Combined Heat & Power Production: Micro-CHP with Stirling Engine

Activities at Siemens Building Technologies

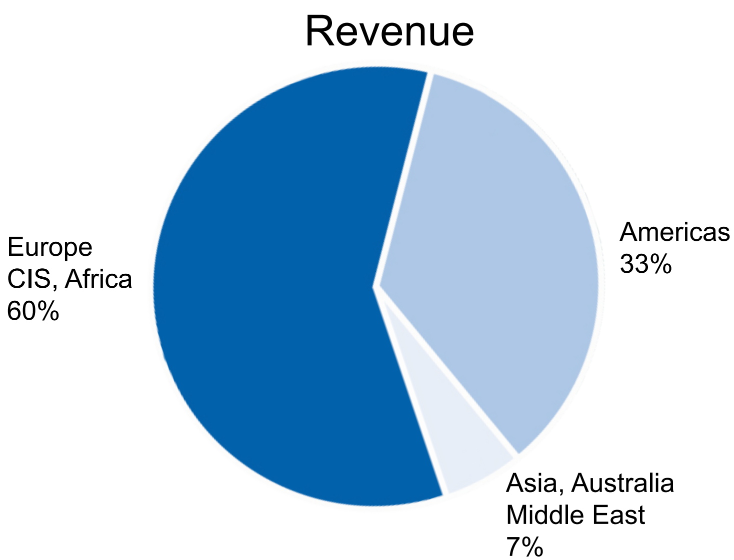
Conrad Gähler, SBT, Zug (CH)

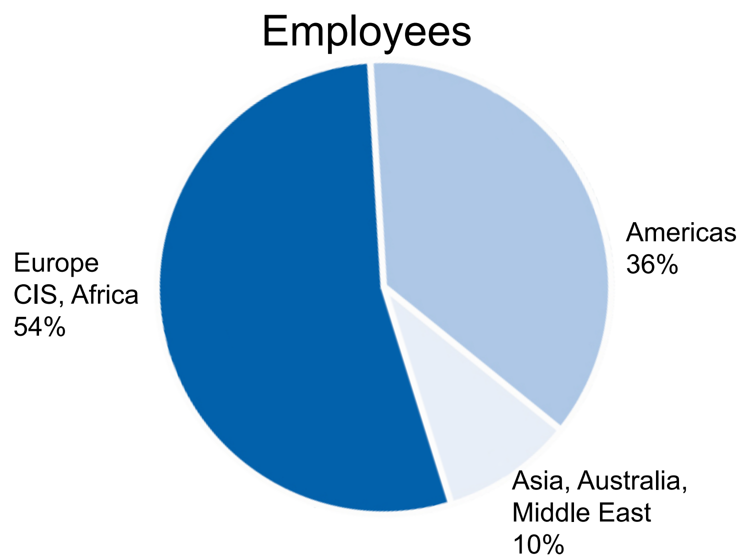
Smart & Efficient Energy Council, Trento, 2009

Siemens Building Technologies (SBT)
Our key figures

SIEMENS

Fiscal year 2008 Oct'07 – Sept'08	SBT	Total Siemens
Revenue (mio. euros)	6.0 G€	
Employees	**38,500**	ca. **500,000**





Building Technologies
Areas of activity

SIEMENS

Security

Fire Safety

Building Automation

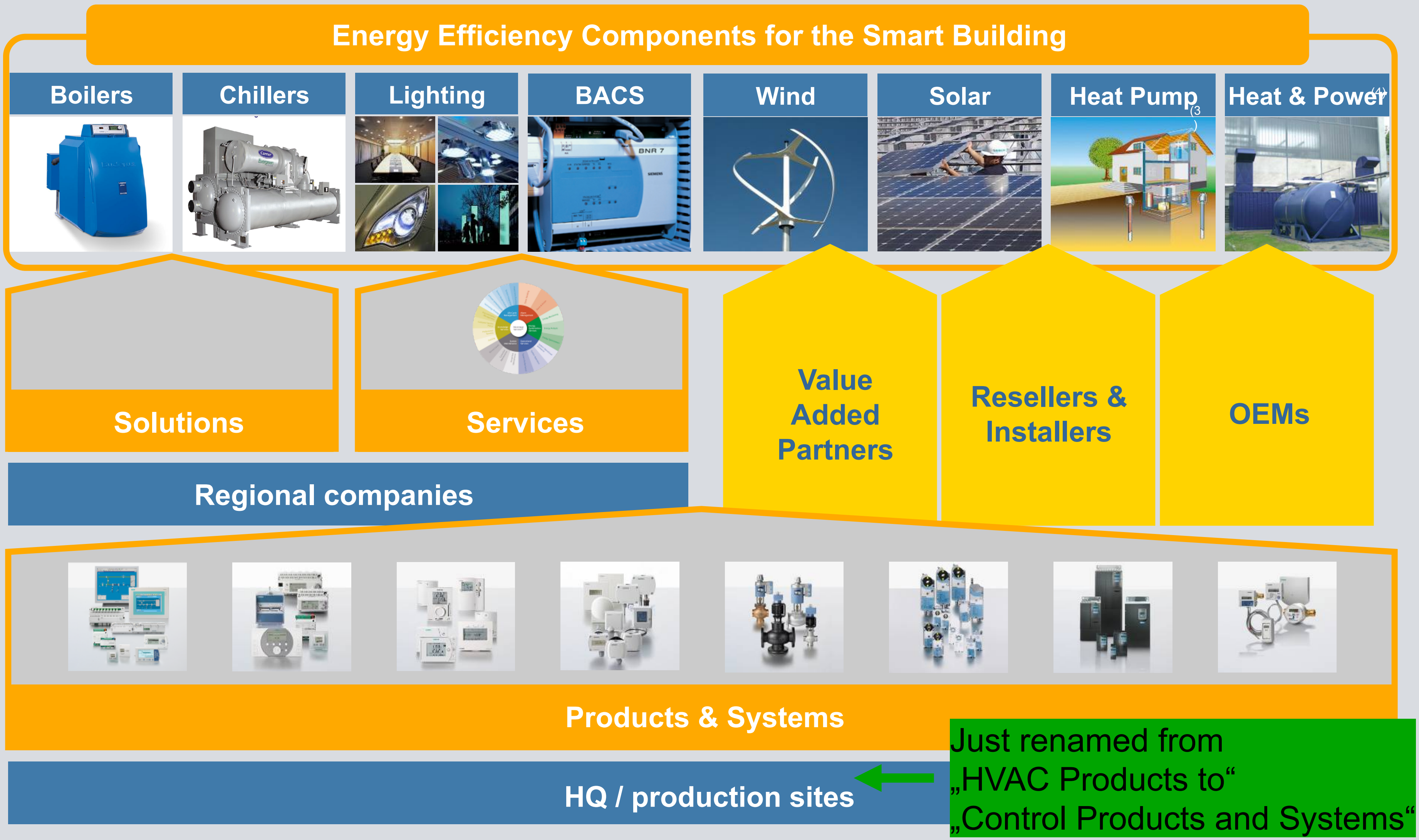
Energy Efficiency

Electrical Installation

Total Building Solutions

SIEMENS

BT Comfort at a glance…



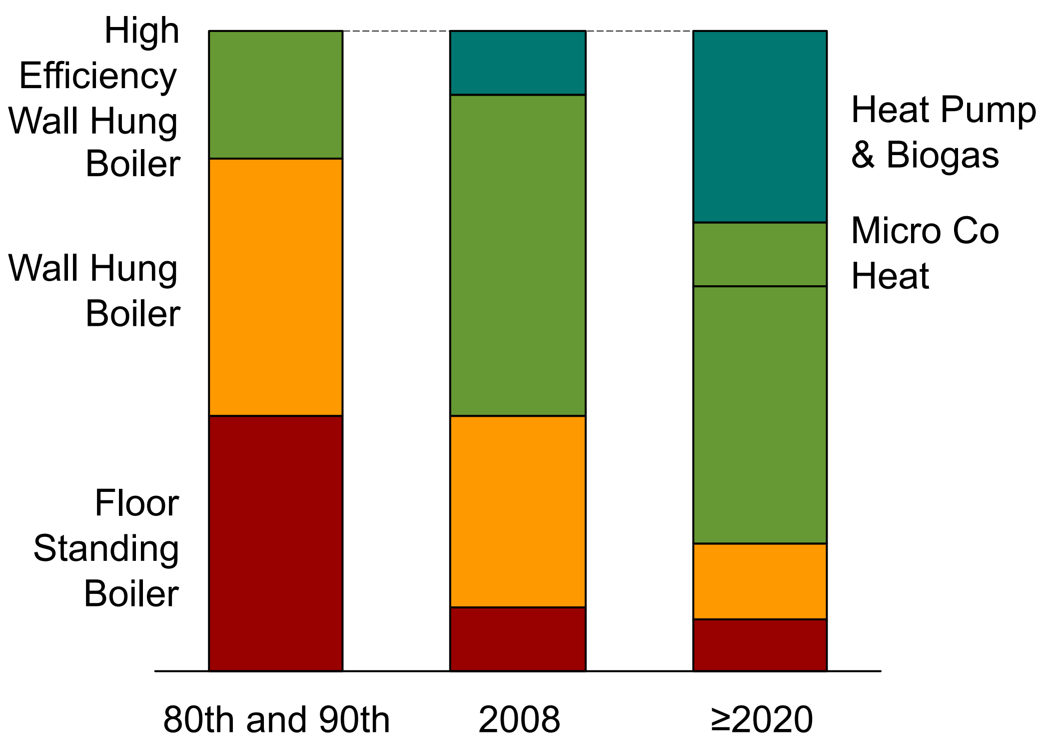
SIEMENS

Agenda

Trends (1)
Alternative energy sources, Renewables

SIEMENS

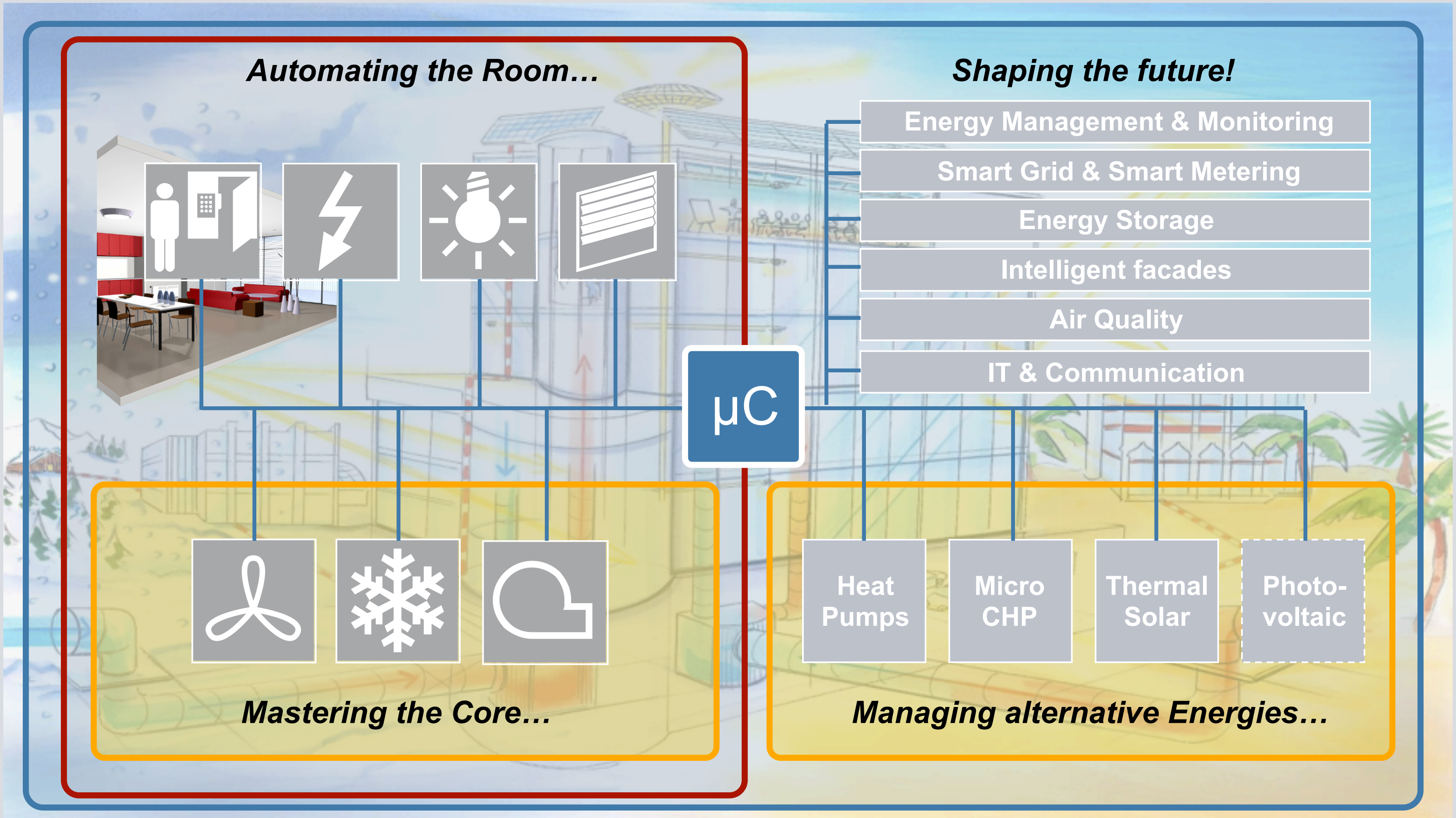
Trend to fragmentation & renewable in residential buildings



Key trends & findings

- Directives for energy- & emission reduction → less heating needed
- Shift from oil & gas towards renewable energies
- Demand based heating, cooling and ventilation

Trends (2)
Integrating more than HVAC



Trends (3)
Energy efficiency

SIEMENS

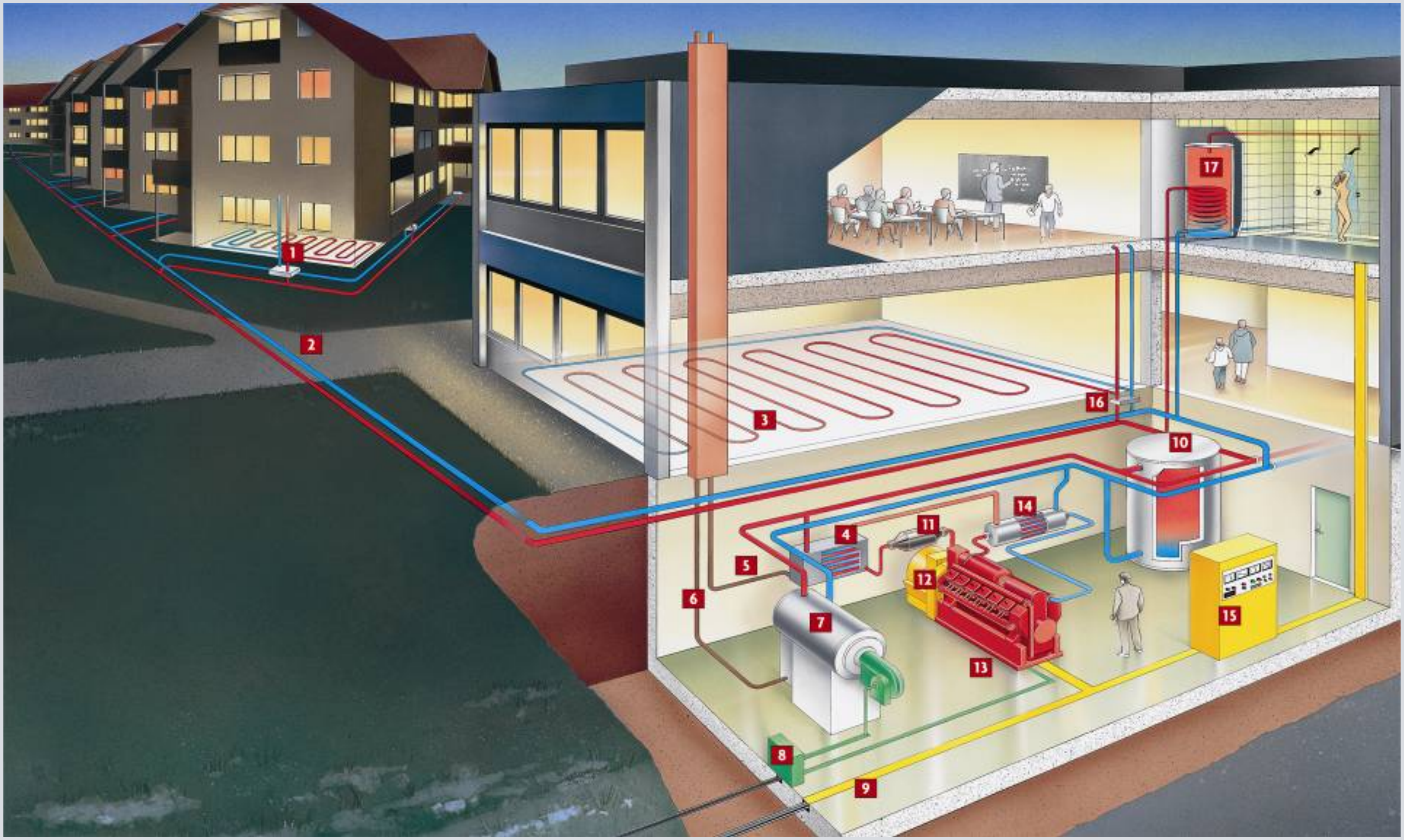
- Laws, regulations,
  committtments of communities and companies
  public opinion / image
- Desigo Building Management System:
  Monitoring, TABS → Low exergy, …
  Additional functionality in next release
- Better quantification of energetic benefit of control functions
  → convince planners, owners, operators, and users
  to ask for the best available technology
  → need for approved results for standard cases;
  simulation tools that can cope with innovative technology;
  norms ...
- Mentioned in all printed matters

Agenda

1	Introduction Siemens Building Technologies
2	Trends in building control (HVAC+)
3	Siemens Micro-CHP Control System (MCS)
4	Micro-CHP: Research
5	… Questions & Answers

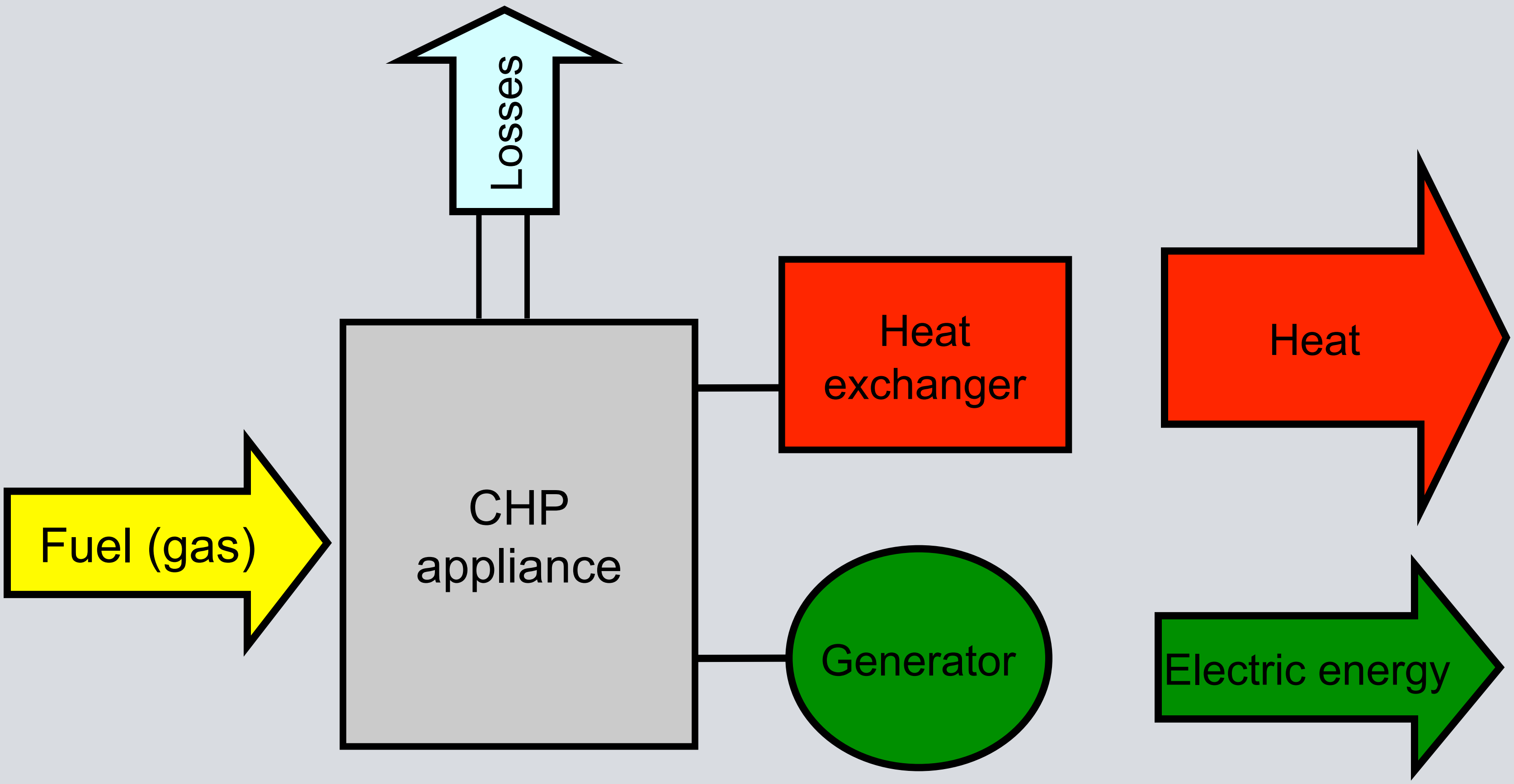
Micro-CHP:
The power plant in the own house

SIEMENS



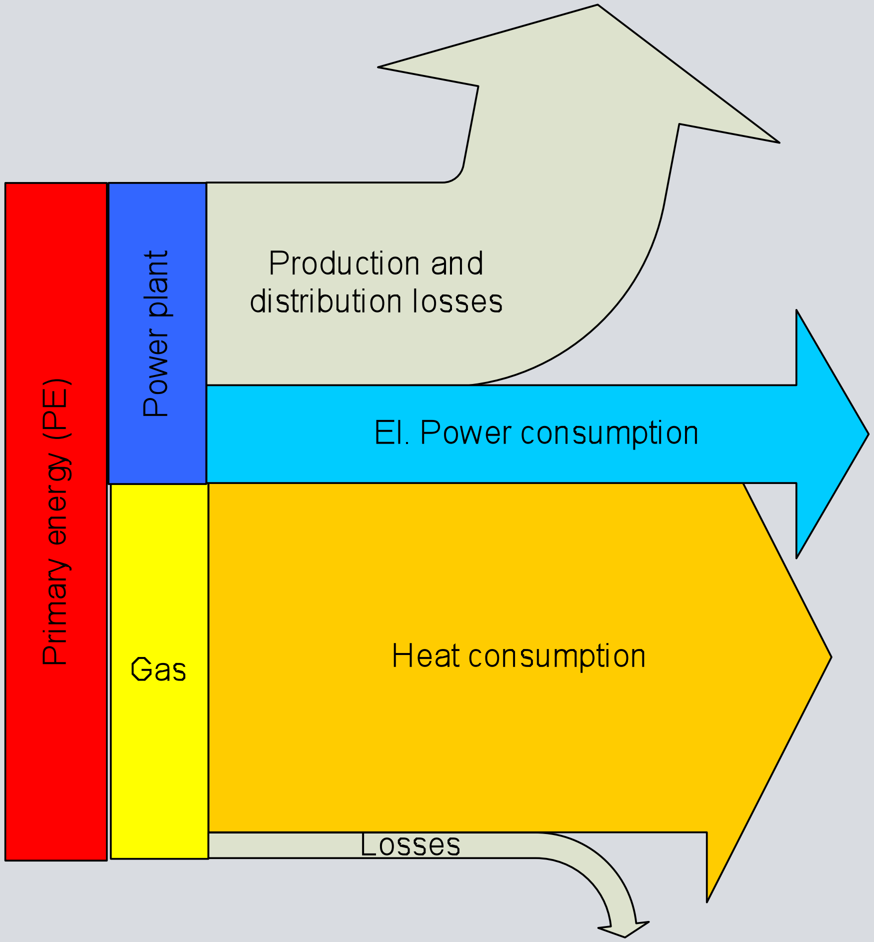
Micro-CHP
Energy flow, principle

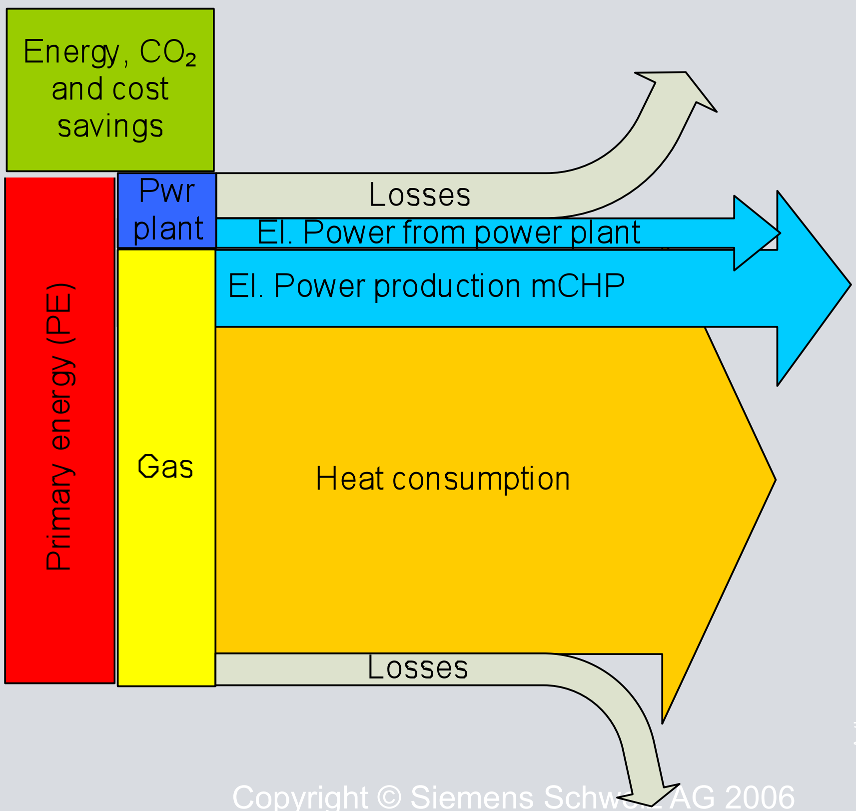
SIEMENS



Micro-CHP
Comparison of energy flows

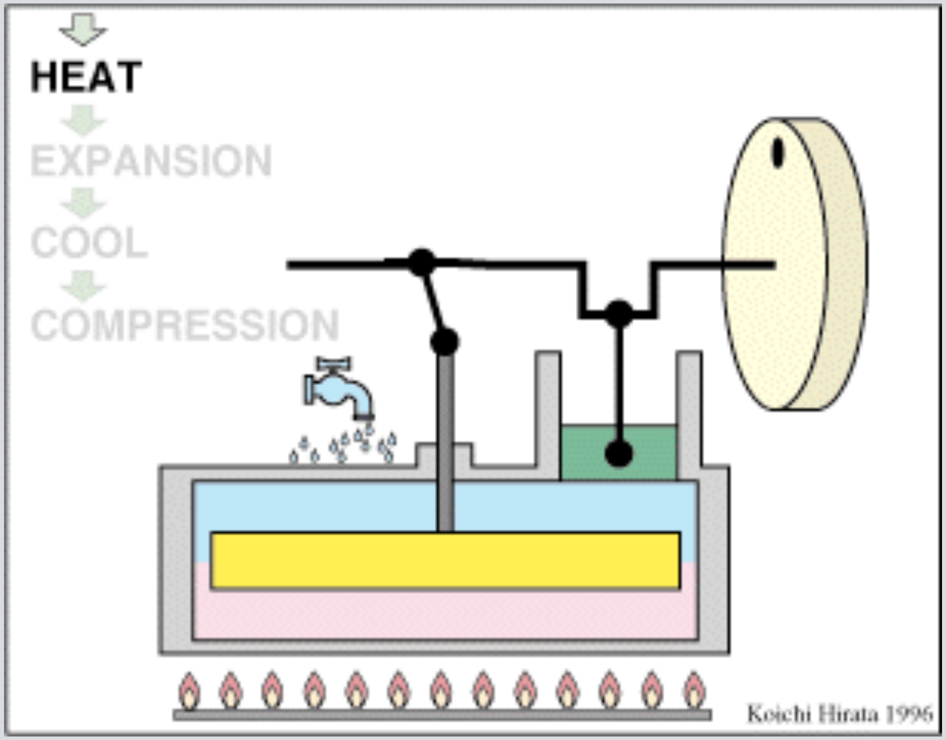
SIEMENS





Stirling engine: Operating principle and key advantages

SIEMENS



Key advantages of SE:

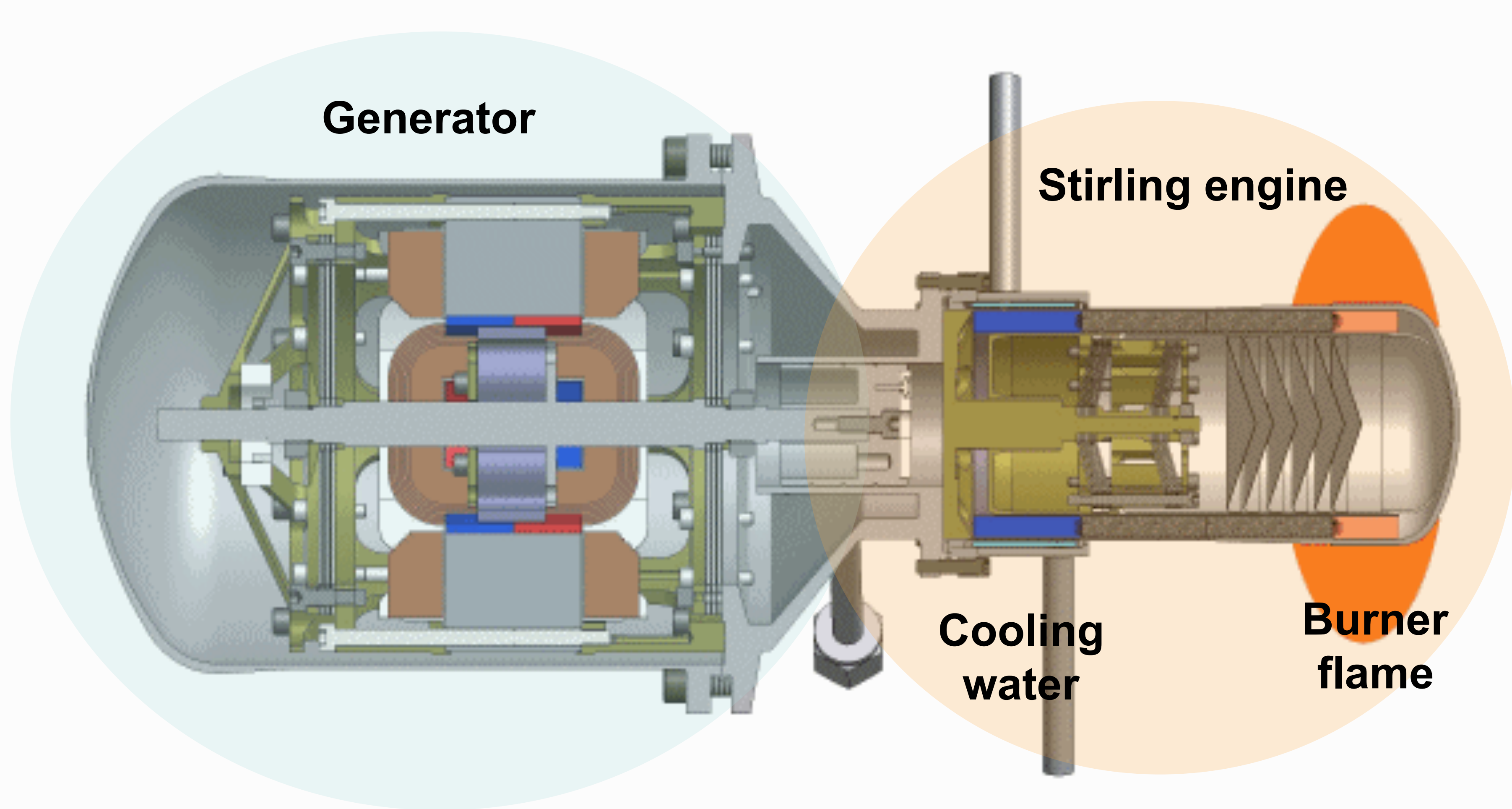
- External combustion
  → „clean“ exhaust gases
- Frequent start/stopps ok
  (comparing to fuel cell)
- Linear arrangement:
  - Running at 50Hz
    → no inverter needed
  - No moving seals
    → maintenance-free
    for whole lifetime

The EU considers domestic heat generation with Stirling-based CHP as one of the most promising technologies to save CO2 in a mid timeline
→ support (Taxes, feed-in tariffs) can be expected

Author

Micro CHP:
Stirling Engine & Generator

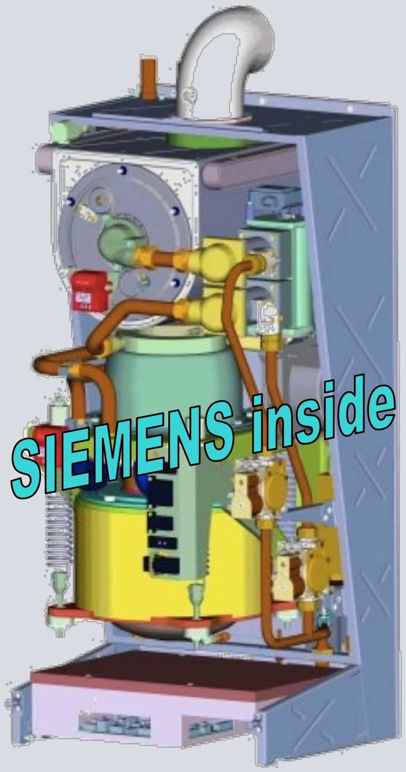
SIEMENS



Author

Micro CHP product development: Partners

SIEMENS



Microgen Stirling Engine

Consortium **MEC**:

European boiler manufacturers:
Remeha, Baxi, and others

Pel: 1 kW
Pth: 6 kW + 10 .. 30 kW

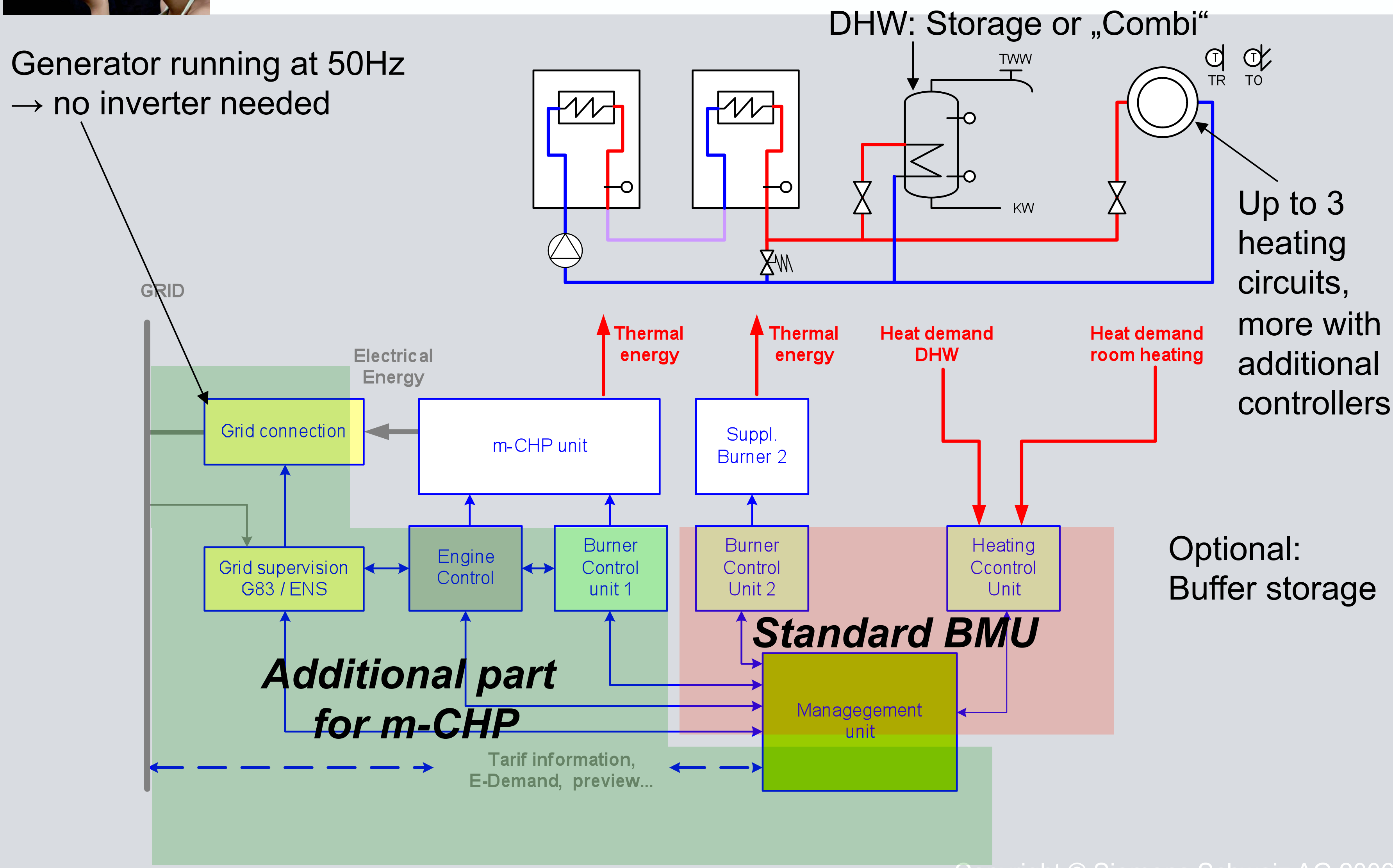
Large field tests 2009
Market introduction 2010

USPs of Siemens solution

- Complete solution: Automatic firing device (gas valve, ignition ...), control (heat production, consumers), grid supervision
- Homogeneous product range for mCHP, conv. Boilers, heat pumps, solar, wood, …

micro CHP
System Architecture

SIEMENS



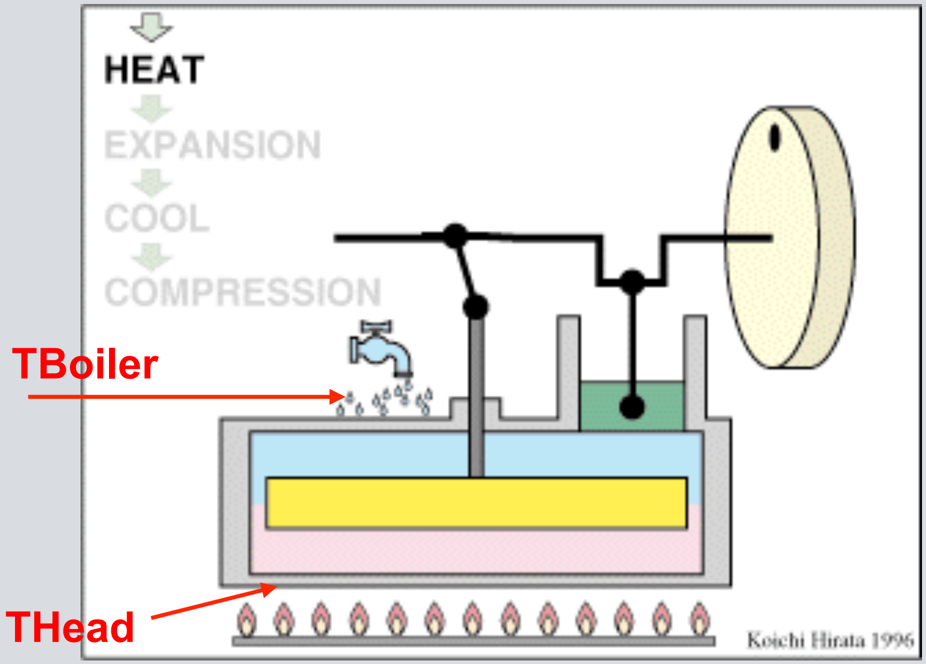
micro CHP
Grid supervision

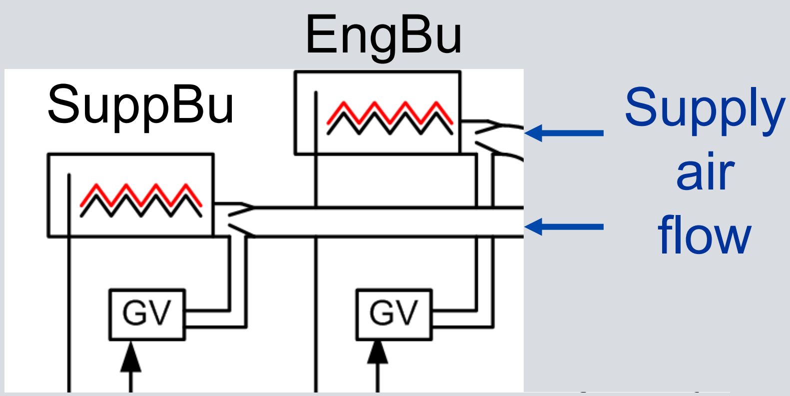
- The electric grid must be supervised
  Generator must be disconnected from the grid very quickly in case of
  - Over-/undervoltage
  - Over-/underfrequency
  - Missing grid (➔ Islanded operation currently not supported)
- Hardware by Siemens A&D
- Norms are country specific:

• GB, NL, …	G83/1	single measurement
• D, A, CH, F	VDE 0126-1-1	redundant measurement

MCS:
Controller tasks & challenges

SIEMENS





To be optimised
- Minimize SuppBu operation
- Maximize EngBu operation

Without too many starts/stopps!
See next topic (Model Predictive Control)!

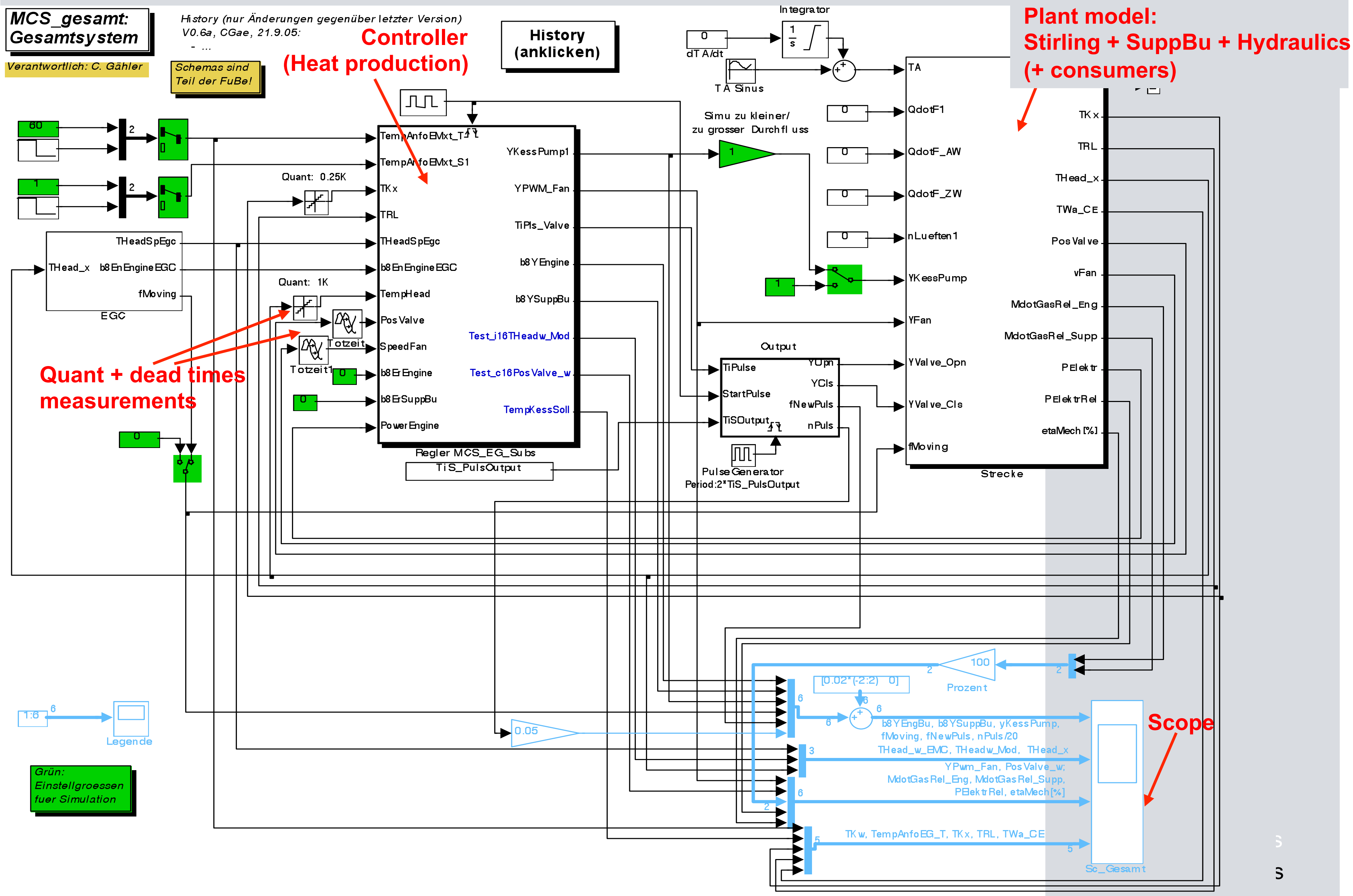
Stirling Engine (6kWth, 1kWel), Supp Burner (10..30kW)

2 Gas valves, ignition; Grid connection and supervision; boiler pump, DHW div. valve

Modulate burner power via supply air mass flow

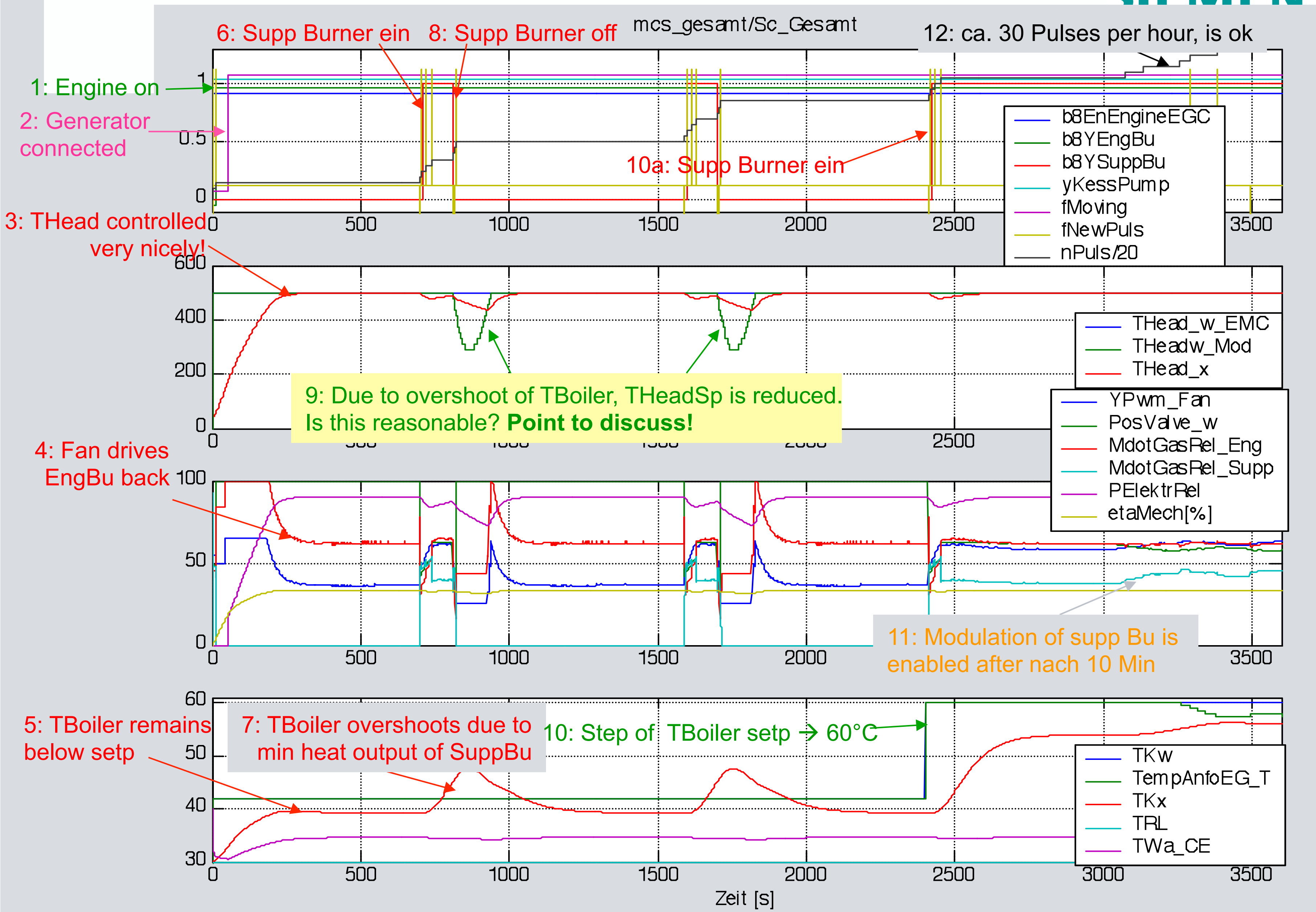
To be controlled: THead (500°C), TBoiler (according to heat demand, e.g. 55°C)

MCS: Model-based design with Simulink



MCS: Simulation results

SIEMENS



SIEMENS

Comparison of workflows

Control problems become apparent only here

„Classical“

Functional specification (requirements)

SW-Spec HVAC

Manual Coding

Module test

Device test (=Test Regelgerät)

Integration in appliance, at customer (England)

Classical: Difficult to see what to change in case of problems

Controller design with Simu: In case of problers with real HW: Good understanding → targetted improvements possible

Model-based design (Simulink)

Functional specification (requirements)

Simulink-Model =verified SW-Spec: Proof of control quality etc.

Code-Generation

Implementation

Module test

Device test

Hardware-in-the-loop test

Integration with engine, at customers (England)

Worked at once without changing one single parameter change!

With Code generation: Changes can be made very quickly & reliably in test phase!

Agenda

1 Introduction Siemens Building Technologies

2 Trends in building control (HVAC+)

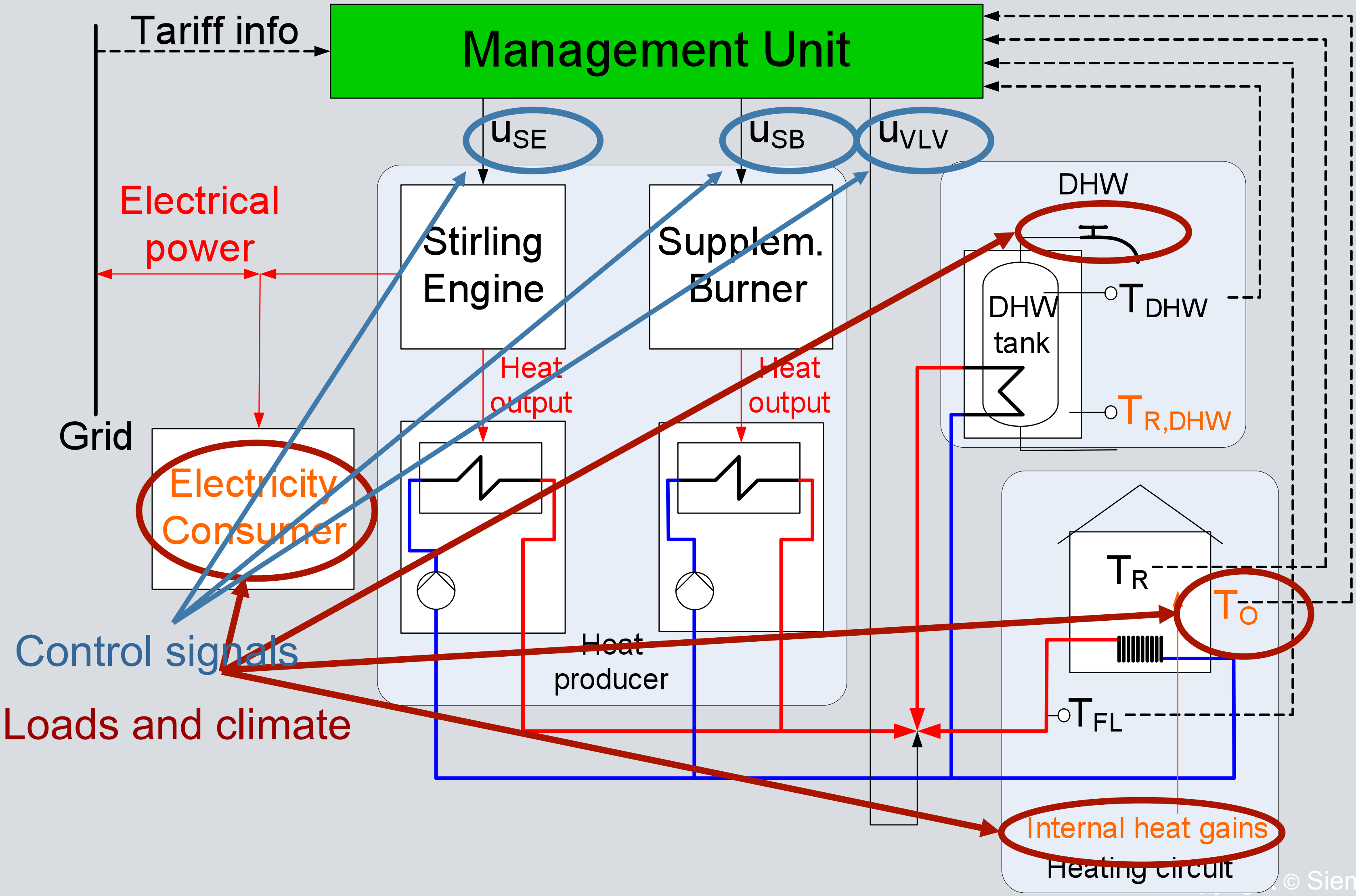
3 Siemens Micro-CHP Control System (MCS)

4 Micro-CHP: Research

5 … Questions & Answers

Optimal control of mCHP building energy system with model predictive control (MPC)

SIEMENS



Optimization method:
Performance bound with Model Predictive Control

1. The control must satisfy the requirements for room &DHW temperature
   - PE-optimal control
   - Cost-optimal control

2. We assume perfect a-priori knowledge of
   - System dynamics
   - Future wheather, hot-water draws etc.

3. We compute the best theoretically possible operation strategy with
   - Model predictive control (MPC)
   - Linear programming (LP)

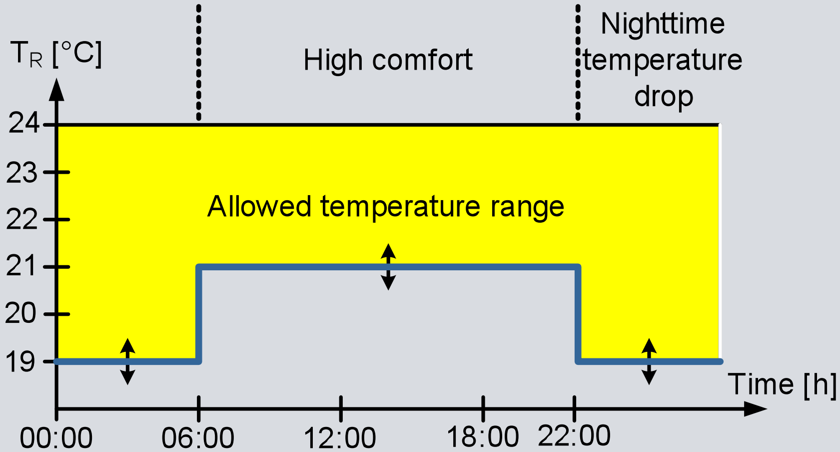
4. This result is called ***performance bound***

Focus / Questions

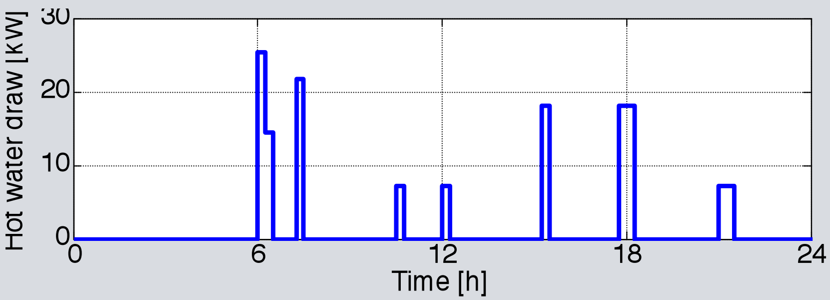
- ***Control strategy:***
  What do cost- and PE-optimal operations look like?
- ***Performance assessment:***
  Possible cost and PE savings?
- ***Impact of different parameters*** on optimal control and performance
  - Sizing of Stirling engine
  - Etc.

Optimization constraints; Loads, climate, and tariffs

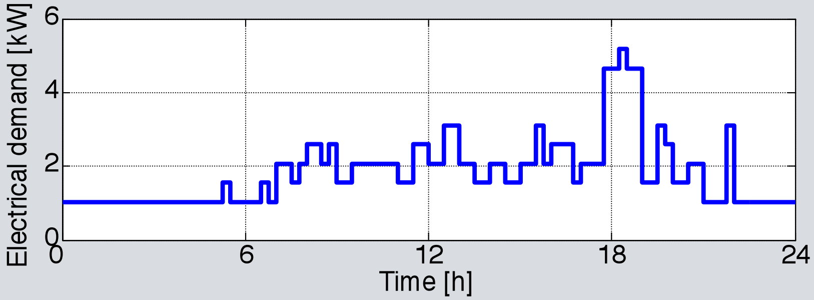
- Room temperature



Hot water demand



- Electricity demand



- Climate, Gas & electricity tariffs: Zurich (Switzerland)

Building types

Three types of buildings (Old, WSV95, EnEV2000):

- 4 apartments, 3 occupants each
- Floor space = 150 m2
- Sizing of SE and SB adapted to building insulation quality

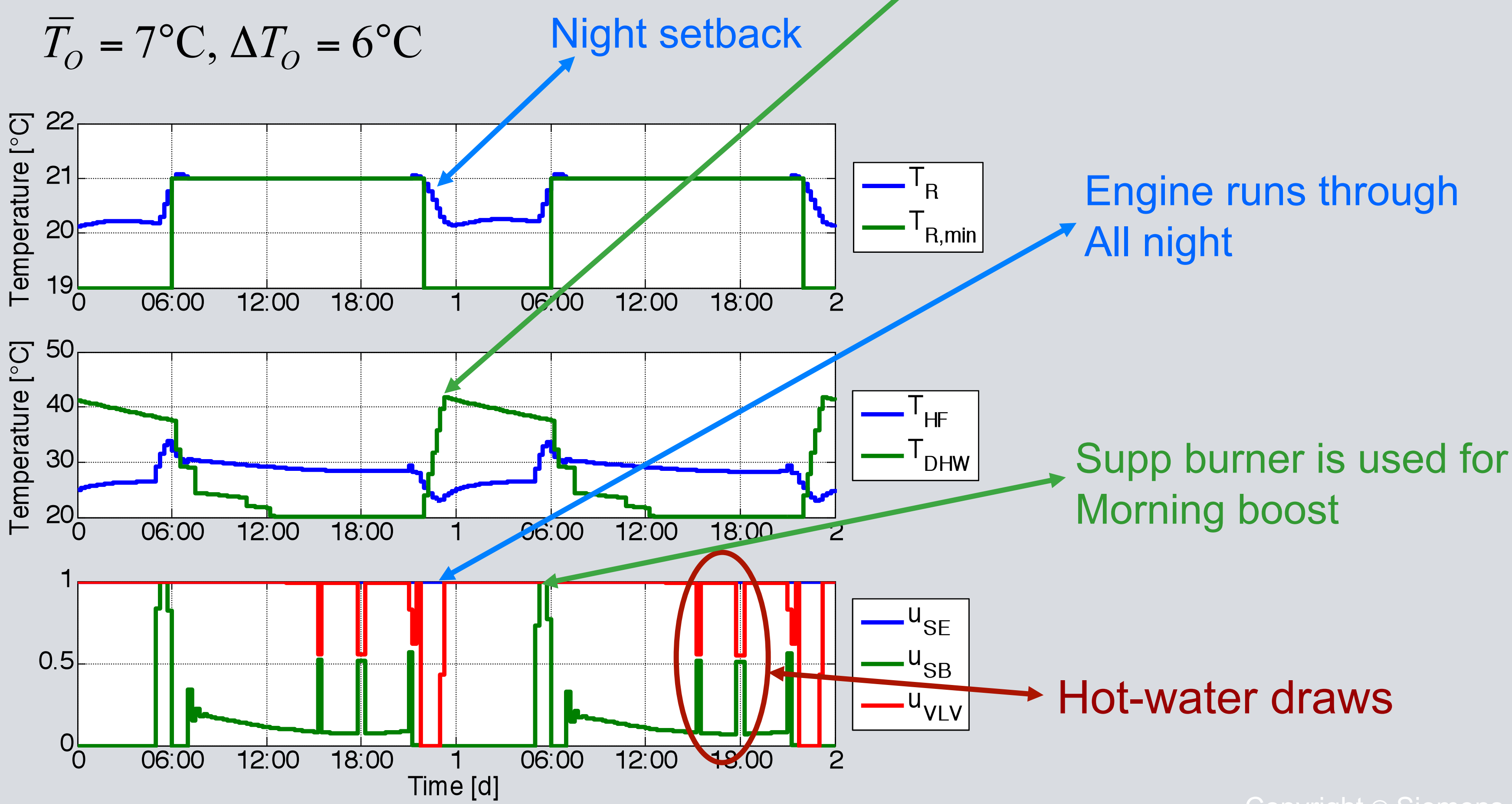
Nominal values		Old (poor)	WSV95 (medium)	EnEV2000 (good)
Building heat losses	[W/K]	446	194	88
Building time constant	[h]	94	162	396
Stirling Eng. heat output (η_{th}=70%)	[kW]	19.9	9.4	5
Stirling Eng. Electr. Power (η_{el}=25%)	[kW]	7.1	3.4	1.8
Supp burner heat output (η_{th}=95%)	[kW]	41	18	8.2

Simulation results:
Diurnal progression (base case)

SIEMENS

- Building type: Old
- PE optimization

$$\bar{T}_O = 7°C, \Delta T_O = 6°C$$



Efficiencies

SIEMENS

Stirling engine: ηel,ref = 25% (as Solo Stirling engine. Microgen has less)

Reference plant: $\eta_{el,ref}$ = 50%

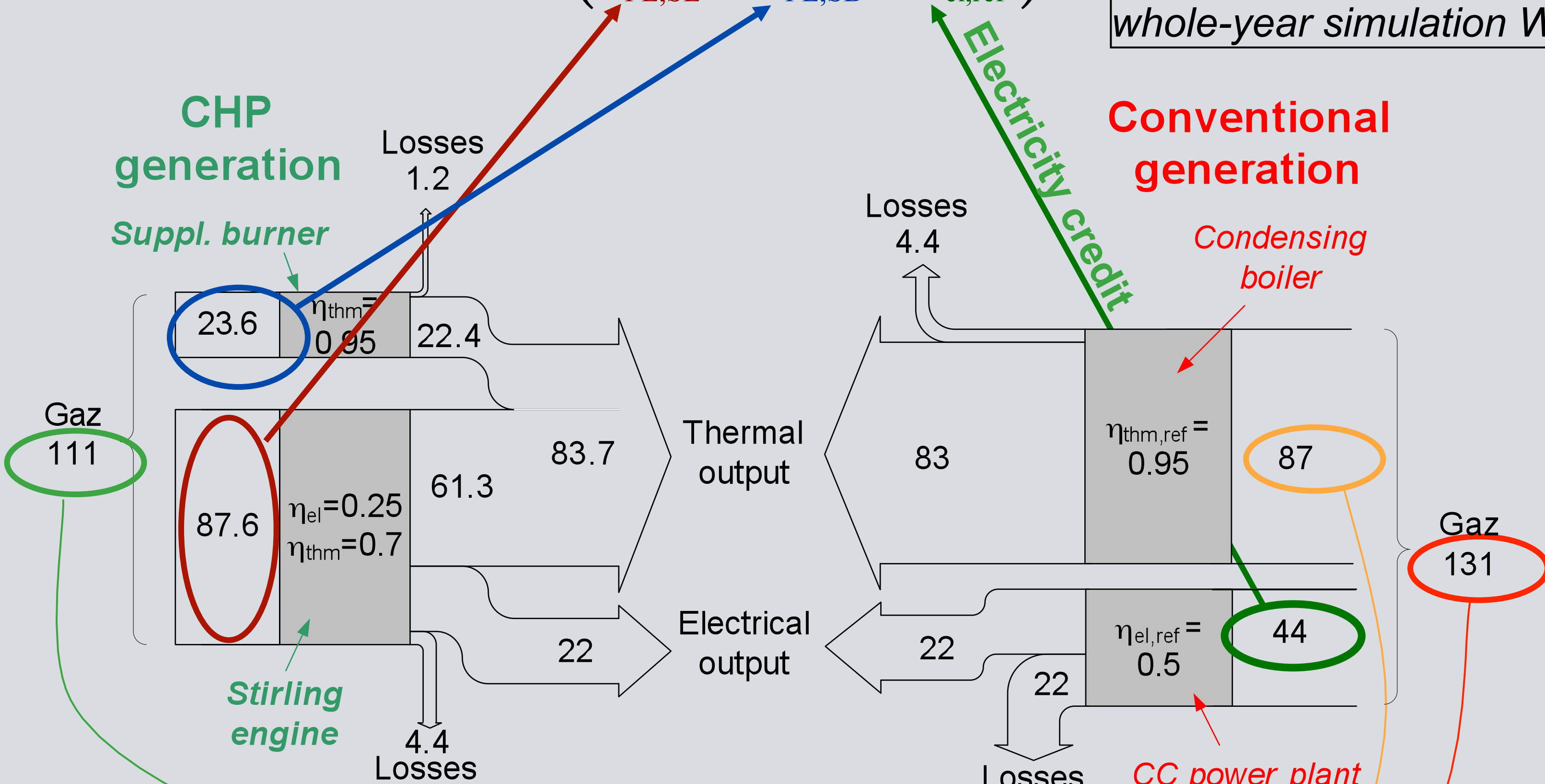
- Marginal approach, modern CC gas plant with $\eta_{el,ref}$ = 56%
- 10% grid losses *always* attributed to ref plant (import, export, in-house consumption)

Primary energy optimization: Energy flow diagram

SIEMENS

Optimization criterion: $\min\left(E_{PE,SE} + E_{PE,SB} - E_{el,ref}\right)$

Numbers: MWh, from whole-year simulation WSV95



Performance assessment:

Savings: 131 – 111 = **20**

Rel. Savings:

20 / 87 = **22.9%**

Performance assessment: Whole-year simulation results

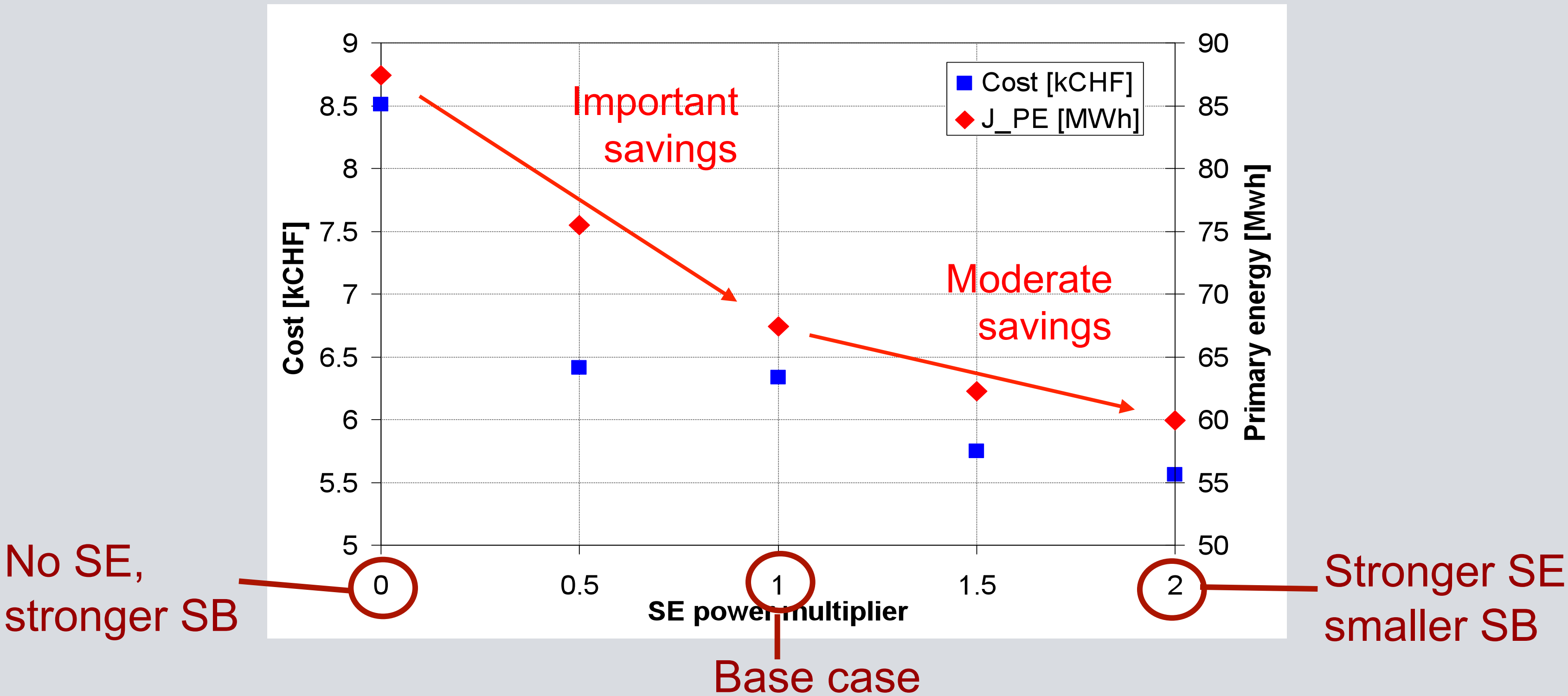
SIEMENS

			Building type		
			Old	WSV95	EnEV2000
Conventional heating (=gas burner alone)		Cost	CHF 15,169.--	CHF 8,512.--	CHF 5,650.--
		PE consumption for heating	196.5 MWh	87.4 MWh	40.5 MWh ($67 kWh/(m^2a)$)
CHP system	Cost-optimal	Cost saving	28.5%	28.1%	23.3%
		PE saving	20.6%	21.9%	23.7%
	PE-optimal control	Cost saving	27.5%	25.5%	20.6%
		PE saving	21.4%	**22.9%**	24.9%

- Equivalent foll-load hours: ca. 270d/year

Simulation results:
Variation of the sizing of the Stirling Engine

SIEMENS



More powerful SE ⇒ less expensive, less PE consumption

⇒ but higher investment costs

⇨ Optimal sizing can be determined by including investment costs

Research Conclusions

- Method allows to determine possible savings
- CHP saves 20%-30% money and 20%-25% PE
  (with assumptions used, e.g. 56% el. Ref. plant,
  in optimal control operation)
- Results give hints and benchmark for simpler control strategies
- Influence of different parameters on optimal control
  - Sizing of Stirling engine, supplementary burner
- Attractive prices for feed-in electricity help to exploit potential