From Pilot Plant to Series Product: Technical Optimisation of Hydrogen Fueling Stations

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FCELL 2013, Stuttgart, 30.09.2013

Simon Schäfer

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The Linde Group:
based on two pillars with extensive synergies

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Linde Gas

Linde Engineering

Our competence on hydrogen

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Linde covers the entire hydrogen value chain

Production

Conventional
(e.g., SMR)

Green
(e.g., BTH)

Supply/Storage

CGH2 storage

LH2 storage

Onsite SMR

Onsite Electrolysis

Compression

Ionic compressor

Cryo pump

Dispenser

350 bar

700 bar

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Linde's Hydrogen Portfolio

Linde's Hydrogen Fueling Technologies

Deep Dive: Technical Optimisation

Infrastructure Outlook

References

Linde's advanced hydrogen fuelling technologies:
Ionic compressor & cryo pump

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The Ionic Compressor

- High throughput of 33,6 kg/h at 900 bar[1]
- Energy consumption reduced by 25%[2]
- Very small number of moving parts (liquid piston)
- Reduced wear and long service life
- Fulfils industry standard SAE J 2601

The Cryo Pump

- Very high throughput of up to 120 kg/h at 900 bar
- Energy consumption reduced by 70%[2]
- Small thermal management system
- High reliability, little maintenance effort and low costs
- Fulfils industry standard SAE J 2601

[1] For one compressor. Modular setup allows for higher throughputs.
[2] In comparison to a conventional piston compressor

Reference projects prove technological maturity

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Linde reference projects

Key facts

— More than 70 hydrogen stations equipped in 15 countries

— More than 350,000 successful fuellings

— Leading supplier of hydrogen fuelling technologies

Key Learnings

- **Technological maturity reached**
- **High level of standardisation reached**
  - Standardised fuelling protocol SAE -J2601
  - Standardised H2 quality
- **Comparable fuelling experience**
  - 3 min / fuelling
  - Touch & feel like conventional stations
  - Integration into existing infrastructure

Market Requirements on Hydrogen Fueling Infrastructure as a Series Product

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Market Requirement	Linde Technology
Small Footprint	▪ System integration
Energy Efficiency	▪ Efficient compression technologies and effective thermal management
Reliability	▪ Use of durable components
Service & Maintenance	▪ Standardised service & maintenance concepts including spare part management and technician service
Low Capex/Opex	▪ Standardised and modular systems
Steady further Development	▪ Further technical optimisation

IC90 for serial production
„IC90"

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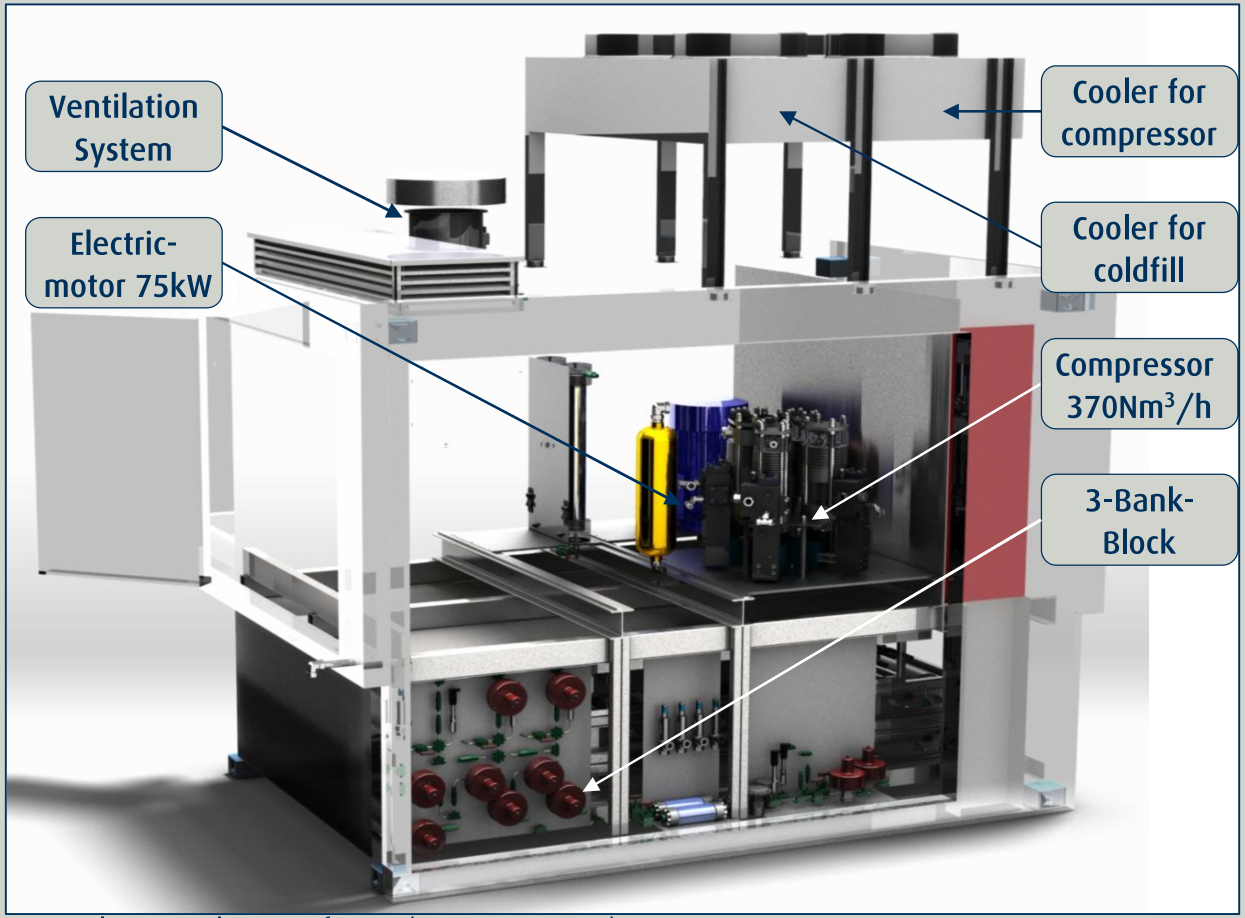

Example: New design of IC90 (US+EU Version)

Layout & performance

- Ionic compressor for **H2**
- Small footprint: **2,7m x 4,3m**
- 5-stage compression
- Max. delivery rate: 370Nm3/h = 33,6kg/h
- Min. input: 5bara
- Max. output: 1.000bar
- Noise emission: <75dB(A)
- Supply: gaseous or liquid
- Option for capacity upgrade (33,6kg/h = 67,2kg/h)
- **Same container for US and EU model**

Standardized HFS Layout Cryopump

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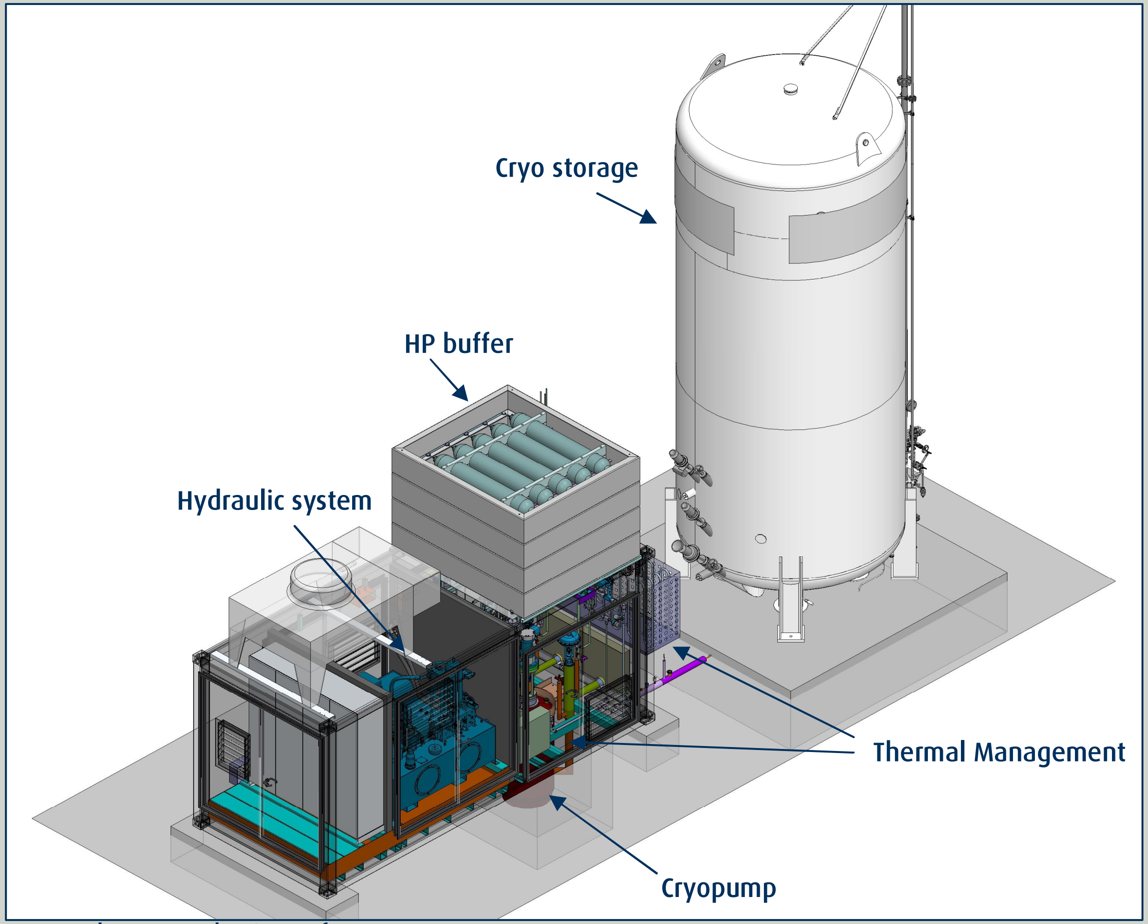

Example: New design of Cryopump

Facts

- Cryopump for **H2**
- Small footprint: **20 ft' container**
- 1-stage pressurization
- Max. delivery rate: 120kg/h
- Min. input: 2 bara
- Max. output: 900bar
- Noise emission: <74 dB(A)
- Supply: liquid

Development of HFS Size
Ionic Compressor

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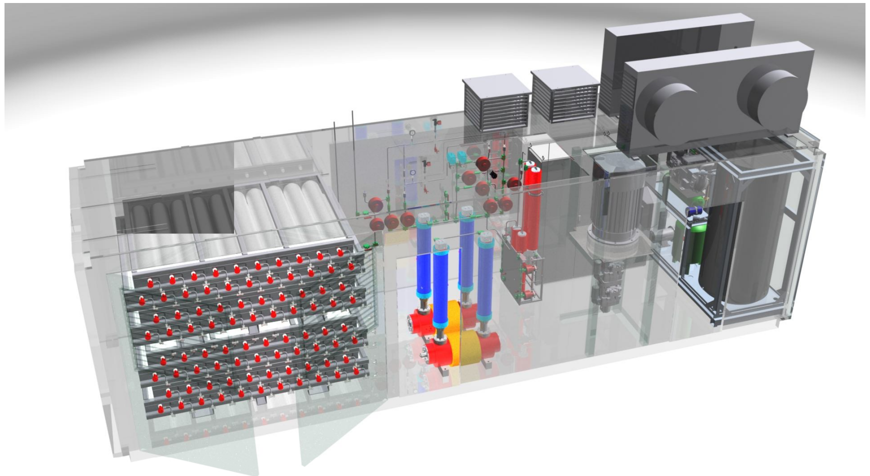
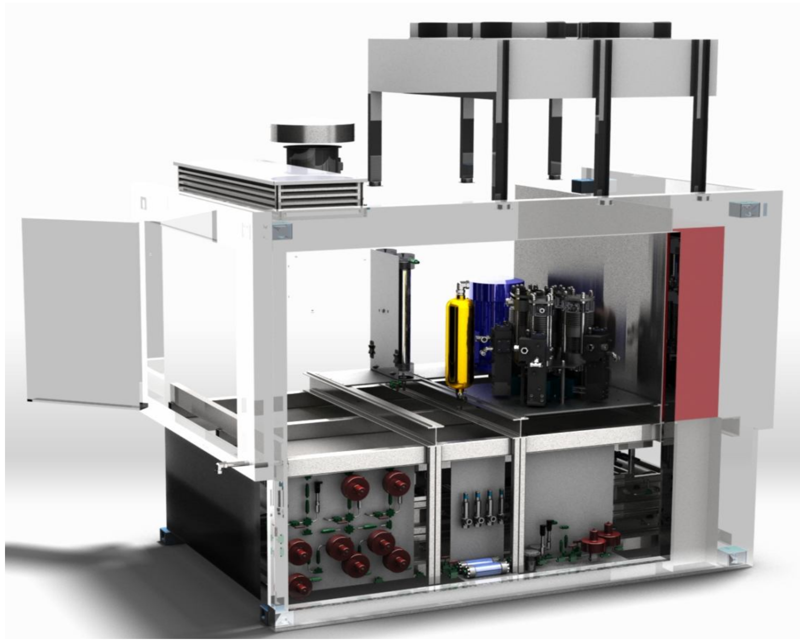
HFS, Type Hydrogear 2011: 30 ft Container



HFS, Type IC90 2013: 14 ft Container



Development of HFS Size
Cryopump

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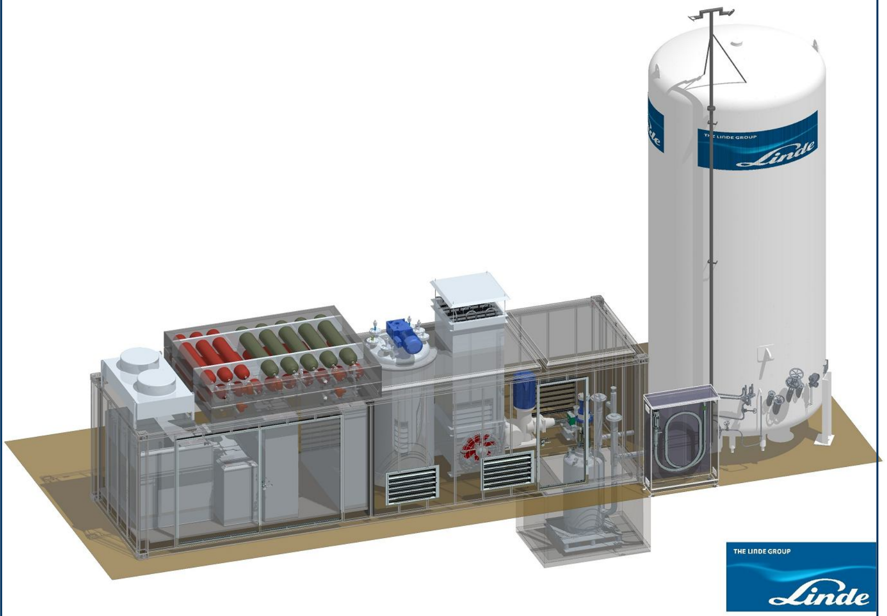
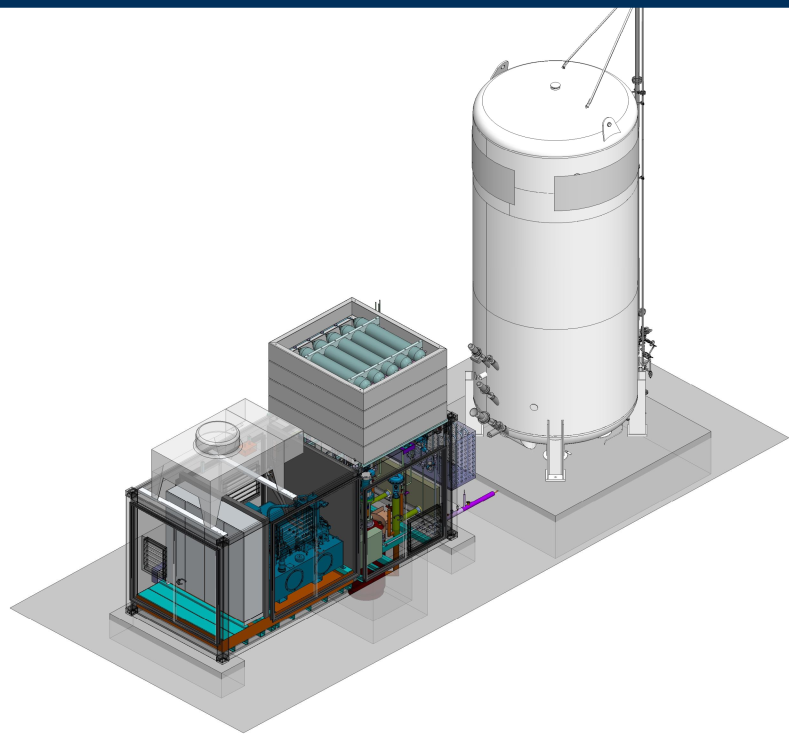
HFS, Type CP 2011: 30 ft Container



HFS, Type CP 2013: 20 ft Container



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Technical Optimisation
Example: Optimisation of Cryopump Technology

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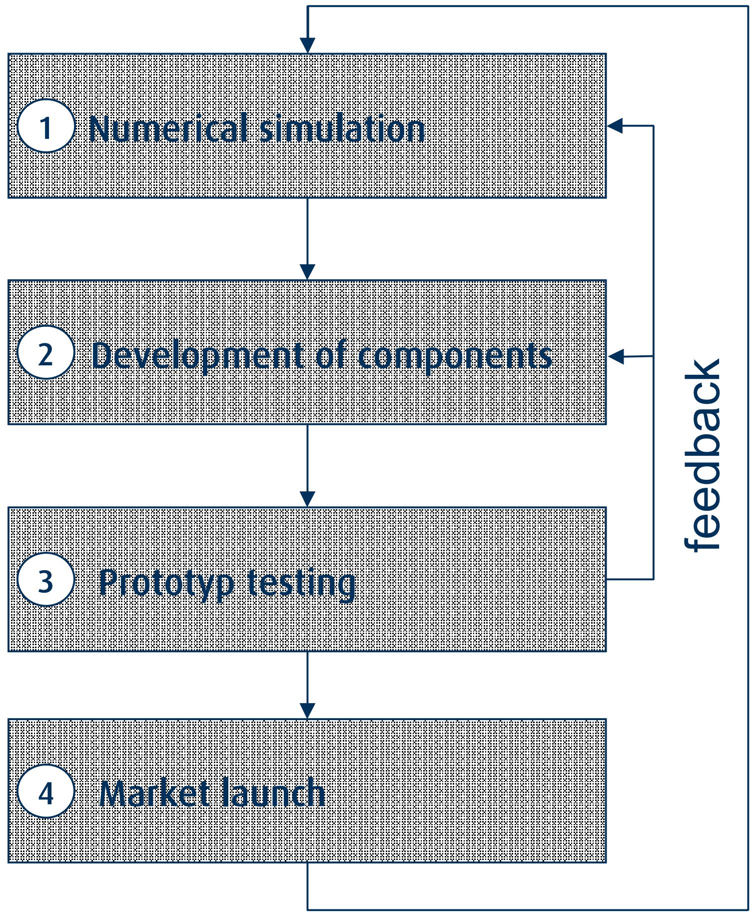
Project Example:

- Project "Further Development of the Cryopump Technology" since 04/2012
- Funding support of overall project by National Innovation Programme Hydrogen and Fuel Cell Technology (NIP)
- Linde AG – Gases Division – Hydrogen Solutions
- Ongoing PhD-Thesis on numerical simulation at Institute of Plant and Process Technology - Technische Universität München

Gefördert durch: Bundesministerium für Verkehr, Bau und Stadtentwicklung

Koordiniert durch: NOW Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie

Technical Optimisation Cycle



Numerical Simulation
What is good for?

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Result	Description
Knowledge	Understanding of thermodynamical conditions
Prediction	Prediction of system behaviour
Evaluation	Test and evaluation of new system designs
Optimisation	Optimise existing systems

Numerical Simulation
Methodical Approach [1]

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Workstep	Description
Simulation target	▪ Prediction of thermal behaviour of the hydrogen fueling station
Theory basis	▪ Applicable model theory e. g. physical laws, equations of state
Mathematical model	▪ Setup of mathematical equations ▪ Implementation in Matlab/Simulink-Software
Validation	▪ Check model validity
Simulation	▪ Use of model for simulation target

Mathematical Model
Balance equations [1]

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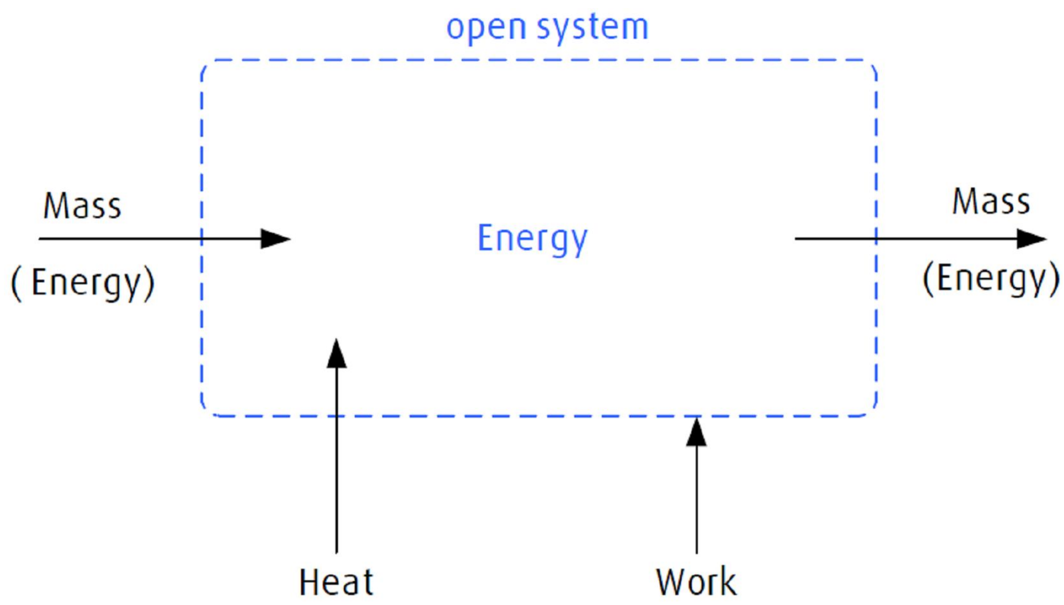

Material Balance

$$\left(\text{Rate of accumulation of mass}\right) = \left(\text{Rate of mass flow in}\right) - \left(\text{Rate of mass flow out}\right)$$

Energy Balance

$$\left(\text{Rate of accumulation of energy}\right) = \left(\text{Rate of energy inpute due to flow}\right) - \left(\text{Rate of energy output due to flow}\right) + \left(\text{Rate of energy inpute due to transfer}\right) + \left(\text{Rate of work done on the system}\right)$$

Mathematical Model
Example: Pipe

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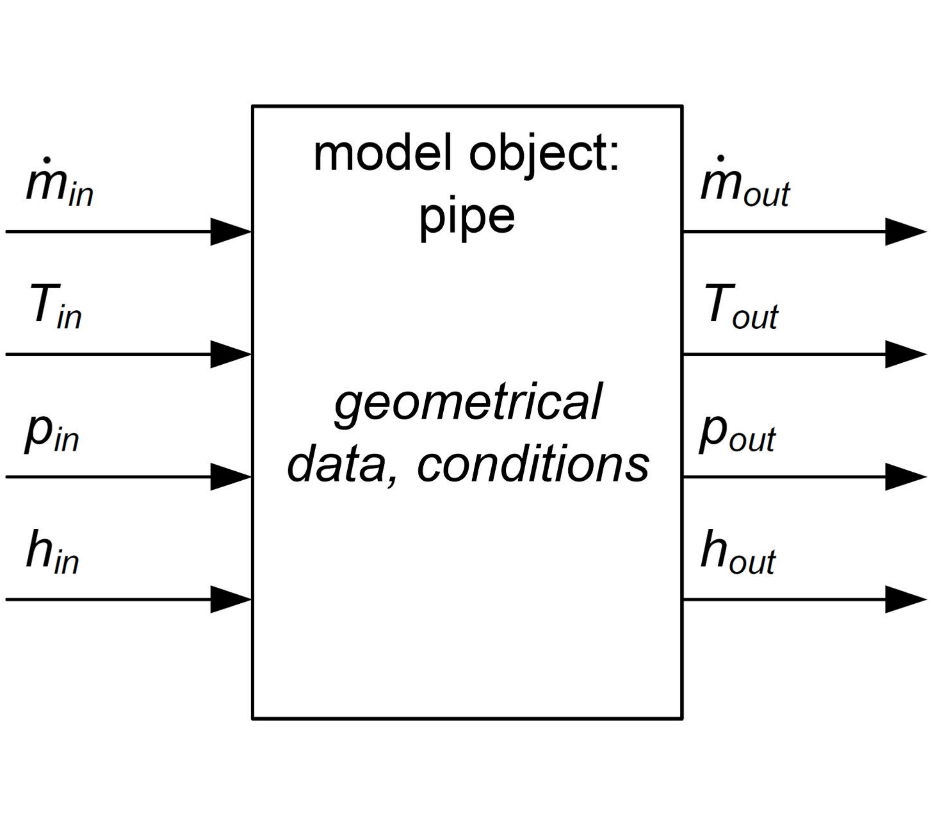
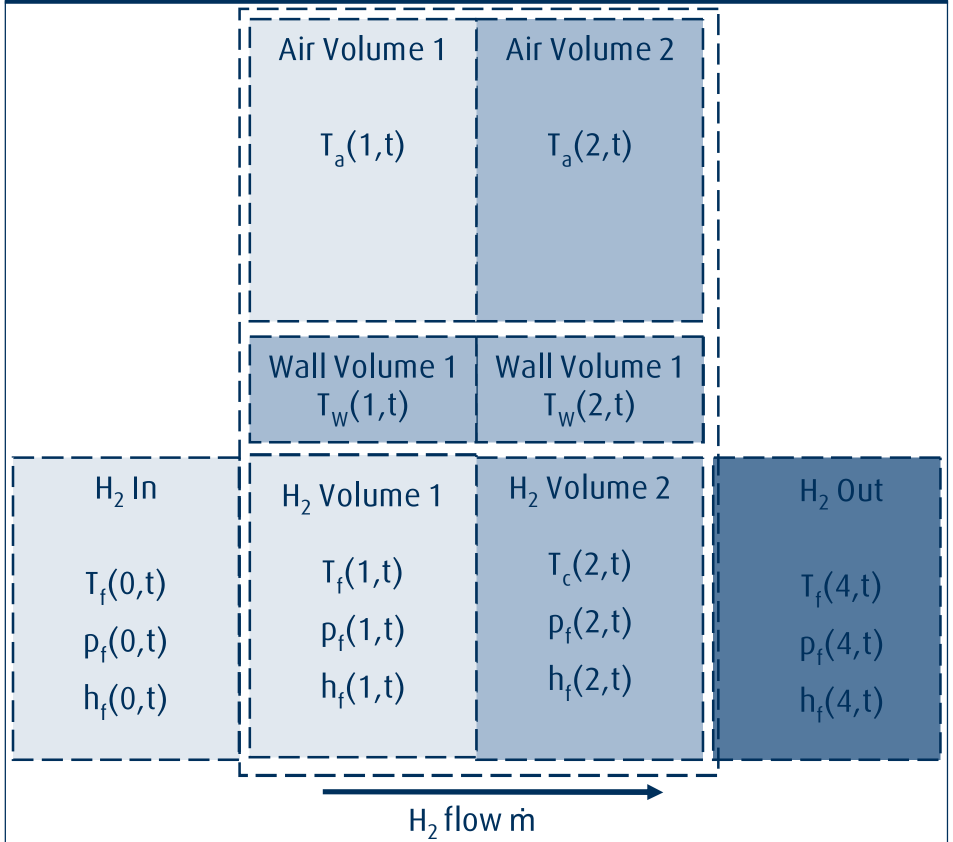
Signals In/Out



Discretisation [4]



Mathematical Model
Example: Pipe

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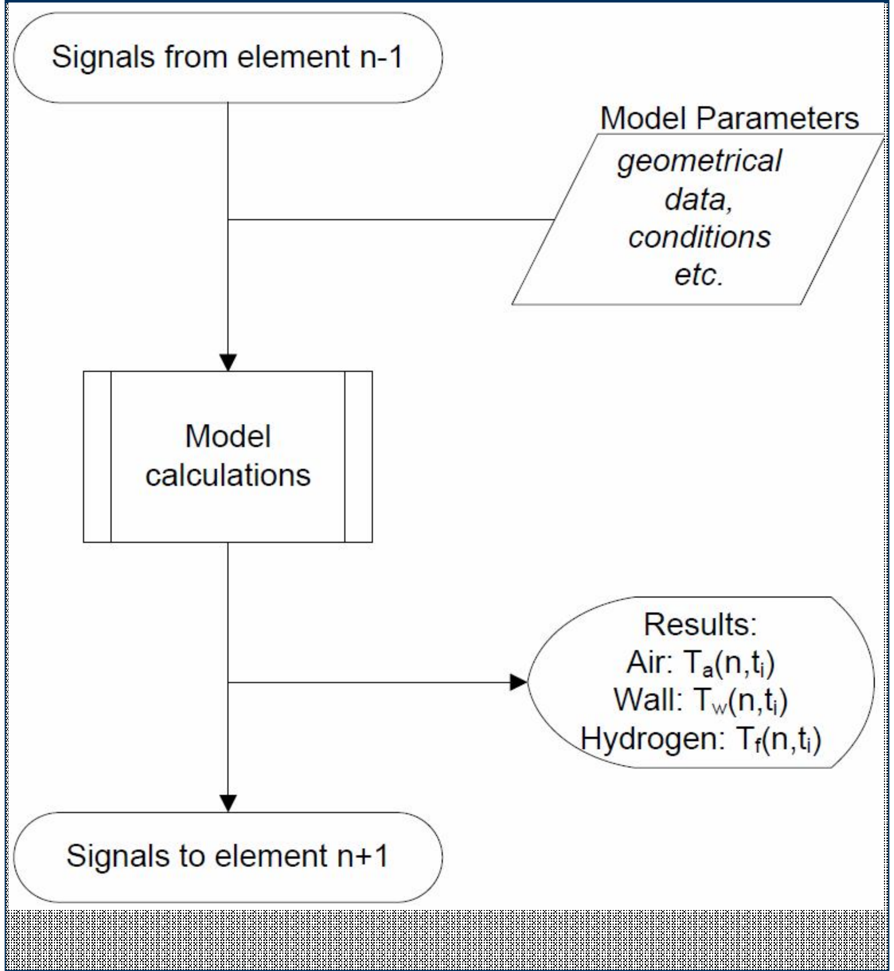
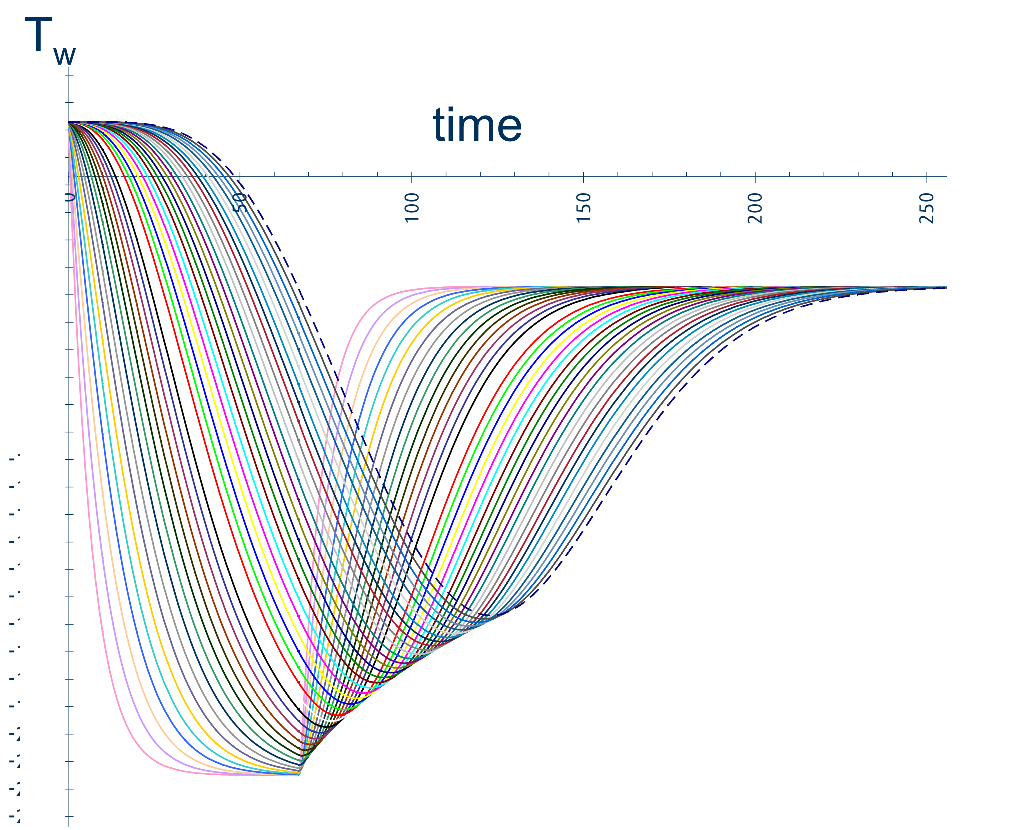
Programme Flowchart: Element n, time t_i



Result: Temperature in pipe wall (qualitative)



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What is needed for a broad commercialization of hydrogen as fuel ?

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Technological maturity of FCEV

Technological maturity of infrastructure

Solving chicken & egg dilemma

- Economies of scale & cost reduction
- Staged investments along population centres
- Long-term partnerships
- Customer acceptance

Staged investments along population centres
Linde & Daimler invest in 20 additional fuelling stations

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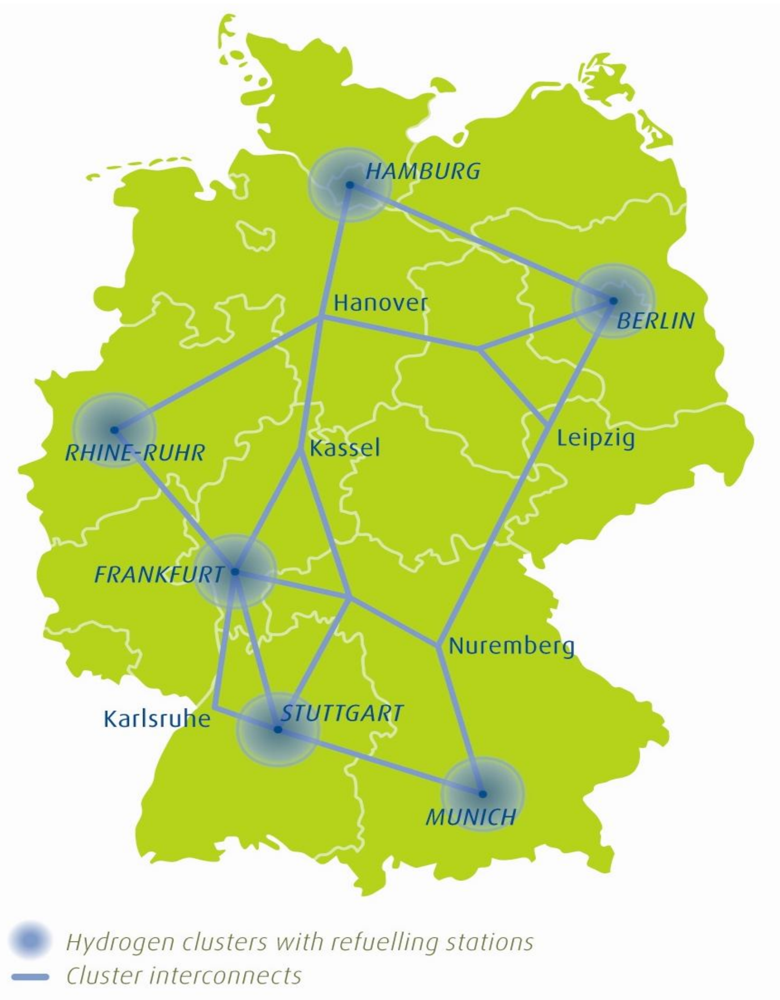
Key facts

- Initiative by Daimler and Linde
- Bridge the gap between demonstration (CEP) and commercialization (H2 Mobility)
- 10 + 10 additional public hydrogen stations in Germany
- Build-up from 2013 onwards
- Strengthen existing cluster and establish links
- Will allow to drive through Germany with hydrogen cars

Distribution of stations (preliminary)



Long-term partnerships
EU Study and H2 Mobility Initiative

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	EU hydrogen FCEV Coalition	H_2-Mobility in Germany	Investment and Business Building
Goal	Fact-based **evaluation** of the **potential of FCEV** until 2050 **Integrated perspective** across hydrogen value chain	Business plan for roll-out of H2 infrastructure in Germany Definition of technological standards	Establishment of "future consortium" Implementation of comprehensive business case (incl. e.g., funding)
Status	Finalized	Finalized	Ongoing

Bosch

Thank you for your attention!

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References

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4	David P. Hawn: *Development of a a Dynamic Model of Counterflow Compact Heat Exchanger for Simulation of the GT-MHR Recuperatur using Matlab and Simulink, Master Thesis* , Ohio State University, 2009.

Backup

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Mathematical Model
Equation of state (EOS)

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Equation of state	Formula	Adequacy
Ideal gas law	$pv = RT$	✗
Peng-Robinson [2]	$p = \frac{RT}{v-b} - \frac{a\alpha}{v^2 - 2vb - b^2}$	✗
EOS by Leachman [3]	$\phi(\tau,\delta) = \frac{f^0(T,\rho) + f^r(T,\rho)}{RT} = \phi^0(\tau,\delta) + \phi^r(\tau,\delta)$	✓