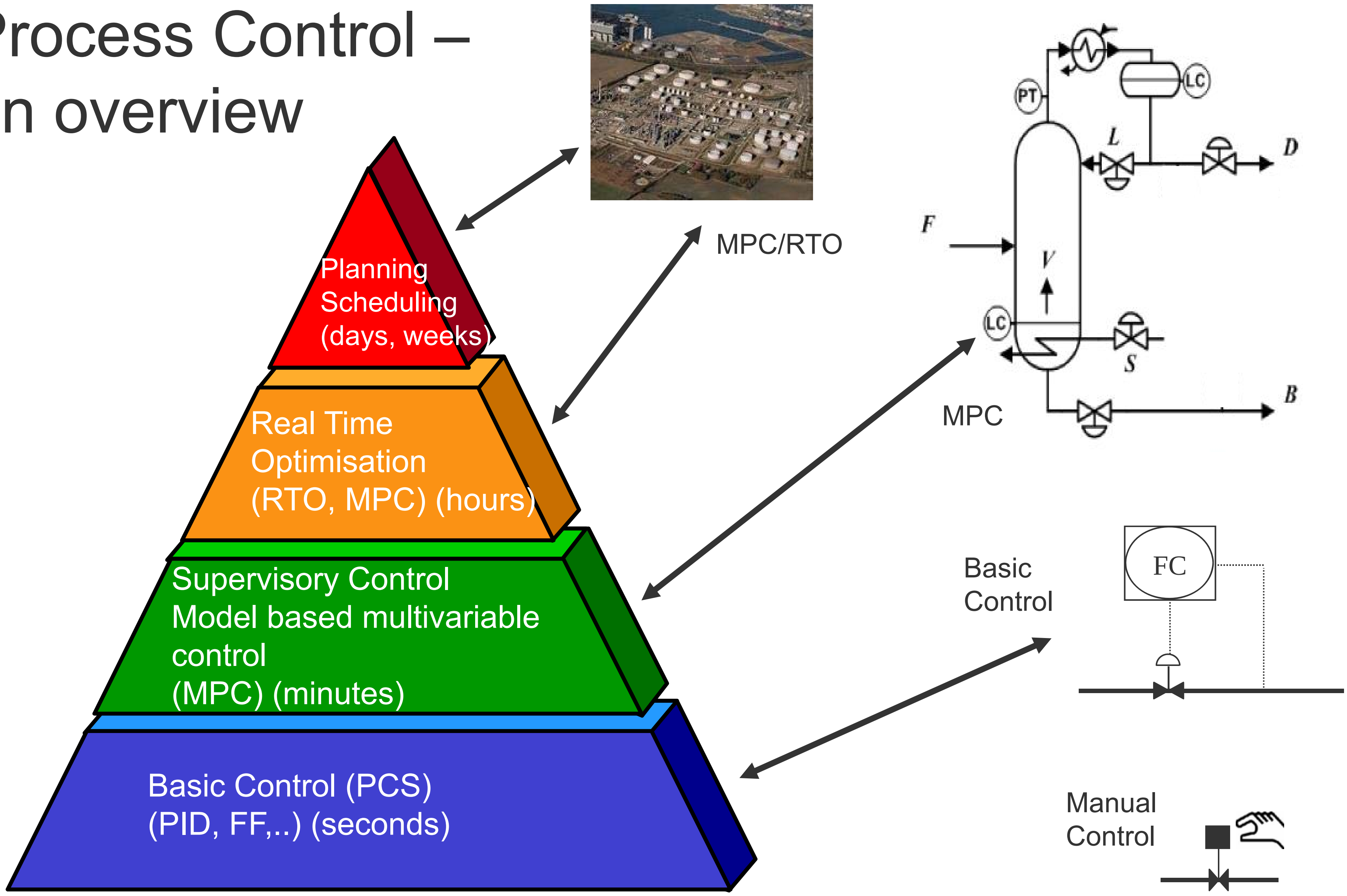
MPC in Statoil

Stig Strand, specialist MPC

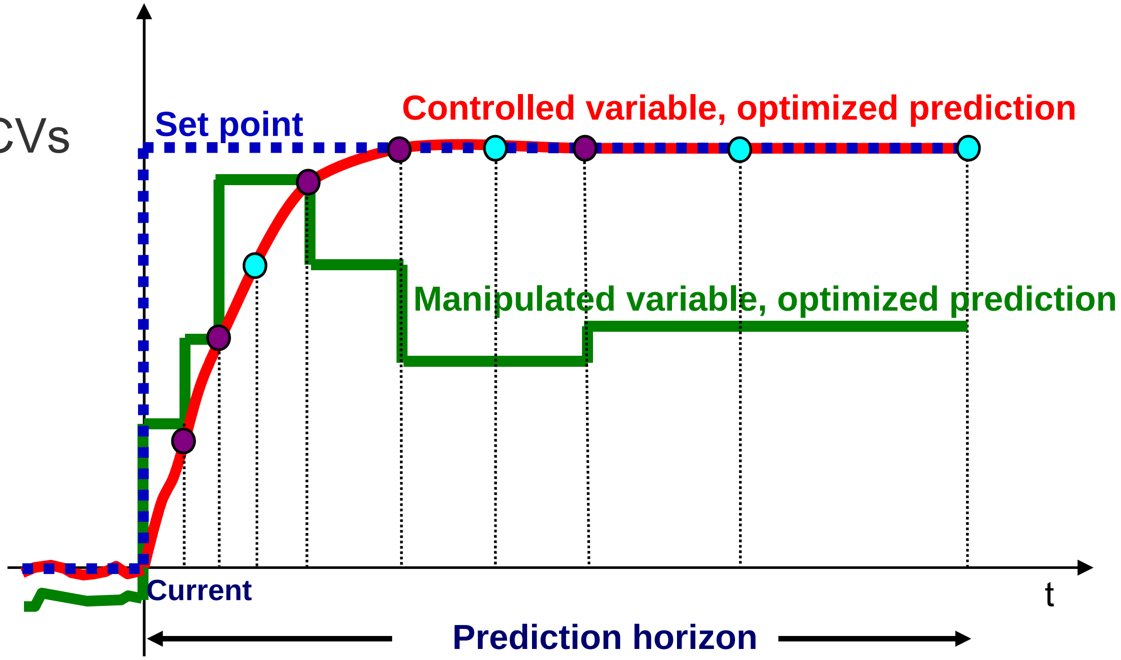
Statoil Research Center 93 →
SINTEF Automatic Control 91-93
Dr. ing 1991: Dynamic Optimisation in State Space Predictive Control Schemes

Process Control – an overview

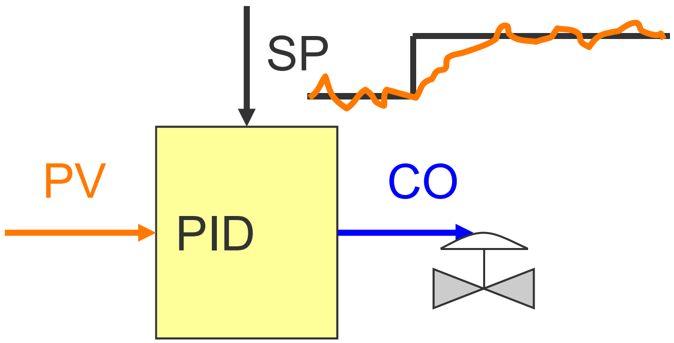


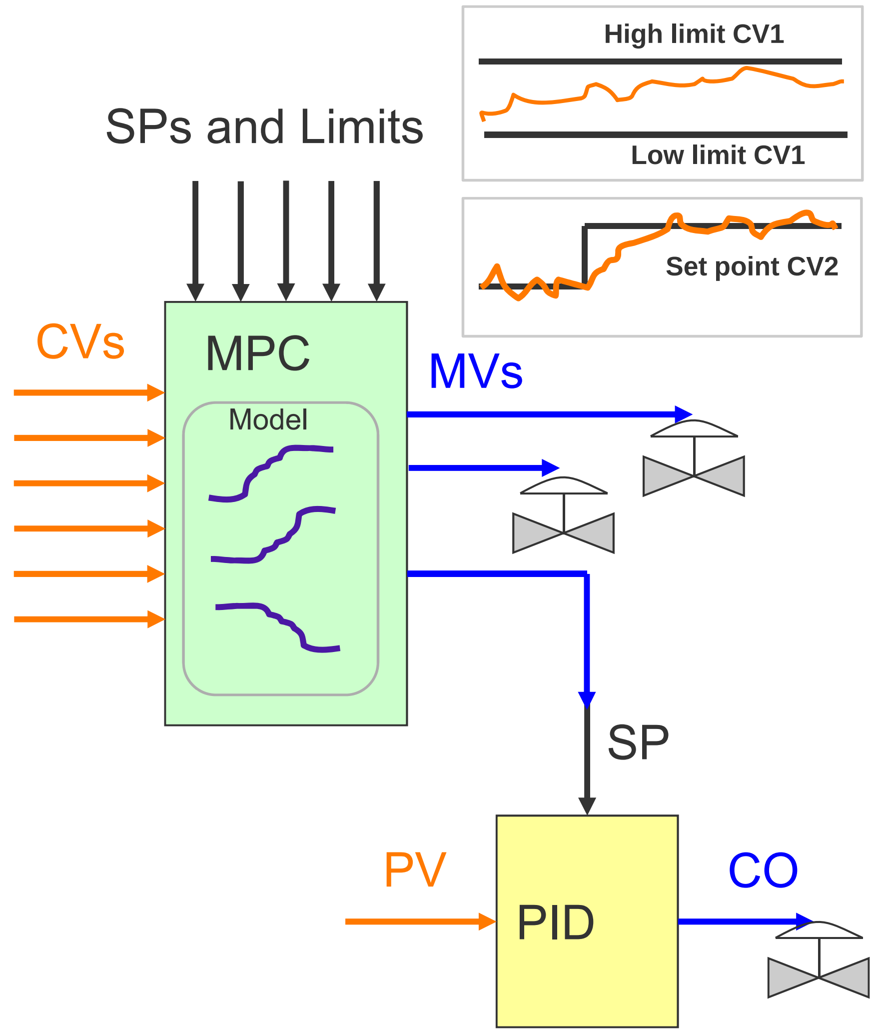
MPC variables

- **Controlled variable (CV)**
  - Set point, high and low limits (constraints)
- **Manipulated variable (MV)**
  - High and low limit, rate of change limit, ideal value (desired, set point)
  - Acts normally on a basic PID controller set point
- **Disturbance variable (DV)**
  - Measurable, affects the CVs



PID compared to Model Predictive Control

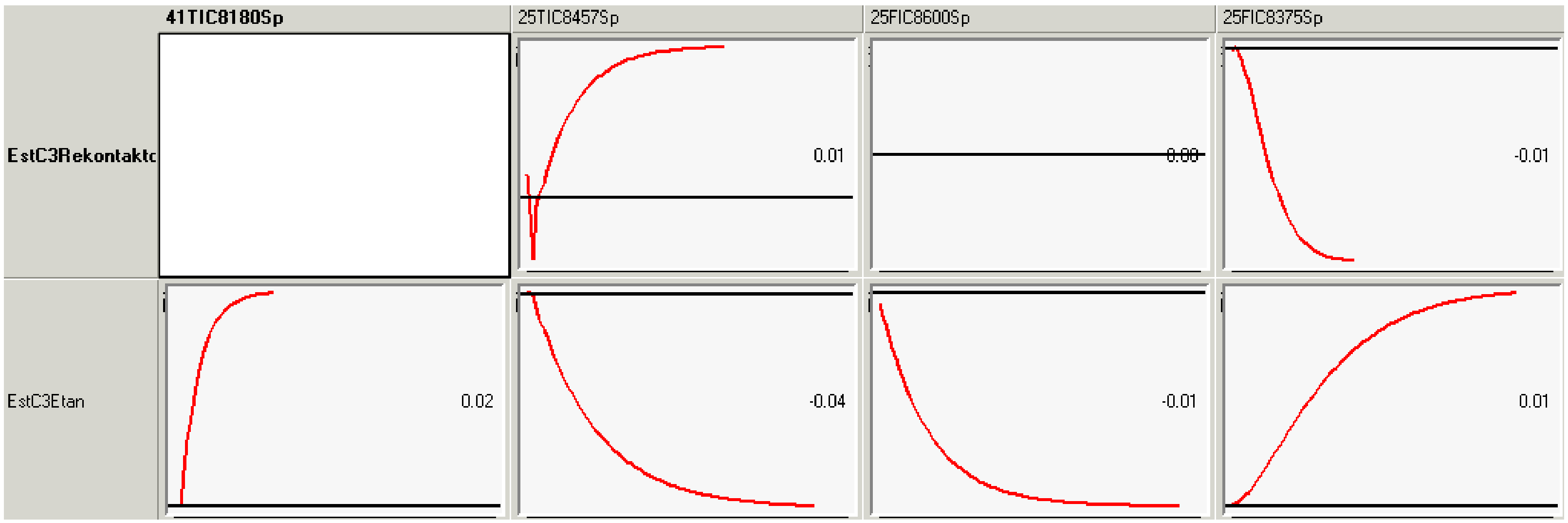




PID controller	MPC controller
1 degree of freedom	More degrees of freedom (# of MVs)
Controls PV to a SP.	Controls CVs to their SP or limits
Has no prediction capability	Has full prediction capability

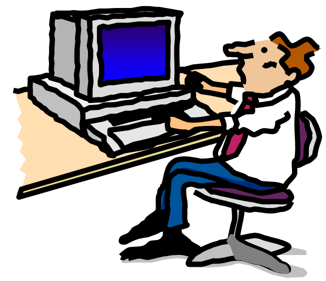
MPC – Model Predictive Control

- Use process measurements and process models to predict the future
- Calculate the optimal control actions to meet the control objectives
- Often uses soft-sensors/inferential models when e.g. quality is un-measured
  These are developed using online analyzer and/or laboratory samples with historic process data

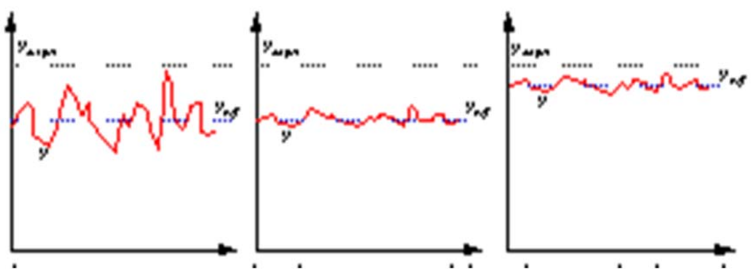


Estimatorer

Name	Desc	Value	Status	Alg
EstC3Rekontaktor	propan over topp i rekontaktor	0.085	GOOD	min(1,pow(0.049093*25TT8205+0.060714*25TT8571-0.0804*25TT8759+2.7456,2))
EstC3Etan	propan over topp i etantårn	0.056	GOOD	min(1,pow(max(0,0.8628-0.011488*25TT8200+0.02052*25TT8394-0.009834*25TT8612+0.038413*25TT8601),2))
EstC3RekontaktorLOG	propan over topp i rekontaktor,logaritmisk transf. modell mot CV	0.085	GOOD	EstC3Rekontaktor
EstC3EtanLOG	propan over topp i etantårn, logaritmisk transf. modell mot CV	0.06	GOOD	EstC3Etan
EstC2	etan i bunn av etantårn	0.49	GOOD	-0.39990*41TIC8180+42.54000

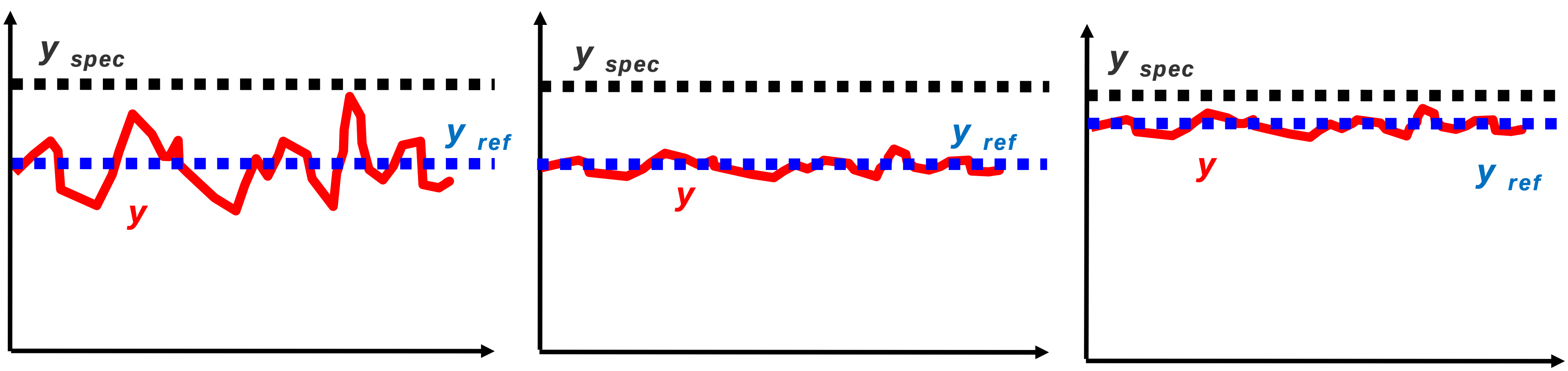


Why MPC?



Contributions of MPC

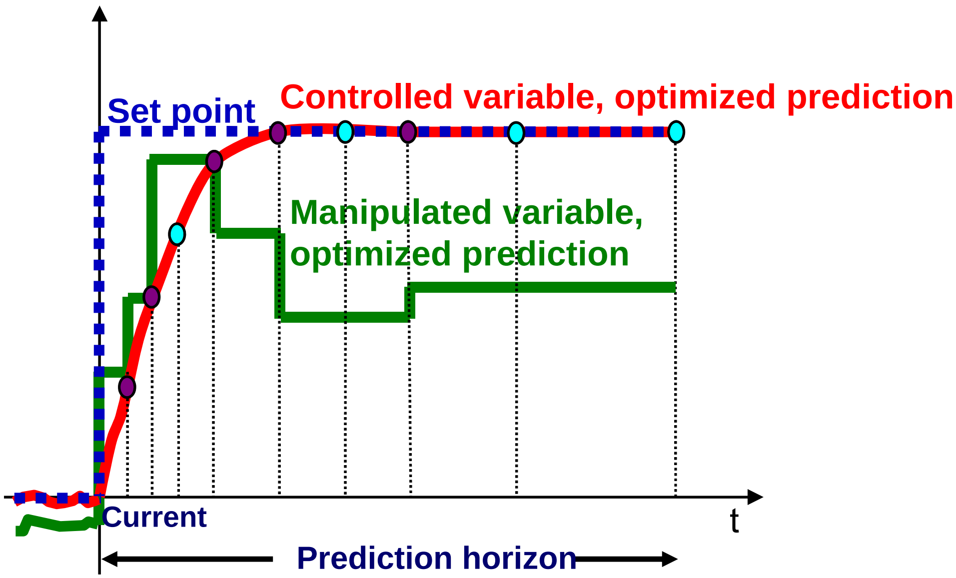
- Flexible, implements decoupling, feedback and feed-forward
- Improved process response to feed variations
- Improved product quality control
- Maximise capacity, maximise profit, reduce cost
- Respect process constraints related to equipment or environment
- Increased process regularity

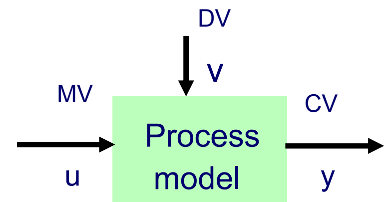


Basic Control MPC RTO – DRTO - MPC

Statoil

MPC solver





$$\min_u \left[(y-y_{ref})^T Q_y (y-y_{ref}) + (u-u_{iv})^T Q_u (u-u_{iv}) + \Delta u^T P \Delta u \right]$$

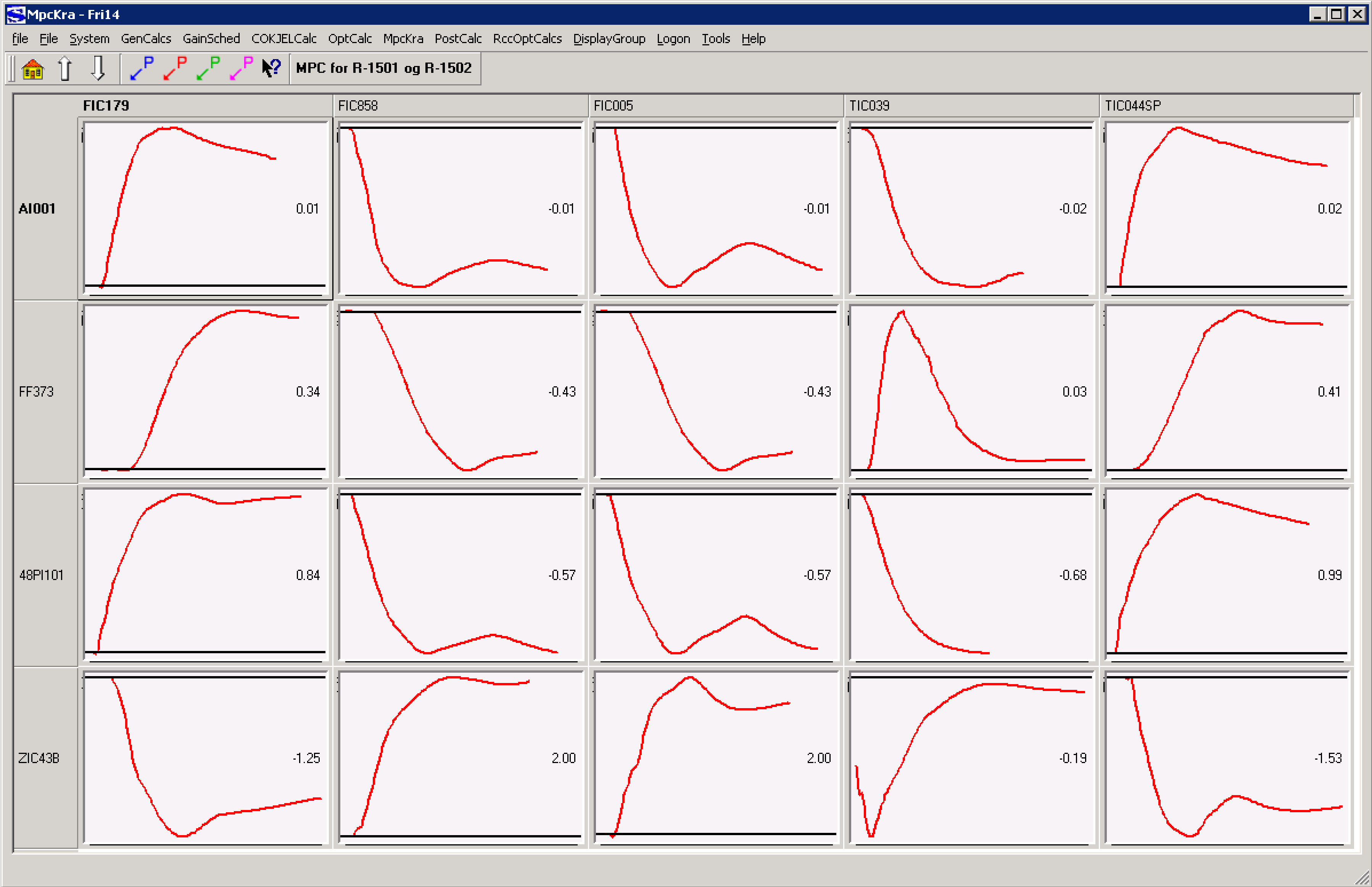
$$\dot{x} = f(x,u,v)$$
$$y = g(x,u)$$
$$u_{\min} < u < u_{\max}$$
$$\Delta u_{\min} < \Delta u < \Delta u_{\max}$$
$$y_{\min} < y < y_{\max}$$

$$y = [y_1\, y_2 \ldots y_n]$$
$$u = [u_1\, u_2 \ldots u_k]$$
$$\Delta u = [\Delta u_1\, \Delta u_2 \ldots \Delta u_k]$$
$$\Delta u_i = u_i - u_{i-1}$$

CV soft constraint:
$y < y_{max} + RP$
$0 <= RP <= RP_{max}$
$w*RP^2$ in objective

- MV blocking → size reduction
- CV evaluation points → size reduction
- CV reference specifications → tuning flexibility set point changes / disturbance rejection
- Soft constraints and priority levels → feasibility and tuning flexibility

MPC linear models



MPC Solver - Control priorities

1. MV rate of change limits
2. MV high/low Limits
3. CV hard constraints (”never” used)
4. CV soft constraints, CV set points, MV ideal values: Priority level 1
5. CV soft constraints, CV set points, MV ideal values: Priority level 2
6. CV soft constraints, CV set points, MV ideal values: Priority level n
7. CV soft constraints, CV set points, MV ideal values: Priority level 99

Sequence of steady-state QP solutions to solve 2 – 7

Then a single dynamic QP to meet the adjusted and feasible steady-state goals

MPC – nonlinear models

- Open loop response is predicted by non-linear model
  - MV assumption : Interpolation of optimal predictions from last sample
- Linearisation by MV step change
  - One step for each MV blocking parameter (increased transient accuracy)
- QP solver as for experimental models (step response type models)
- Closed loop response is predicted by non-linear model
- Iterate solution until satisfactory convergence

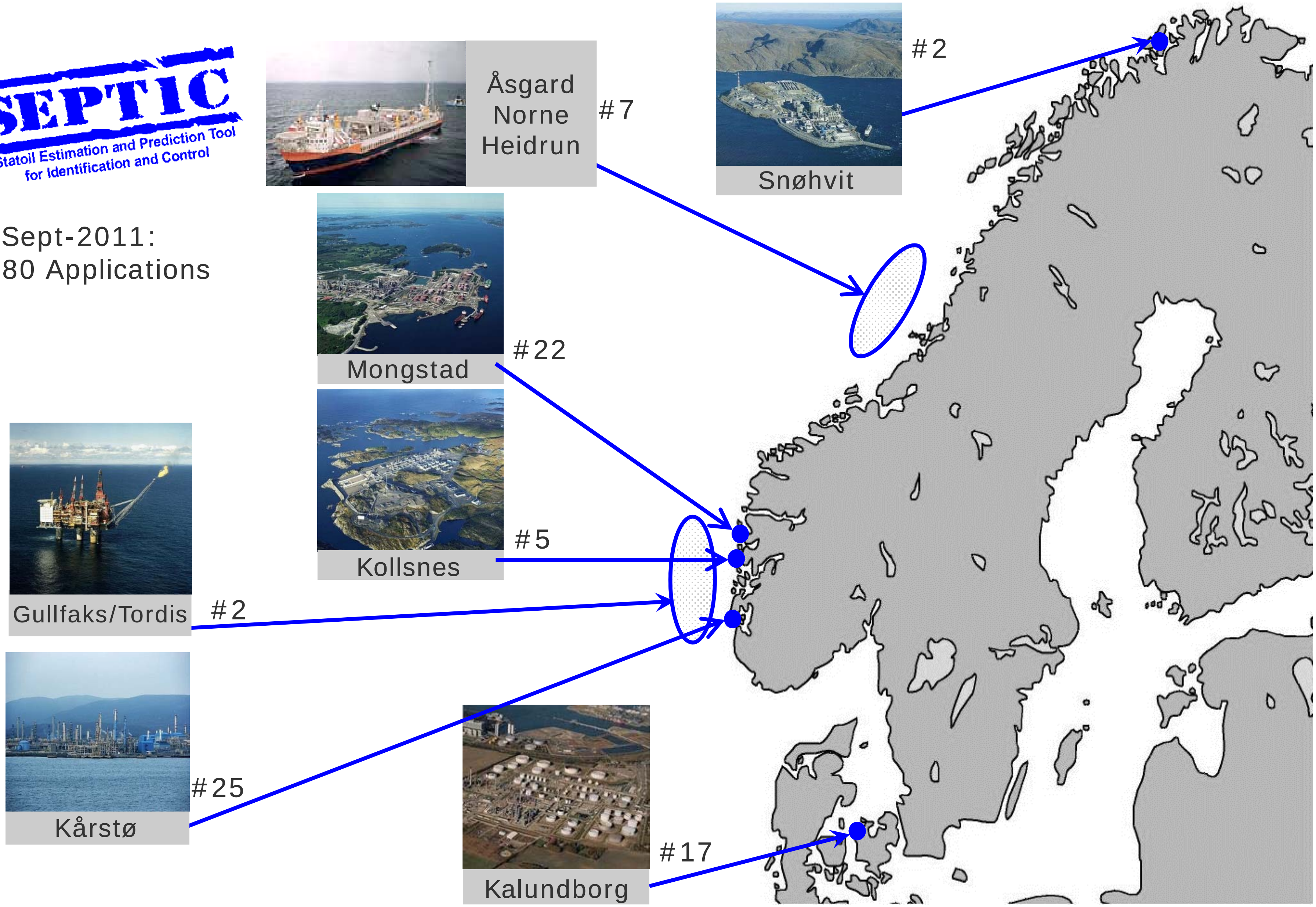
MPC in Statoil

PROCESS CONTROL
”The SEPTIC story”

- The in-house developed SEPTIC MPC tool was established in 1997 and has continuously been improved since then, securing state-of-the-art technology
- The process control group at R&D is responsible for SEPTIC, and works with Statoil customers only
- The philosophy with SEPTIC is to implement MPC applications together with the users, which have resulted in;
  - Flexible and quick installations
  - Cheaper solutions than using external vendors
  - Non-bureaucratic way of work
  - Building in-house competence
- In 2013 there are 90 (+/-) SEPTIC based applications are installed in Statoil

SEPTIC
Statoil Estimation and Prediction Tool for Identification and Control

Sept-2011:
80 Applications



Implementation

- Operation knowledge – benefit study? or strategy? → MPC project
- Site personnel / Statoil R&D joint implementation project
- (MPC computer, data interface to DCS, operator interface to MPC)
- MPC design → MV/CV/DV
- DCS preparation (controller tuning, instrumentation, MV handles, communication logics etc)
- Control room operator pre-training and motivation
- Product quality control → Data collection (process/lab) → Inferential model
- MV/DV step testing → dynamic models
- Model judgement/singularity analysis → remove models? change models?
- MPC pre-tuning by simulation → MPC activation – step by step and with care – challenging different constraint combinations – adjust models?
- Control room operator training
- MPC in normal operation, with at least 99% service factor

- Benefit evaluation?
- Continuous supervision and maintenance

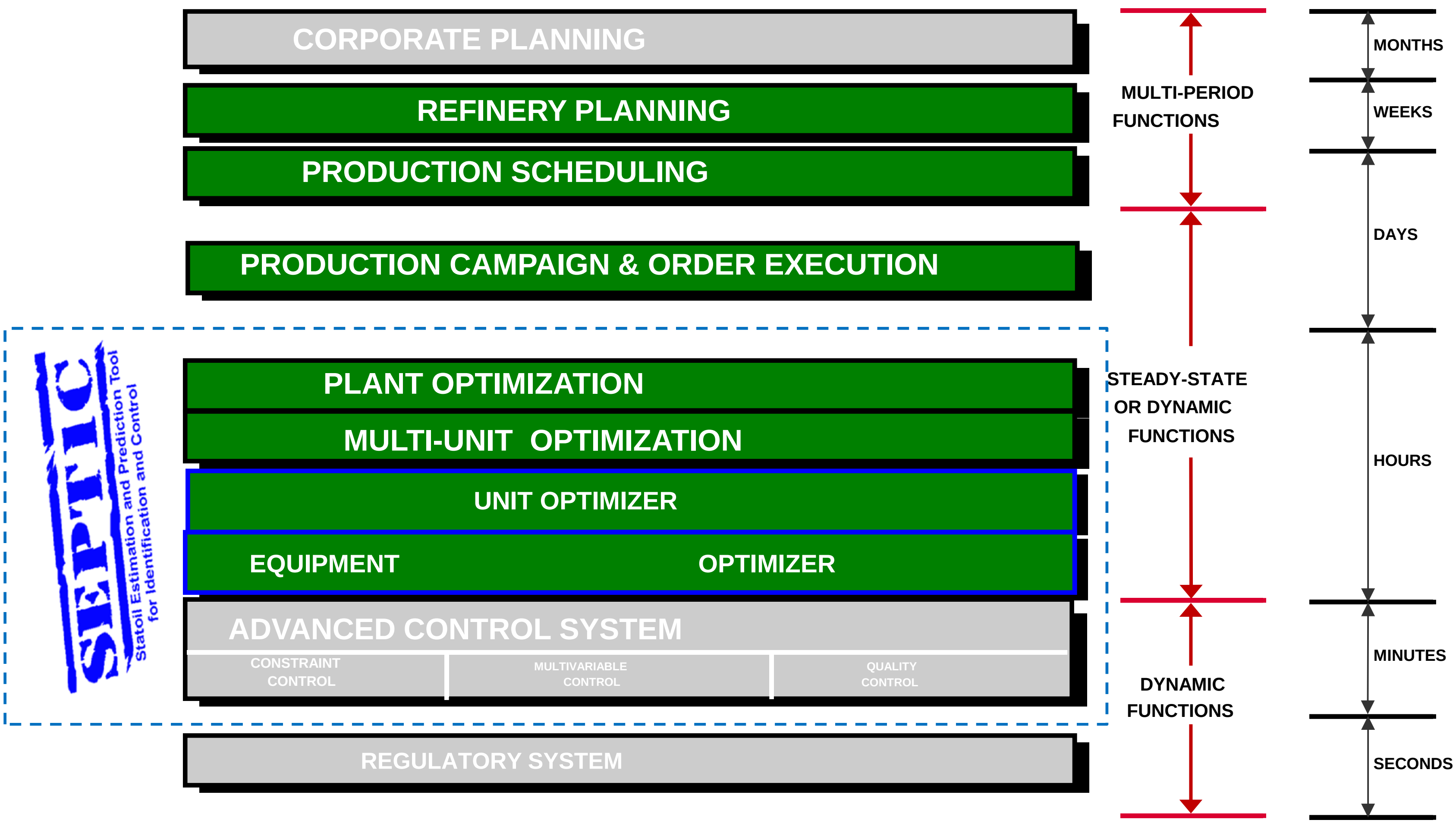
- Each project increases the in-house competence → increased efficiency in maintenance and new projects

MPC applications in Statoil, examples

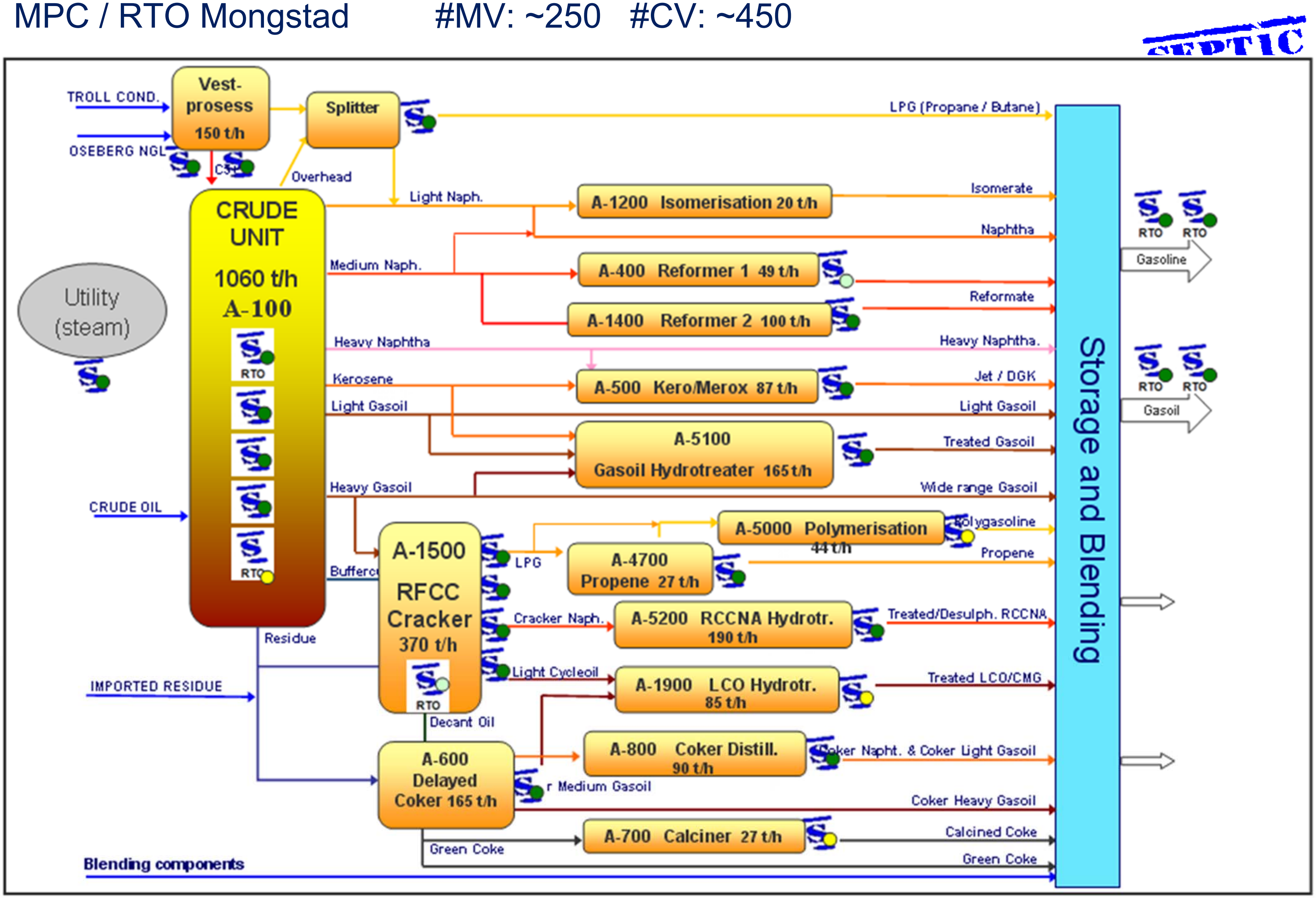
- Oil refining (Mongstad and Kalundborg)
  - Distillation columns
  - Product blending (gasoline, gas oil)
  - Cracking, reforming and hydrotreating
  - Heat exchanger network (RTO)
  - Multi-unit optimisation (RTO/DRTO)
- Gas processing (Kårstø, Kollsnes, Snøhvit)
  - Distillation
  - Gas quality control
  - Pipeline pressure control
  - Optimisation
- Offshore production
  - Extended slug control
  - Crude blending
  - Production optimisation

Oil refining at Mongstad

Planning and control layers in oil refining



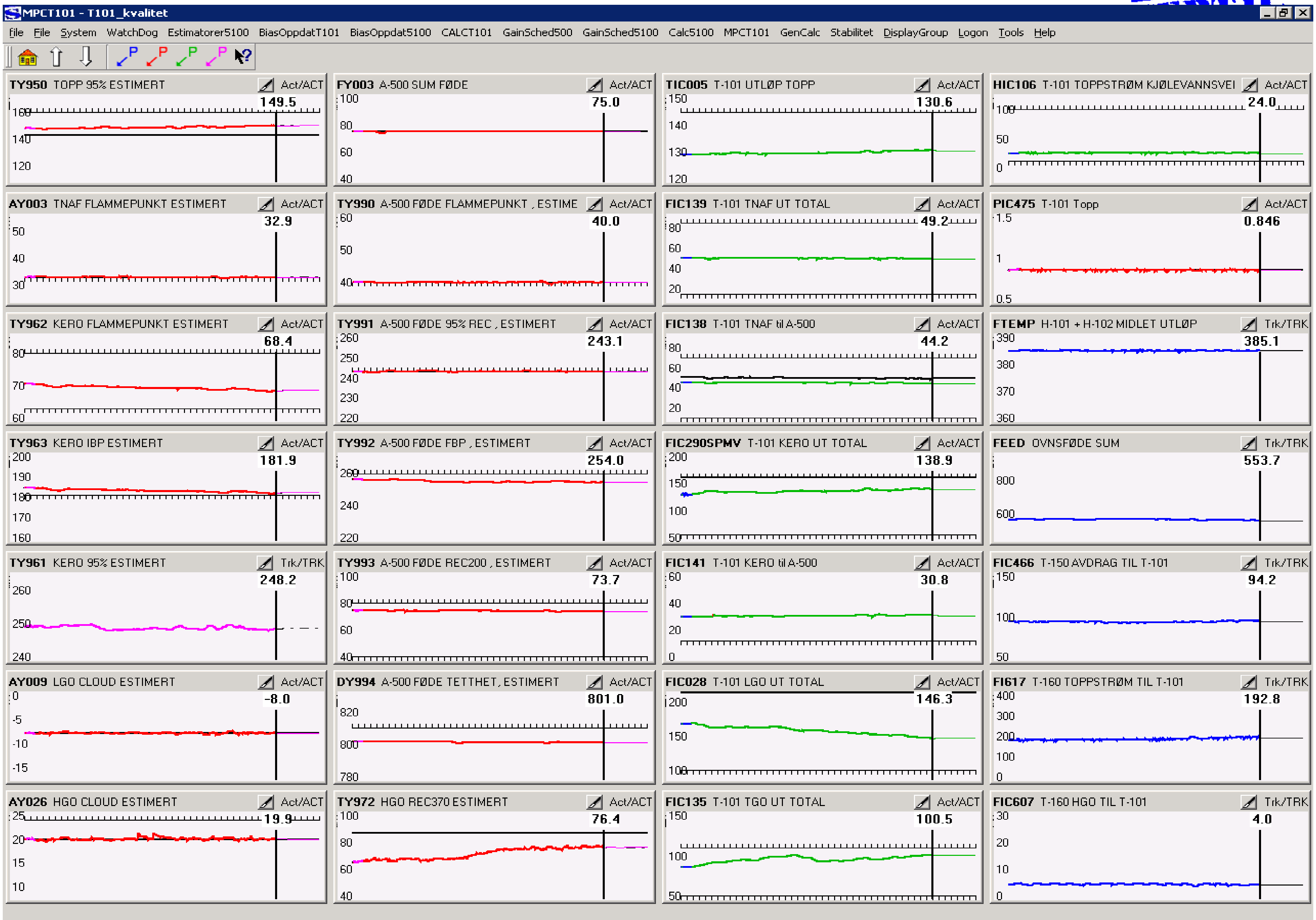
MPC / RTO Mongstad #MV: ~250 #CV: ~450



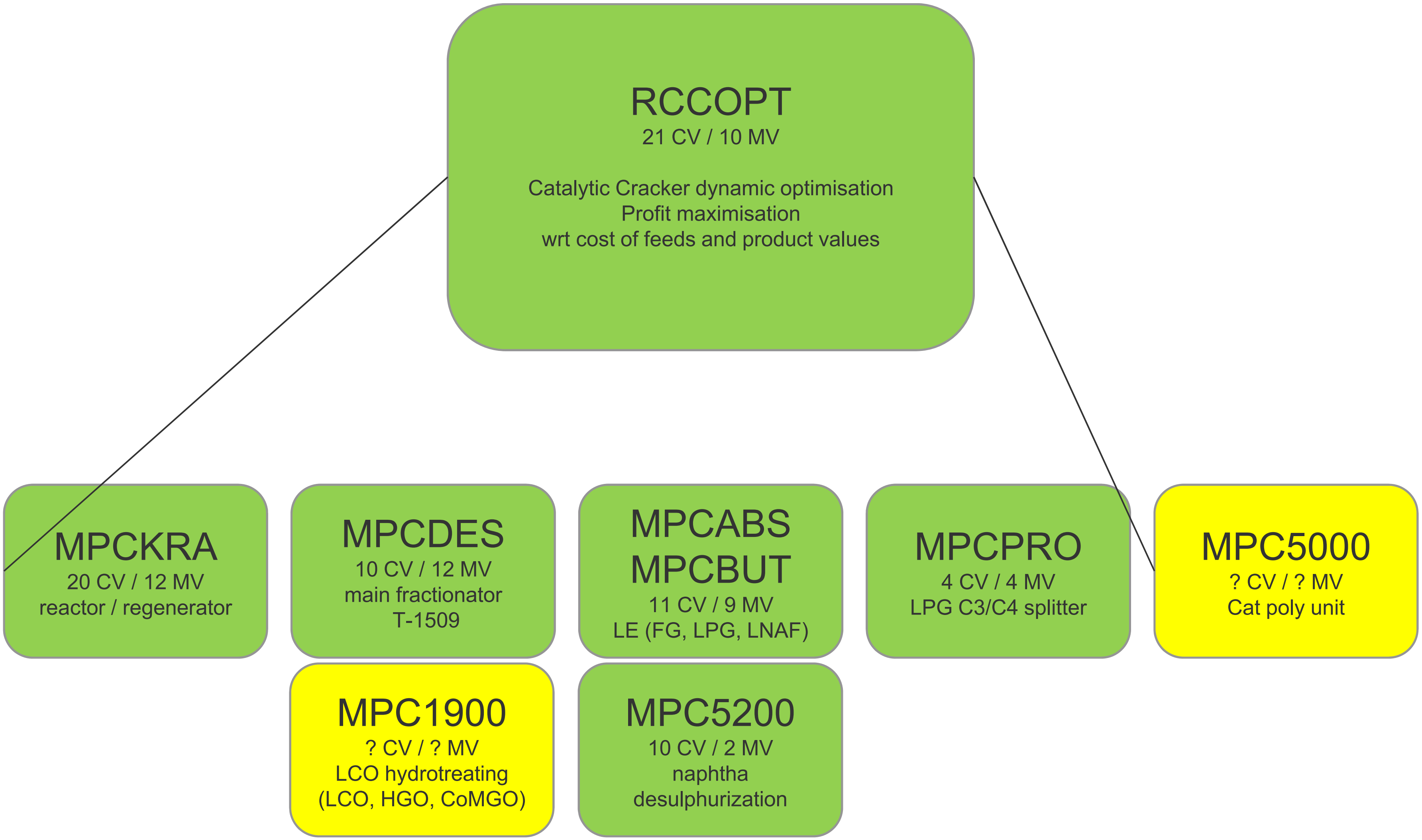
Notation: Running Application Implementation ongoing Future Application

Statoil

Crude distillation column #MV: 27 #CV: 45



RCCOPT Mongstad (Cat Cracker Optimiser)



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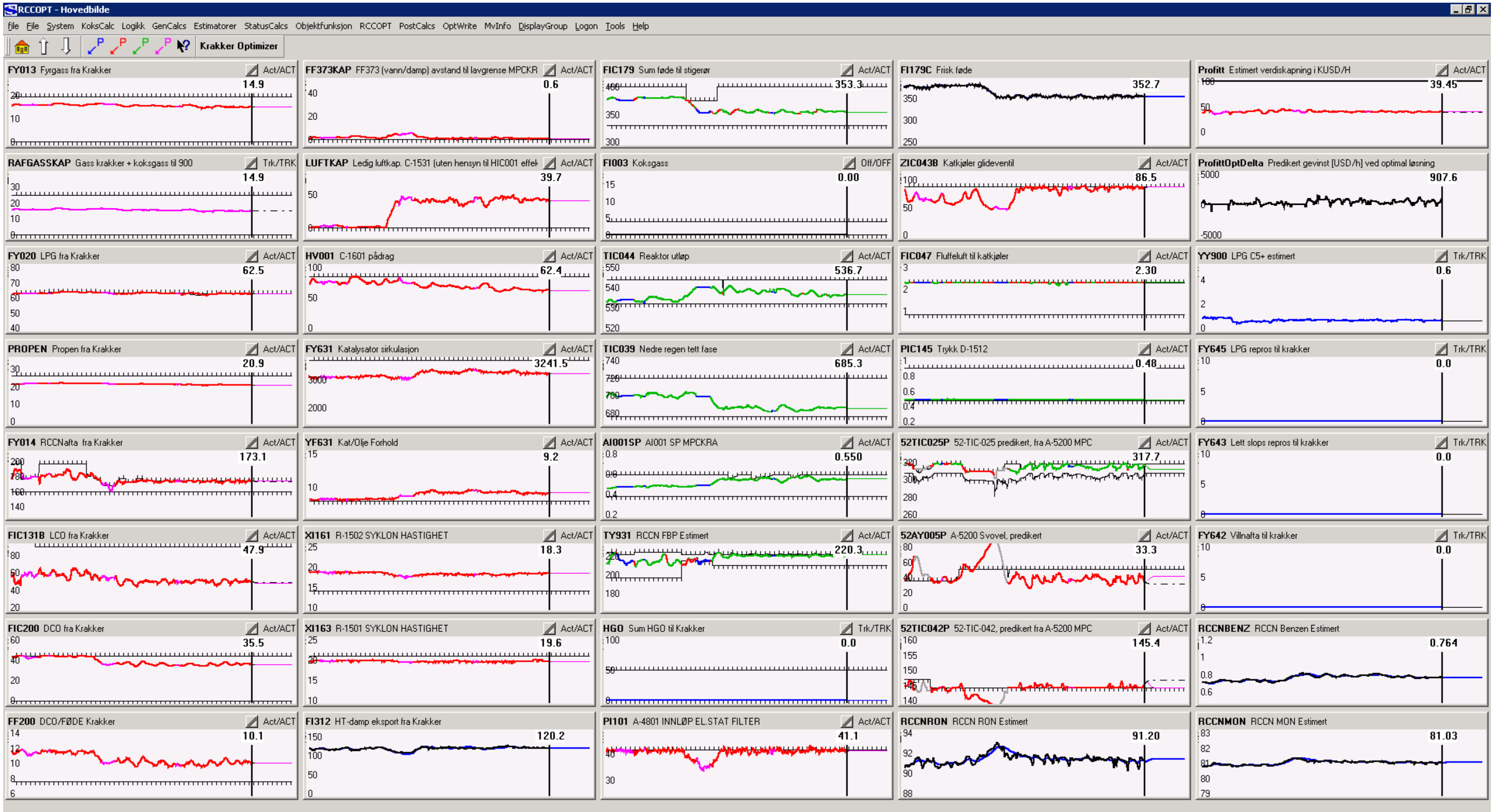


RCCOPT Mongstad (Cat Cracker Optimiser)

Objective function (Profit)

RCCOPT - Objektfunksjon

File File System KoksCalc Logikk GenCalcs Estimatorer StatusCalcs Objektfunksjon RCCOPT PostCalcs OptWrite MvInfo DisplayGroup Logon Tools Help

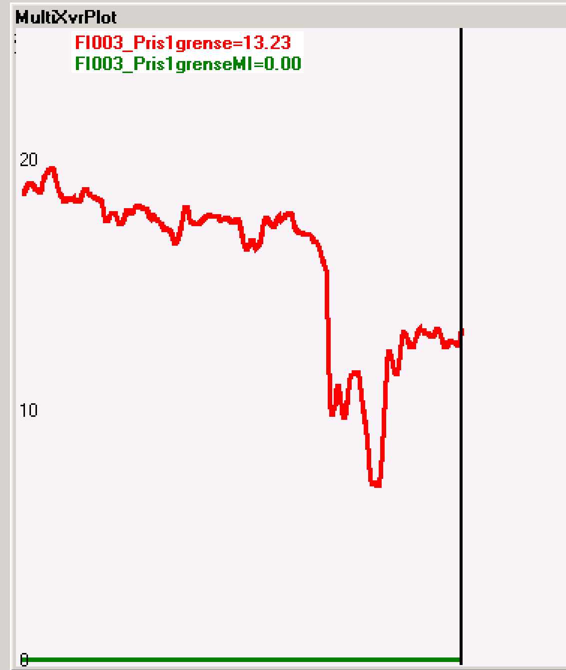
Krakker Optimizer

Priser Føde, Gass, Damp, DCO

Residue	USD/T	741.0
HGO	USD/T	835.0
Fyrgass	USD/T	386.0
Eksportdamp	USD/T	48.6
DCO pris som føde koksanlegg	USD/T	524.0
DCO mengde til koksanlegg	T/H	10.0
DCO pris eksport	USD/T	524.0

Koksgass prisfunksjoner

Fyrgass balanse regassere	T/H	1.07
Minimum fyrgass til CHP	T/H	4.00
Aktuell fyrgass til CHP	T/H	10.53
Fyrgass balanse til CHP	T/H	6.43
Fyrgass balanse inkl CHP	T/H	7.50
Koksgass mengde til Krakker,aktuell	T/H	0.00
Koksgass prisgrense, beregnet	T/H	13.23
Koksgass prisgrense, manuelt satt	T/H	0.00
Koksgass prisgrense switsj (PÅ = beregnet)		☐
Koksgass pris ved fyrgass overskudd	USD/T	0.0
Koksgass pris ved fyrgass underskudd	USD/T	0.0
Koksgass prisgrense	T/H	0.00



LPG prisfunksjoner

PROPEN pris 1	USD/T	1111.0
PROPEN pris 1 max mengde	T/H	30.0
PROPEN pris 2	USD/T	999.0
POLY pris	USD/T	1166.0
A-5000 max fødemengde	T/H	40.0
BUTAN pris	USD/T	950.0
BUTEN pris	USD/T	948.0

RCCN prisfunksjoner

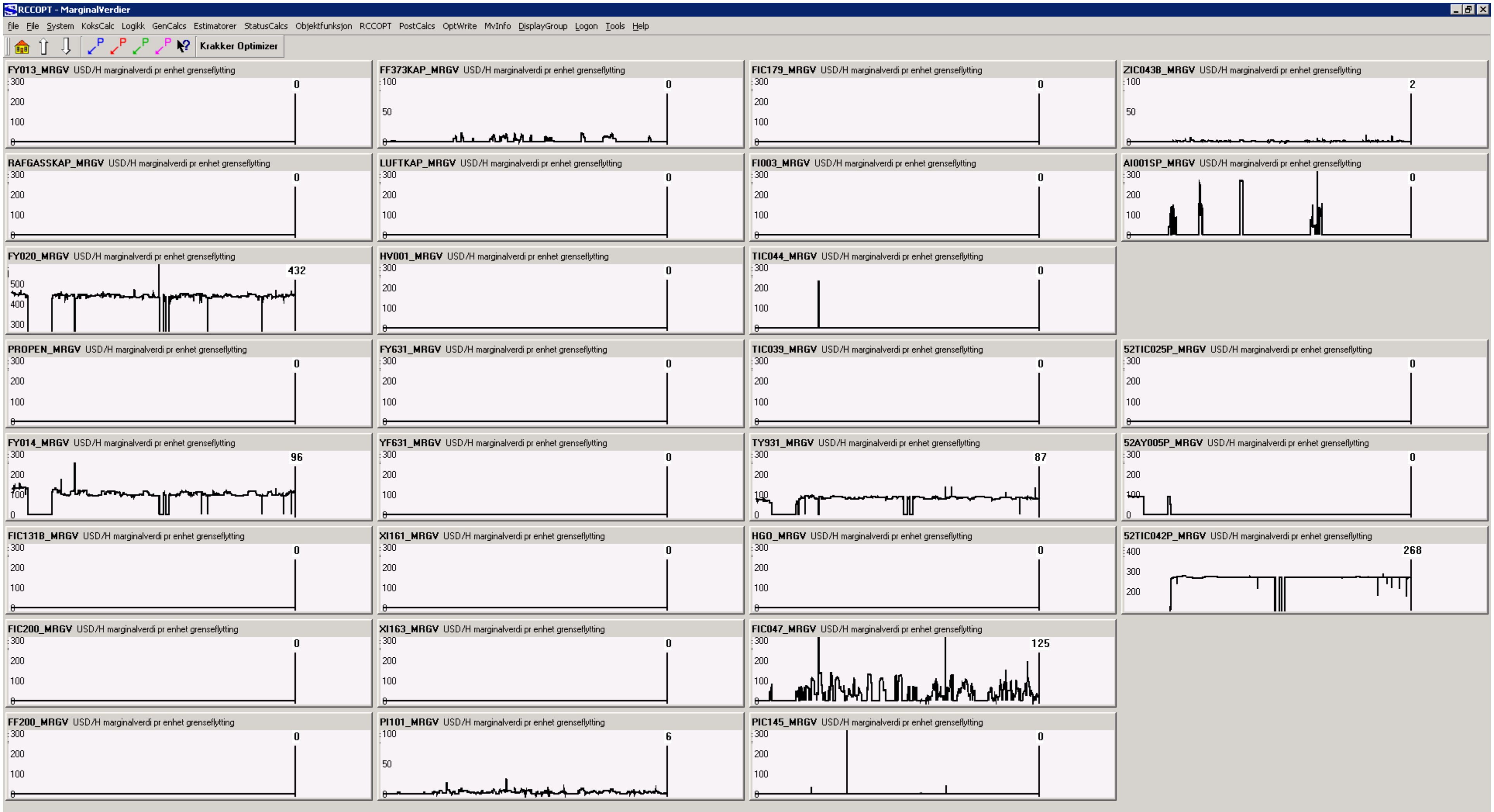
RCCN pris	USD/T	997.0
DENS basisverdi	kg/m3	755.0
MON basisverdi		80.6
MON premie	USD/monenhet/m3	8.80
RON basisverdi		90.7
RON premie	USD/monenhet/m3	8.90
BENZENE basisverdi	vol%	0.87
BENZENE premie	USD/vol%/m3	29.00

LCO prisfunksjoner

HLCO pris til gassolje	USD/T	825.0
Max HLCO mengde gassolje	T/H	30.0
HLCO pris til eksport	USD/T	825.0
Max HLCO mengde eksport	T/H	90.0
ULCO pris til eksport	USD/T	825.0
DENS basisverdi	kg/m3	845.0

RCCOPT Mongstad (Cat Cracker Optimiser)

Marginal values (profit sensitivities of constraints)



RCCOPT Mongstad (Cat Cracker Optimiser)

Implementation

- Process responses fairly linear within the acceptable operation window, steady-state modelling from 4-hours averaged process data for the last 4 years of operation
- Objective function is nonlinear due to quality-dependent value of product flows
- Prices are updated weekly by planning department when rerunning the refinery LP. Much effort has been spent on consistency between LP and RCCOPT s.t. the price set used in RCCOPT contributes to a global refinery optimisation rather than a suboptimal local optimum.
- The first version of RCCOPT was made 15 years ago, but was never in closed loop of several reasons, the most important being pricing mechanisms and model discrepancy issues.
- The current RCCOPT application development started in June 2011, was in advisory mode from Dec 2011 till April 2012, and has been in closed loop since then.
- RCCOPT is currently tightly coupled to 5 standard MPC applications, communicating control signals forth and back. The models are dynamic, and the application executes once per minute.
- The benefit is estimated to 35 - 60 MNOK per year.

Master thesis on a Mongstad-specific MPC case?

Contact me!

MPC in Statoil

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