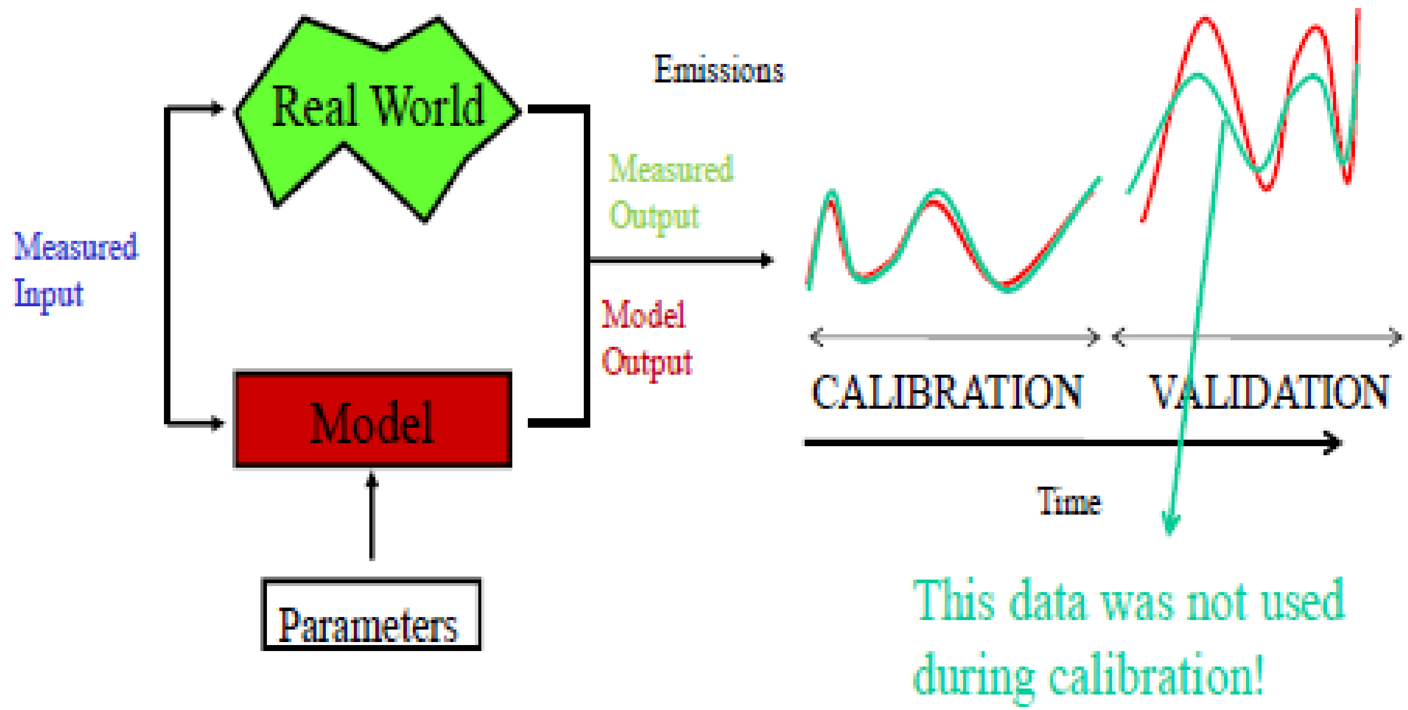
PEMS: objective 2



Use PEMS as early warning system in case of problems with AMS!

Model set-up

- Modelling

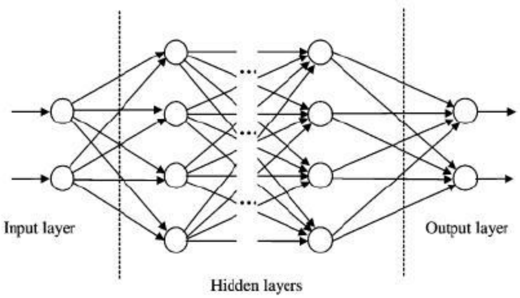


Model set-up

Real World

Model

Emissions from a CCGT



Measured Input

9 Inputs : Temperatures of combustion, Pressures in combustion chamber, Lower heating value of methane, air valve positions, …

Measured Output

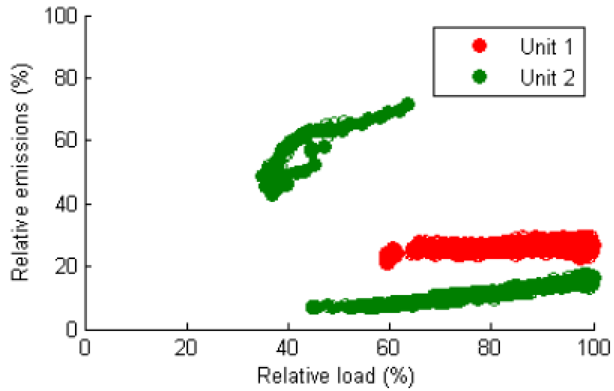
NOx and CO by the on-site AMS

Calculated Output

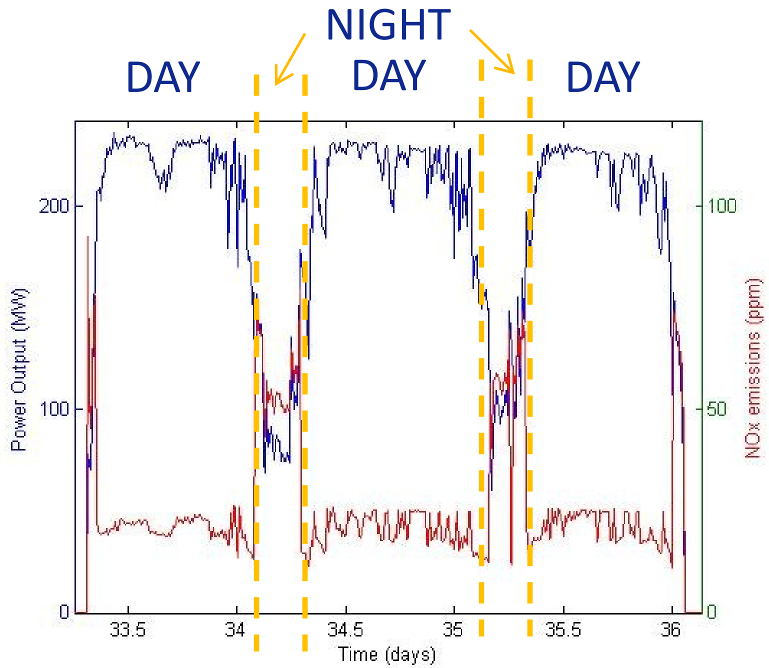
NOx and CO by the on-site AMS

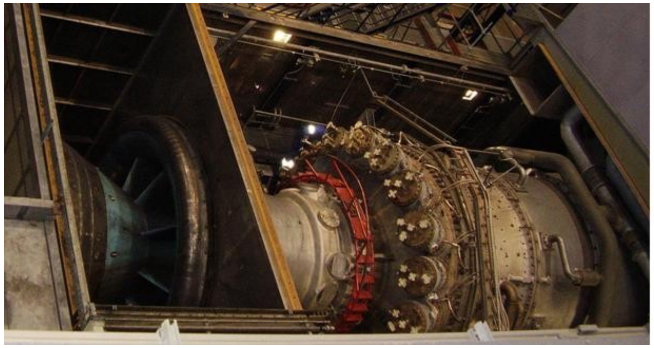
NOx & CO modelling

- Test case selection (2009)
  - Offline test
  - Eems 5: GE 9FA – 230 MWe



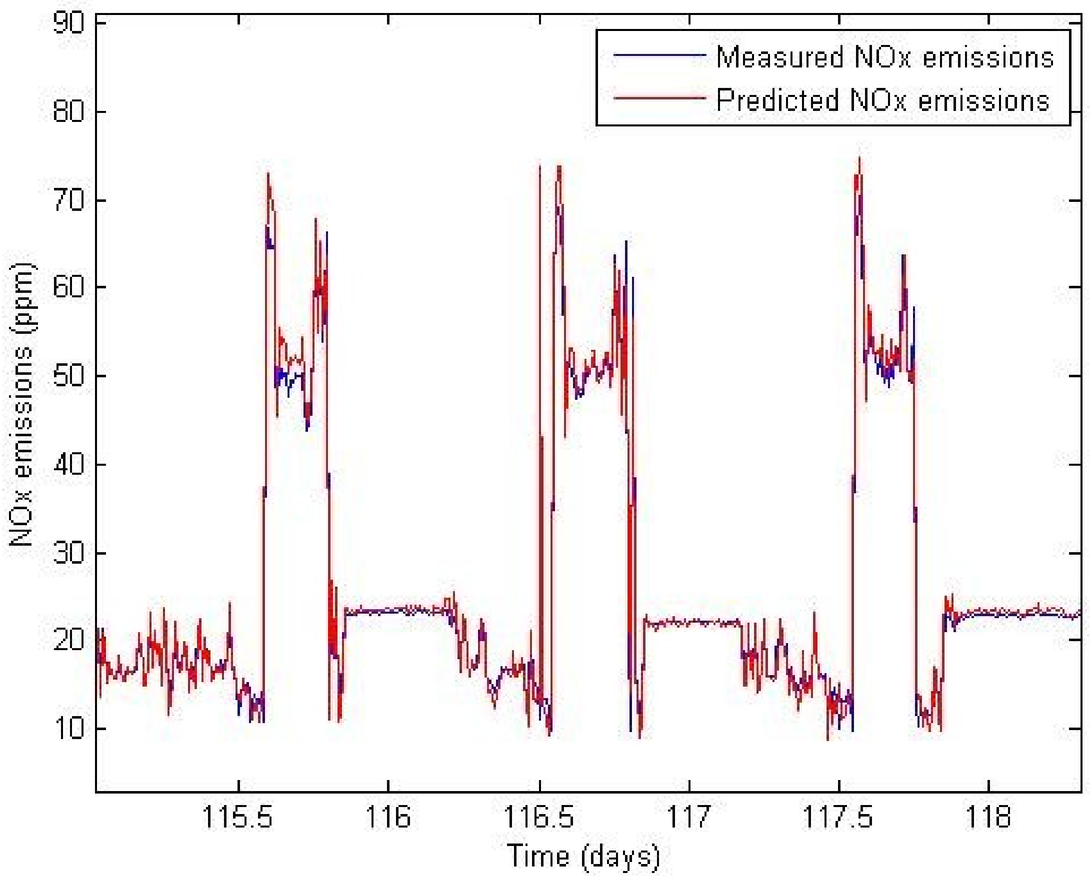
  - Later… SIE V94.2, GE 9FB …



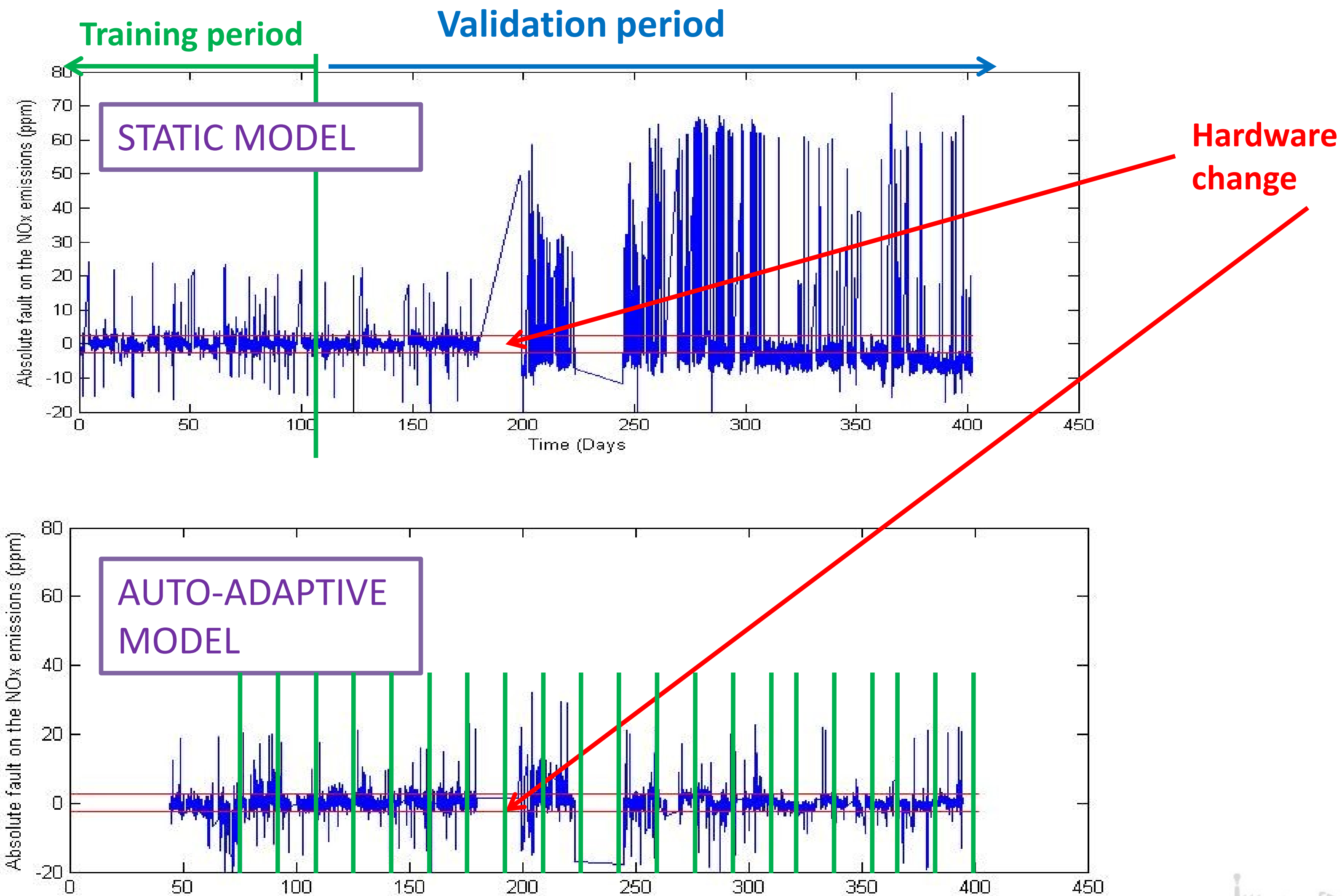


NOx & CO modelling

- Results



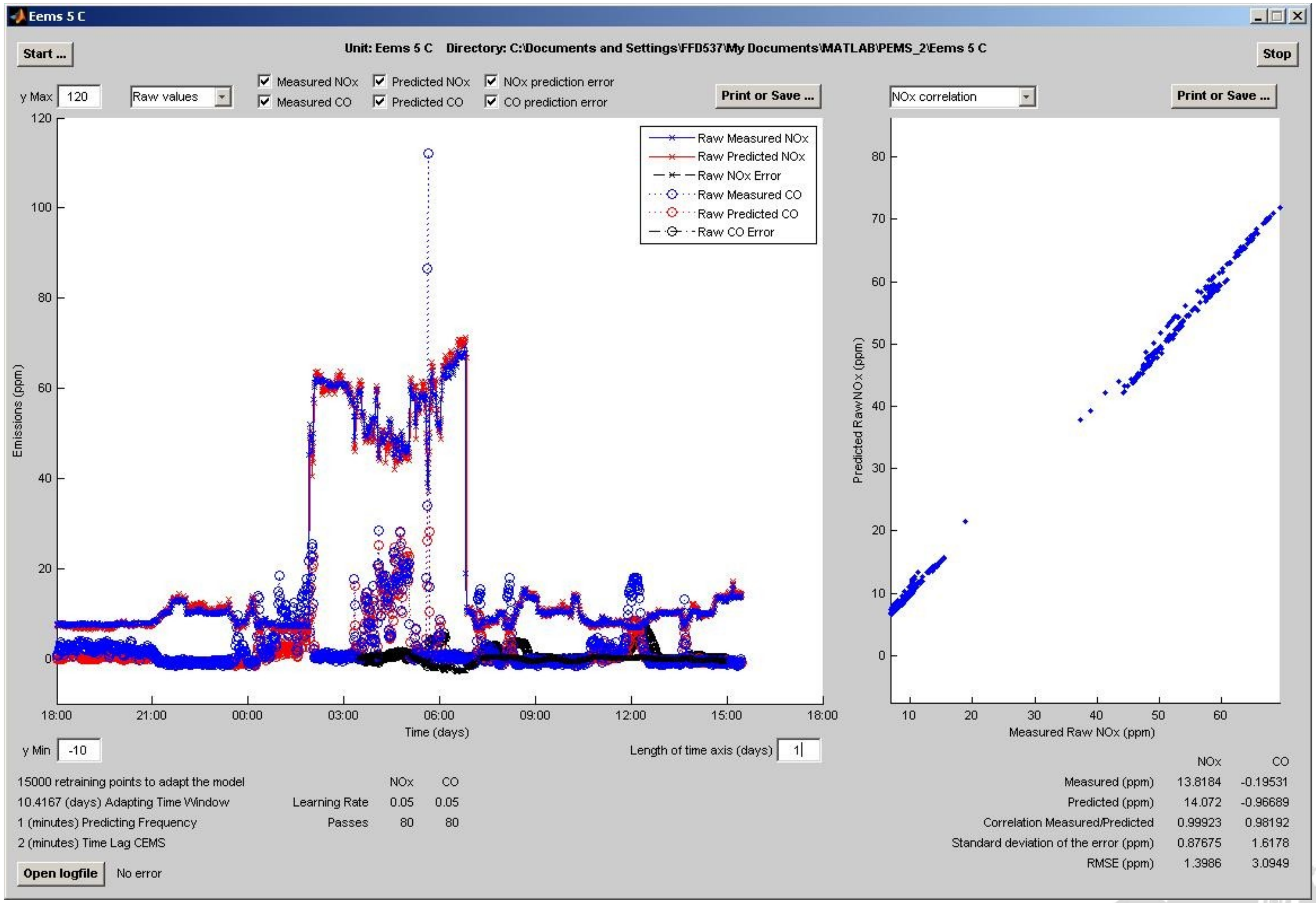
NOx & CO modelling



⚠ AMS needed to provide data for auto-adaptation

NOx & CO modelling

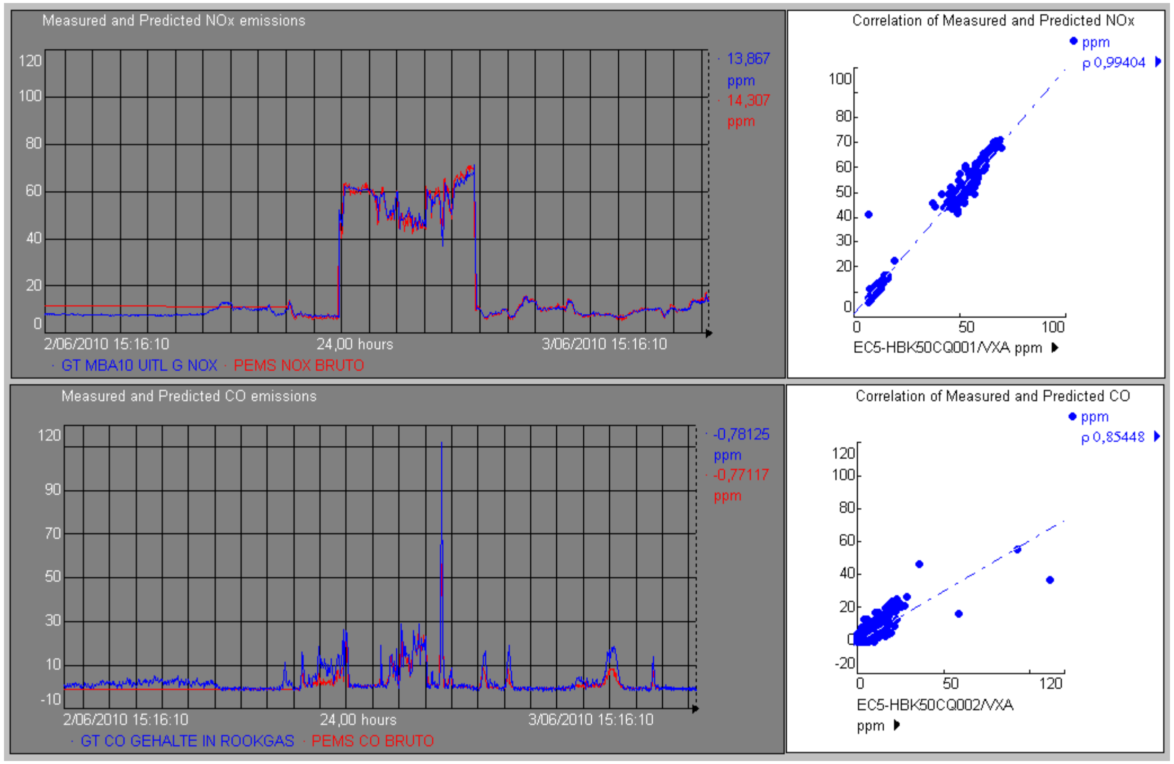
- Implementation in MATLAB ⇔ PI (2010)



NOx & CO modelling

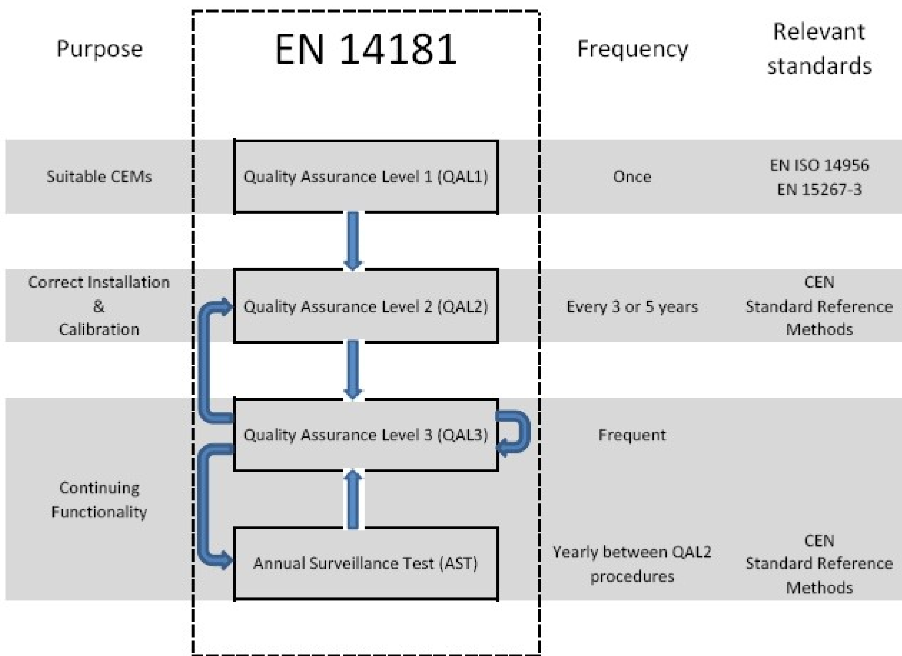
LABORELEC

- Results & Follow-up (2010)
  - Long term stability ?
  - NOx ☺
  - CO ☺



QA of PEMS

- Translating EN14181 to PEMS: (2010)



QA of PEMS

QAL1: $$U_{PEMS} = 2\sqrt{u_{input}^2 + u_{modelling}^2 + u_{analyser}^2}$$

- u_{Input} = uncertainty related to inputs (T & P, valve positions ,…)
- $u_{modelling}$ = modelling error, goodness-of-fit measure (RMSE)
- $u_{analyser}$ = measurement error of AMS (S_{AMS}) and O_2 AMS

The calculated U_{PEMS} must be < LCPD uncertainty

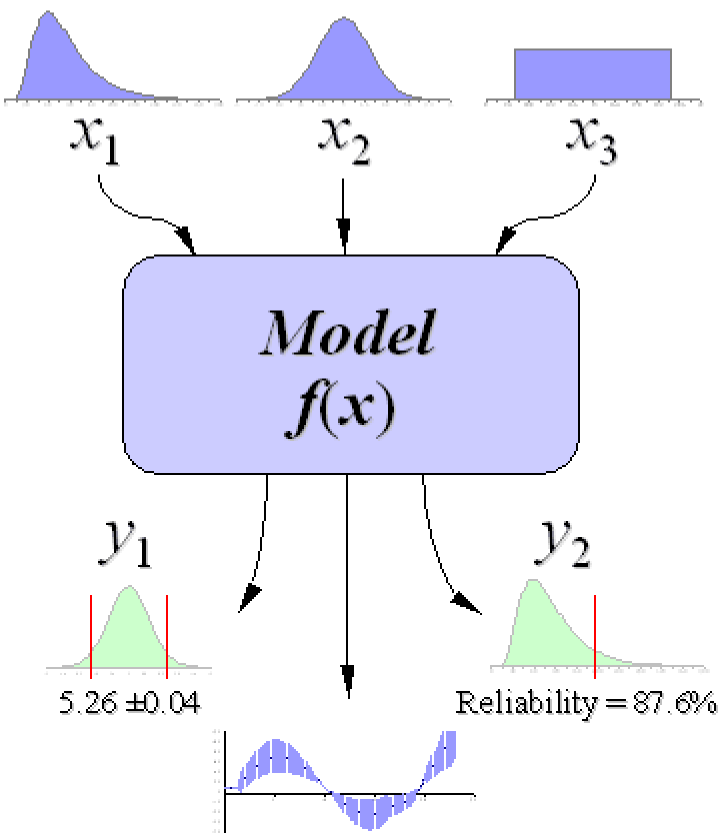
(= 20% of ELV for NOx and 10 % of ELV for CO)

QA of PEMS

$$U_{PEMS} = 2\sqrt{u_{input}^2 + u_{modelling}^2 + u_{analyser}^2}$$

- u_{Input} = uncertainty related to inputs

⇒ estimate error for each input and carry out a **Monte Carlo analysis**



* Generate 10,000 sets of inputs: 1 set = 9 input values with random ‘error’ added (eg. for Temperature , assume 1 K max. error so 1 K = 3 σ)

* 10,000 model runs (1 run = 15000 minutes or a little over 10 days)

* Analyse effect of error on inputs on simulated NO_x and CO ⇒
  calculate standard deviation per
  (i) minute or (ii) per 30 minutes and
  take maximum over entire period

QA of PEMS

$$U_{PEMS} = 2\sqrt{u_{input}^2 + u_{modelling}^2 + u_{analyser}^2}$$

- u_{Input} = uncertainty related to inputs

⇒ estimate error for each input and carry out a Monte Carlo analysis

* **CASE 1: model run every 1 minute and average NO_x and CO on 30 minutes:**
    * u_{NOx} = 0.1 ppm & u_{CO} = 0.3 ppm

* **CASE 2: model every 1 minute and report NO_x and CO every 1 minute:**
    * u_{NOx} = 1.4 ppm & u_{CO} = 2.6 ppm

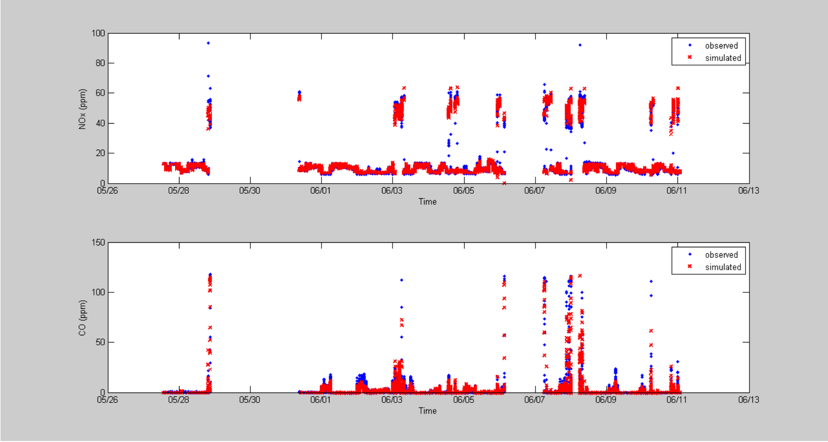
QA of PEMS

$$U_{PEMS} = 2\sqrt{u_{input}^2 + u_{modelling}^2 + u_{analyser}^2}$$

- $u_{modelling}$ = uncertainty related to goodness of fit of the model

⇒ Simply calculate a goodness –of-fit

$$u_{modelling} = \sqrt{\frac{\sum_{i=1}^{n} (E_i - E_m)^2}{n-1}} \quad \text{with} \quad \begin{cases} E_i = (O_i - M_i) \\ E_m = \frac{\sum_{i=1}^{n} E_i}{n} \end{cases}$$



* **CASE 1: model every 1 minute and average NO_x and CO on 30 minutes:**

* u_{NOx} = 0.9 ppm & u_{CO} = 1.4 ppm

* **CASE 2: model every 1 minute and report NO_x and CO every 1 minute:**

* u_{NOx} = 2.2 ppm & u_{CO} = 3.2 ppm

QA of PEMS

LABORELEC

$$U_{PEMS} = 2\sqrt{u_{input}^2 + u_{modelling}^2 + u_{analyser}^2}$$

- $u_{analyser}$ = measurement error of AMS and O_2 AMS

⇒ Error = f([Error of AMS and O_2 analyser]) & f([oxygen concentration]) & f([NOx concentration])

$$u_c^2([C]_{O2,ref}) = \left([C]_{O2,ref}\right)^2 \times \left(\frac{u^2([C]_{O2,actual})}{\left([C]_{O2,actual}\right)^2} + \frac{u^2([O_{2,actual}])}{(20.9 - [O_{2,actual}])^2} \right)$$ **(equation 1)**

*** QAL1 certificate of SIEMENS URAS 23:**

S_{AMS}(NO: 0 – 100 mg/m3) = 1.7 ppm

S_{AMS}(CO: 0 – 150 mg/m3) = 1.5 ppm

Assume 2 *S_{AMS} for O_2 = 0.4 vol%

*** CASE 1: model every 1 minute and average NO_x and CO on 30 minutes:**

⇒ u_{NOx} = 2.2 ppm & u_{CO} = 2.1 ppm

*** CASE 2: model every 1 minute and report NO_x and CO every 1 minute:**

⇒ u_{NOx} = 3.6 ppm & u_{CO} = 4.5 ppm

QA of PEMS

$$U_{PEMS} = 2\sqrt{u_{input}^2 + u_{modelling}^2 + u_{analyser}^2}$$

- U_{PEMS} =

CASE 1:

	NOx (ppm)	CO (ppm)
u_{input}	0.1	0.3
u_{model}	0.9	1.4
$u_{analyser}$	2.2	2.1
TOTAL U_{PEMS}	4.7	5.1

CASE 2:

	NOx (ppm)	CO (ppm)
u_{input}	1.4	2.6
u_{model}	2.2	3.2
$u_{analyser}$	3.6	4.5
TOTAL U_{PEMS}	8.9	12.2

- $U_{analyser}$ = highest contributor for total U ⇒ high quality PEMS calibration data = CRUCIAL!
- Since half-hourly = what needs to be reported ⇒ PEMS suitable when:

  ELV(NOx) > 24 ppm and ELV(CO) > 51 ppm

QA of PEMS

$$U_{PEMS} = 2\sqrt{u_{input}^2 + u_{modelling}^2 + u_{analyser}^2}$$

Remark: $u_{analyser}$ not taken into account in emission monitoring EN standards: ie. data used for calibration are supposed to be certain (eg. SRM for QAL2)

$\Rightarrow$ Not realistic & thus currently debated in several EN WG!

$\Rightarrow$ French AFNOR PEMS guide: even if SRM is used for PEMS calibration data, its uncertainty needs to be accounted for!

$\Rightarrow$ Our analysis confirms the importance of this analyser uncertainty!

QA of PEMS

- QAL2 & AST:

  => Standard Reference Method (SRM) parallel measurements

  (planned end of 2010)

- QAL3: **Methodology to be developed in 2011**

Inputs may drift:

- Use of reference materials if they exist (e.g. calibration gas)
- Can the instruments be verified in-situ / easily taken out
- Metrological follow-up in a legal framework

Alternative methods can be:

- Correlation coefficients
- Inter-comparisons with measurements of the same type
- Data reconciliation techniques

Questions…

LABORELEC

Thank You for Your Attention

[Five reasons for you to choose Laborelec]

- You have one-stop shopping for your energy related services
- You get access to more than 40 years of experience
- You increase the profitability of your installations
- You benefit from independent and confidential advice
- You are supported by a recognized and accredited laboratory

LABORELEC

The Technical **Competence Centre**
in **energy processes** and energy use

Laborelec Belgium
Rodestraat 125
1630 Linkebeek
Belgium

T. +32 2 382 02 11
F. +32 2 382 02 41
RPR/RPM Brussels 0400.902.582
BTW/TVA BE 0400 902 582

www.laborelec.com
info@laborelec.com

Laborelec The Netherlands
Amerikalaan 35
6199 AE
Maastricht-Airport

The Netherlands
T. +31 63 88 26 022