2nd International Workshop Advances in Cleaner Production

20-22 May 2009 • São Paulo

Modelling of an Iron Ore Reduction Furnace Operated with Pure Hydrogen

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Nancy - France

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"KEY ELEMENTS FOR A SUSTAINABLE WORLD: ENERGY, WATER AND CLIMATE CHANG

Steel Production

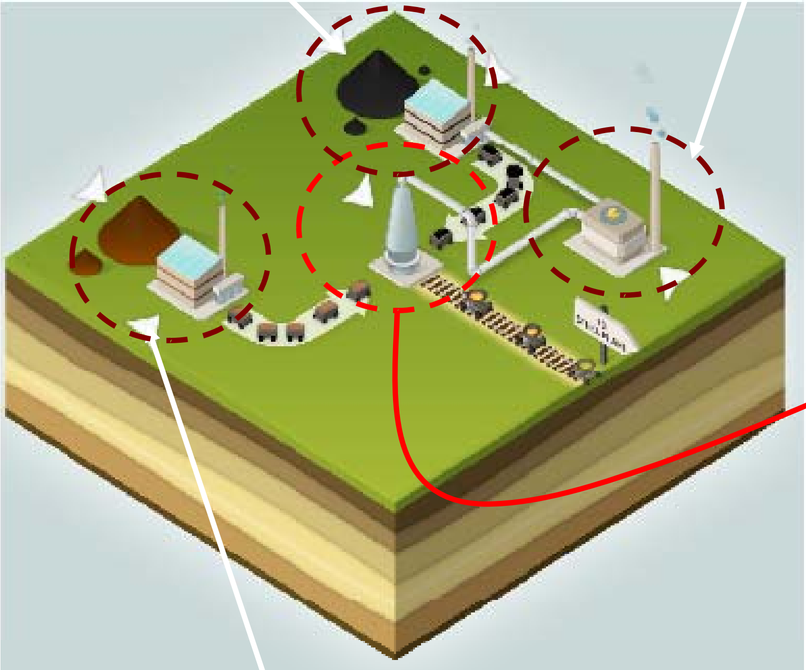
- **Steel production (1950) ⇒ ≈ 200 million tons worldwide[1]**
- **Steel production (2007) ⇒ ≈ 1.3 billion tons worldwide[1]**
- **Steel consumption (2015) ⇒ ≈ 1.8 billion tons[2]**
  - future growth: 3-5%[1]
  - 8-10% growth in BRIC countries (Brazil, Russia, India, China) [1] ⇒ dynamic expansion of their economies and infrastructures.
- **Steel**
  - Environment friendly material
    - can be recycled indefinitely
    - no loss of quality.
    - 40% of steel produced is recycled from scrap
  - Use in durable products/infrastructure
    - not enough scrap available.

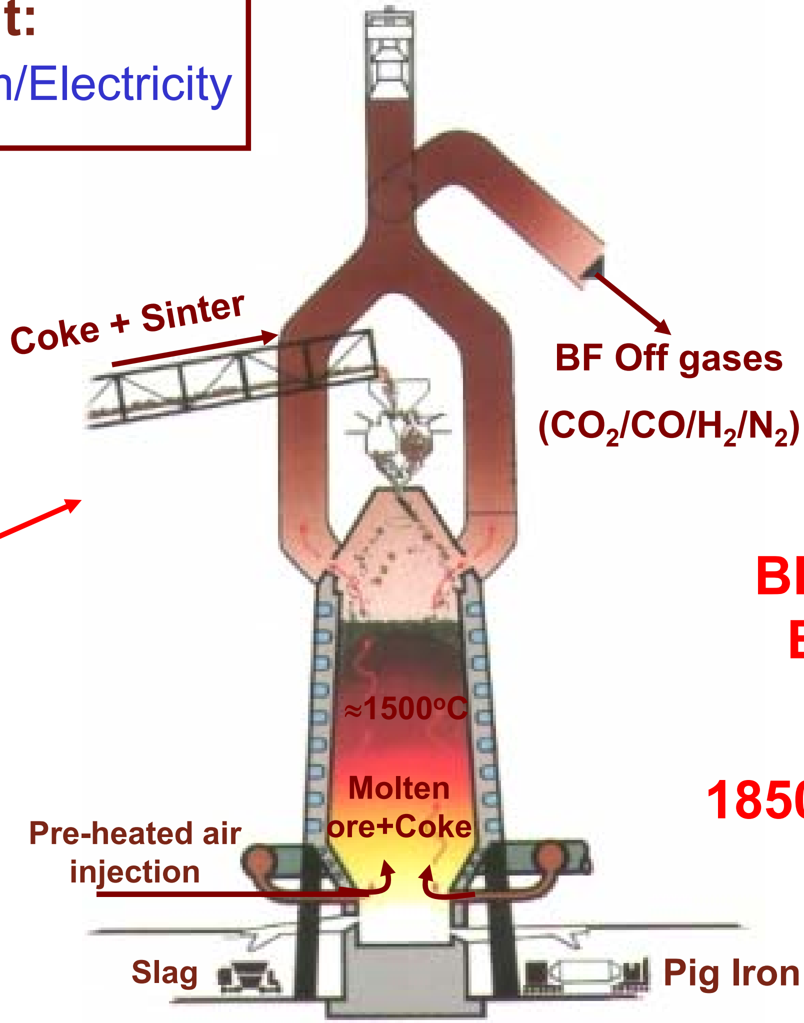
[1] *International Iron and Steel Institute (IISI): www.worldsteel.org*
[2] *ULCOS Project website: www.ulcos.org*

Ironmaking today – Blast Furnace (BF)

Coke Plant:
Coal → Coke

Power Plant:
BF Off gases → Steam/Electricity

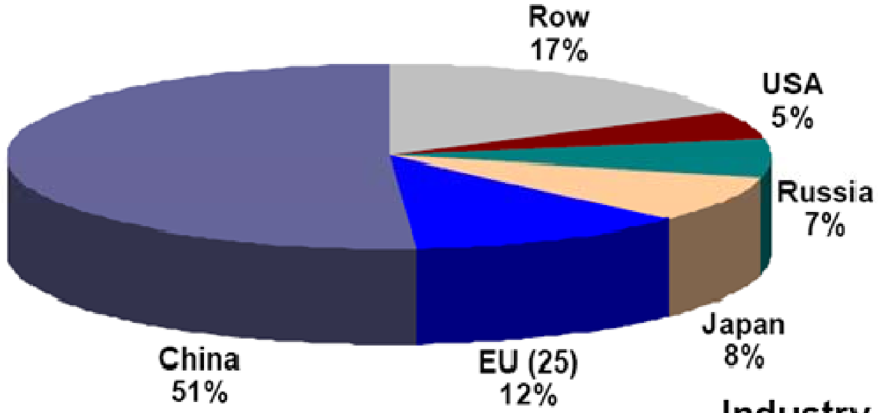




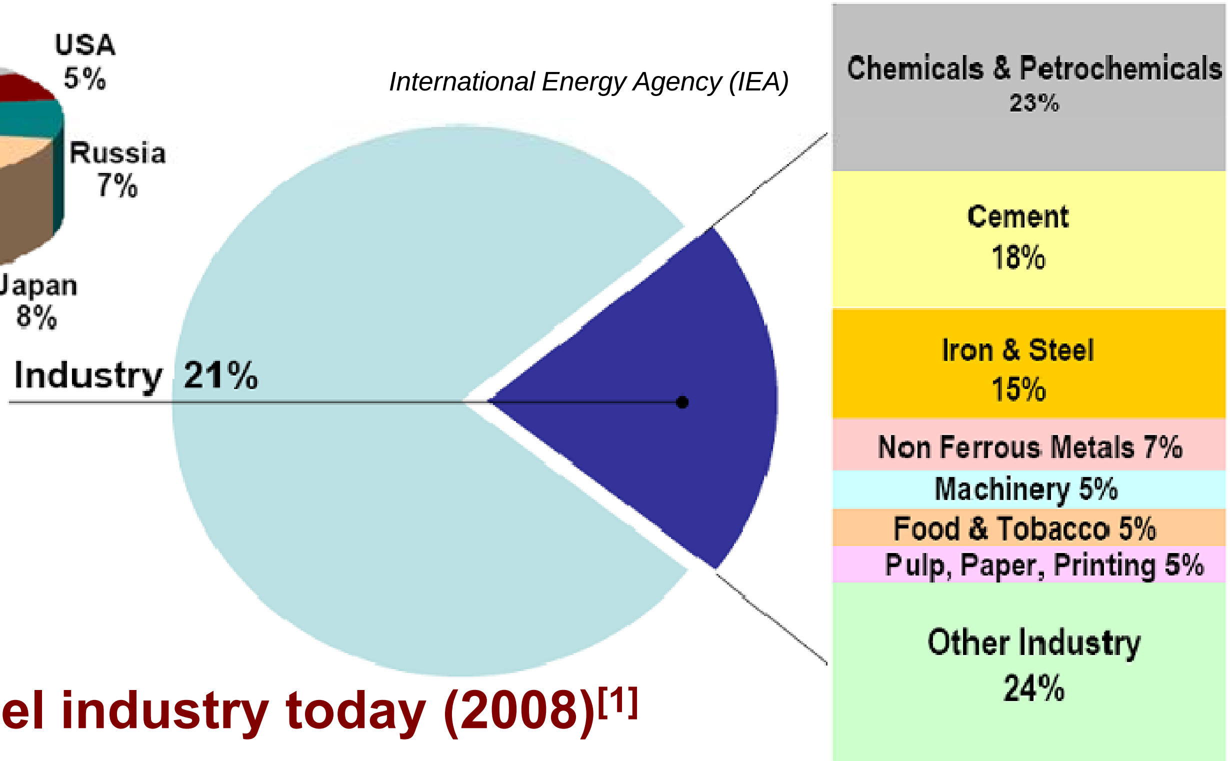
BF followed by BOF and CC
↓
1850 kg CO_2/t steel

Pellet / Sinter Plant
Raw ore → heat treatments/additives → Sinter/pellets (better properties)

Steel: the Essential Numbers



International Iron and Steel Institute (IISI)



World steel industry today (2008)[1]

- 1.3 billion tonnes of steel
- 1.9 ton CO_2 /ton steel
- 2.2 billion tonnes of CO_2
- 4 to 5% of total man-made greenhouse gases

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[1] *International Iron and Steel Institute (IISI): www.worldsteel.org*

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"KEY ELEMENTS FOR A SUSTAINABLE WORLD: ENERGY, WATER AND CLIMATE CHANGE"

CO_2 Emissions x Climate Change

- CO_2 Emissions ⇒ Climate Change ⇒ Natural disasters



- The best European steel plants are operating at the limits of what is presently technically possible.

- Breakthrough technologies for steelmaking industry

ULCOS (*U*ltra *L*ow *CO*$_2$ *S*teelmaking) Project

- Aim: design new steelmaking processes able to reduce by more than 50% the CO_2 emissions of the steel industry as compared to the current benchmark route (integrated plant, BF-CC)
- Launched by the major European steel companies at Sep/04
- Supported by European Commission
- 48 partners, 59 M€ budget, 5-year duration

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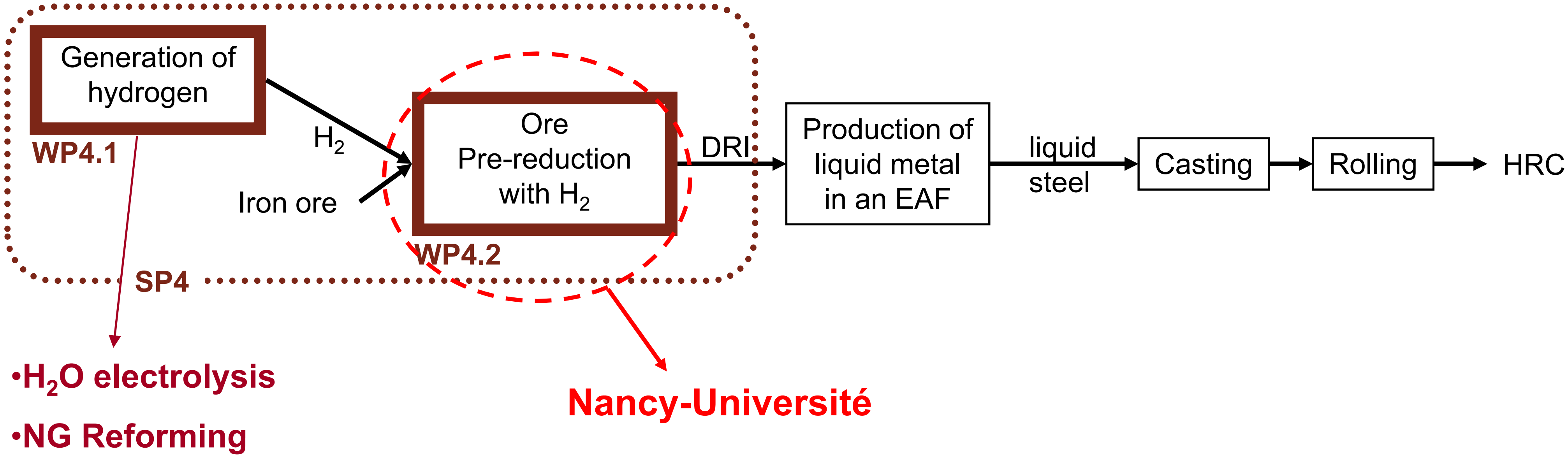
ULCOS Breakthrough Technologies

- Optimization of the blast furnace + CCS
- New smelting technologies
- Hydrogen steelmaking
- Electrolysis + nuclear power

■ **Hydrogen-based route defined**



Low CO_2 Emissions: from 200 to 400 kg CO_2/t steel

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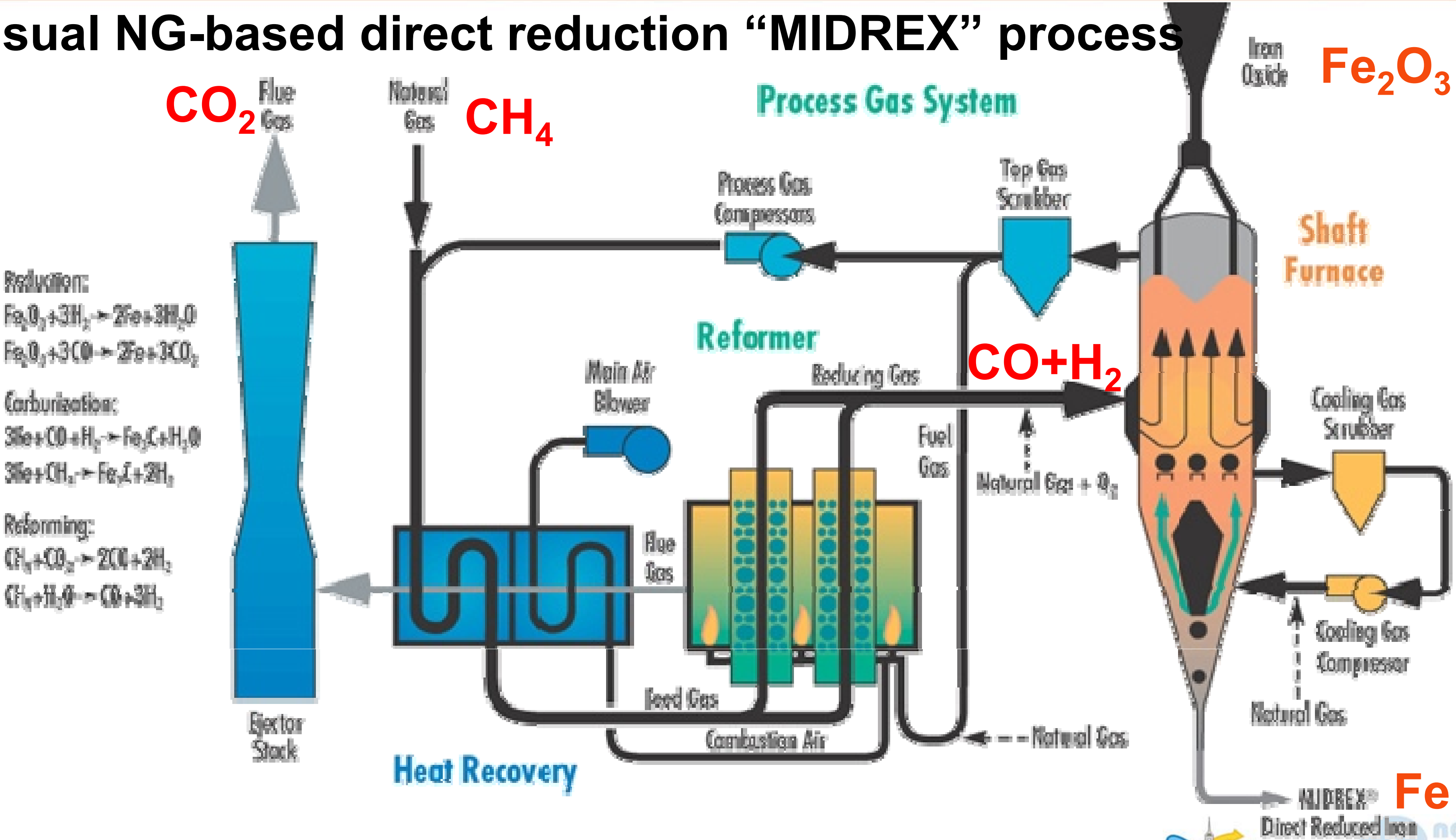
Using hydrogen for ironmaking

- **Usual NG-based direct reduction "MIDREX" process**



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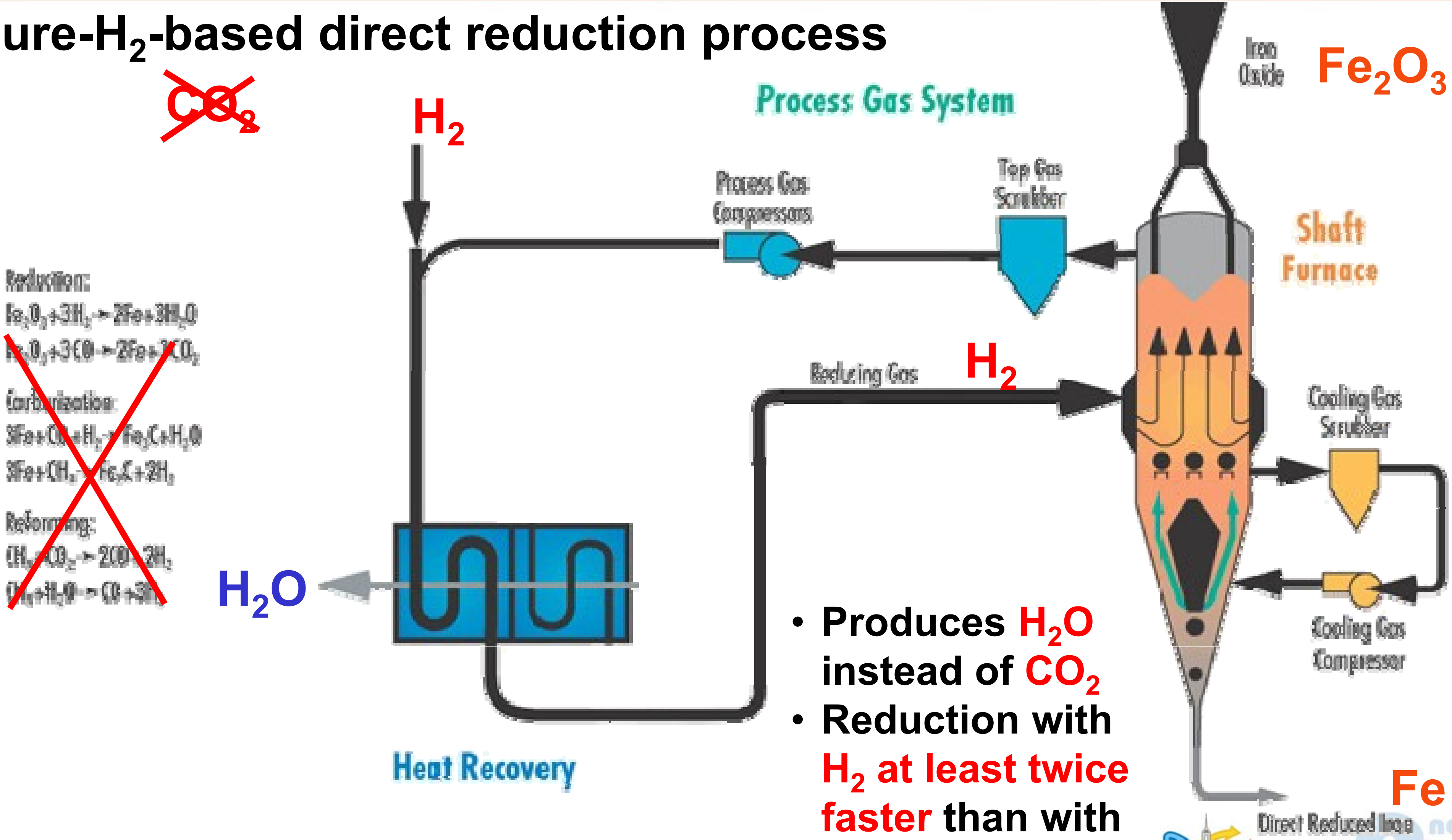
Using hydrogen for ironmaking

- **Pure-H_2-based direct reduction process**



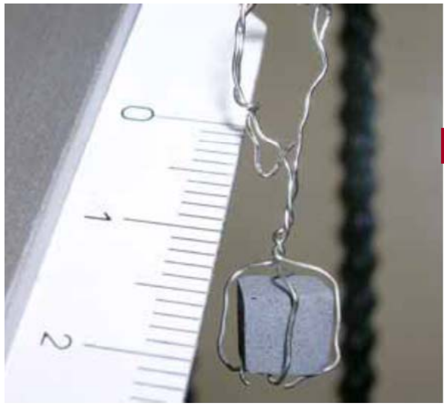
- **Produces H_2O instead of CO_2**
- **Reduction with H_2 at least twice faster than with CO**

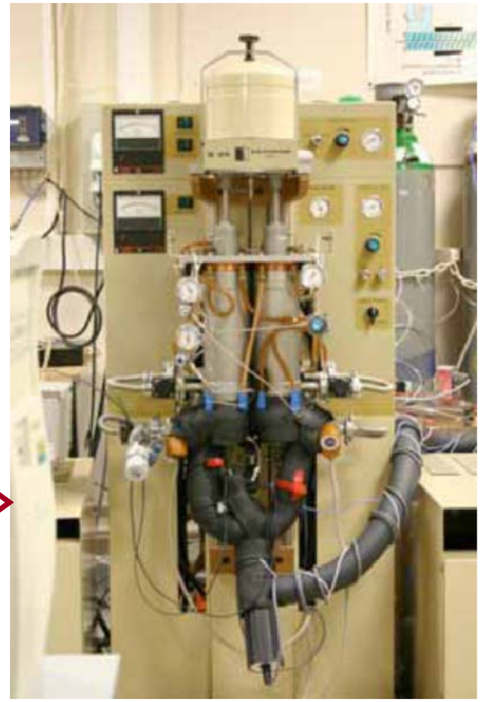
Let the hydrogen option open

- Major unknowns $\Rightarrow$ future price of H_2 and the CO_2 cost of the H_2 generation (electricity).
- In the 2020's H_2-economy may emerge, as a result of the evolution of transportation and energy industries.
- In this event, steelmakers should be ready to make massive use of H_2.

Research at Nancy Université

- **Aim:**
  - Check the technical feasibility of hydrogen ironmaking and its performance from modelling work:
  - Thermogravimetric experiments and sample characterizations to better understand the kinetic of the reactions
  - Development of a pellet-scale kinetic model
  - Development of a 2D numerical model of the reactor
  - Study of the sticking phenomenon





Main technical problems to be solved

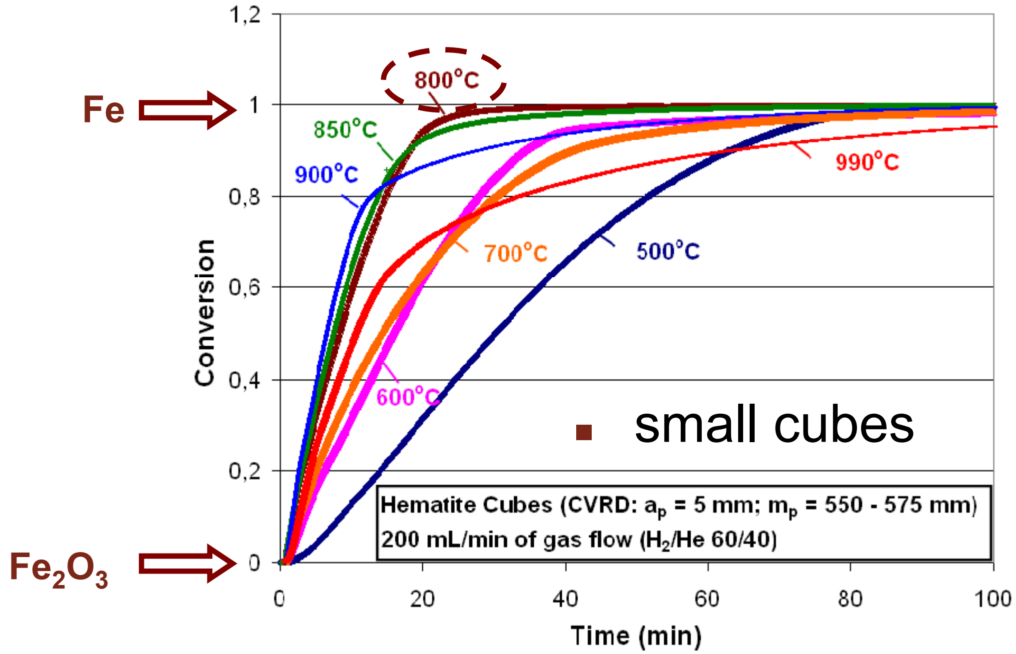
$Fe_2O_3 + 3H_2 \leftrightarrow 2\,Fe + 3H_2O$ $\xrightarrow{\text{3 steps}}$

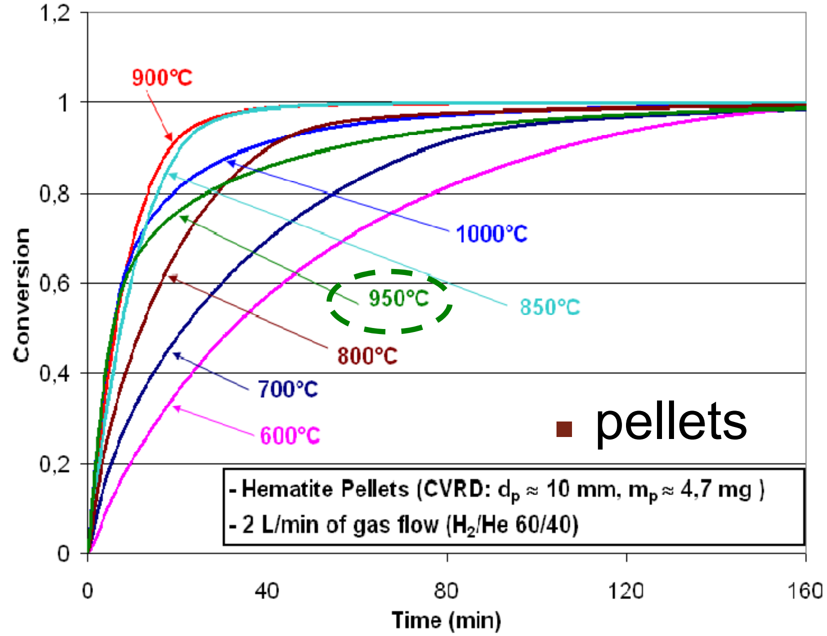
$3\,Fe_2O_3 + H_2 \leftrightarrow 2\,Fe_3O_4 + H_2O$

$Fe_3O_4 + H_2 \leftrightarrow 3\,FeO + H_2O$

$FeO + H_2 \leftrightarrow Fe + H_2O$

Influence of the temperature on the reaction rate varies significantly with the raw material





Optimum at 800 °C

Minimum at 950 °C

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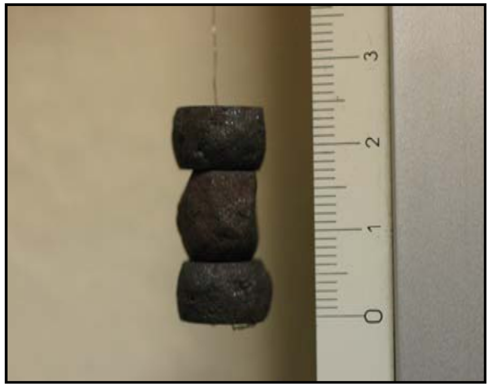
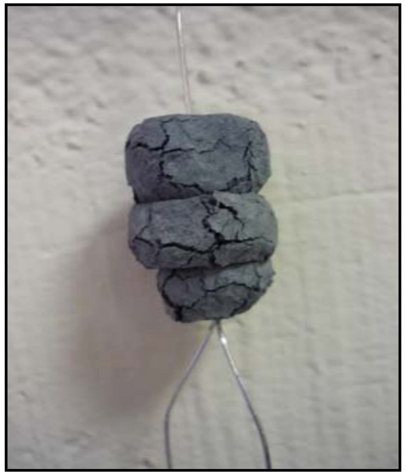
Main technical problems to be solved

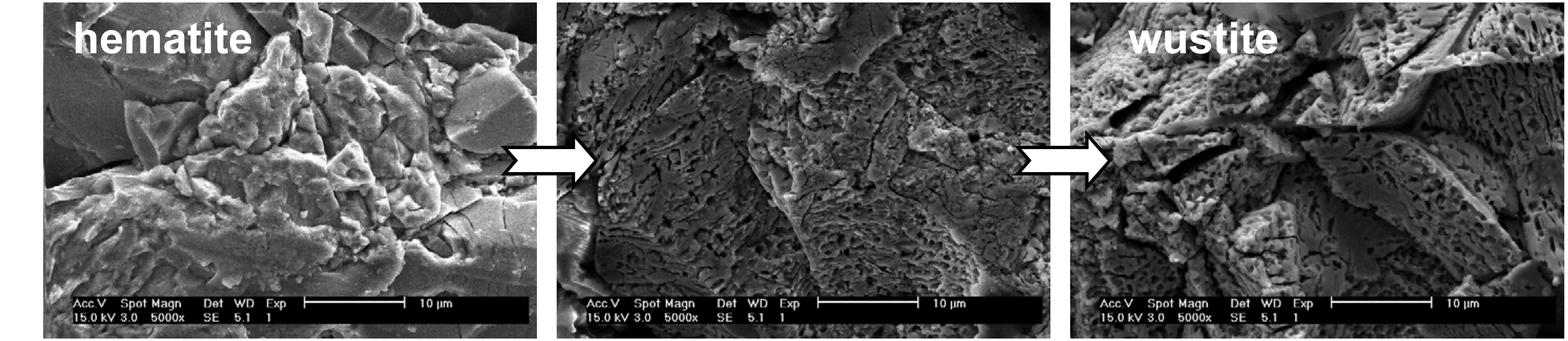
Sticking Phenomenon

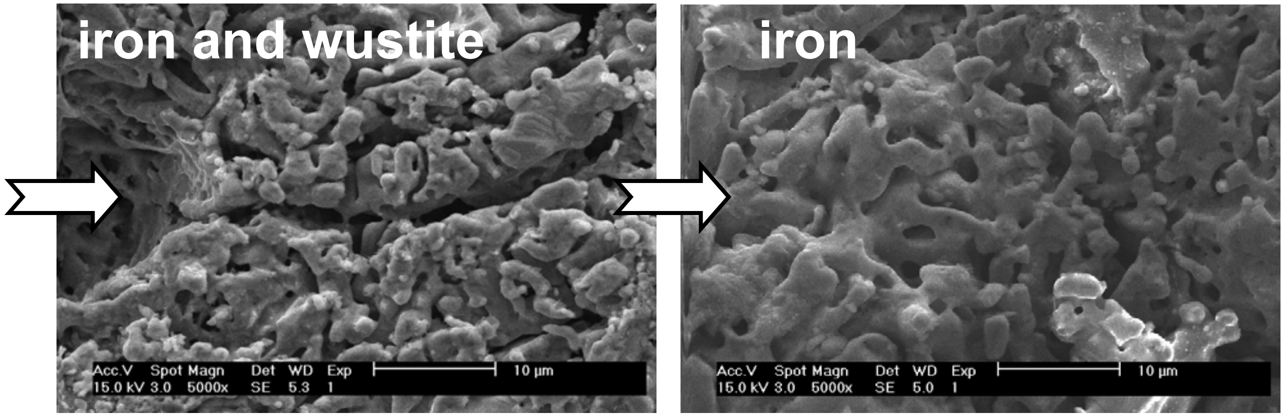
- H_2 reduction of DR grade pellets is faster at high temperatures.
- High temperatures seem to favour the “sticking”:
  - Reduced iron pellets stick to each other with a noticeable force.
  - Hinder or block the solid flow in shaft furnaces (MIDREX, HYL).
  - Lead to a complete defluidization of fluidized beds (FINMET).

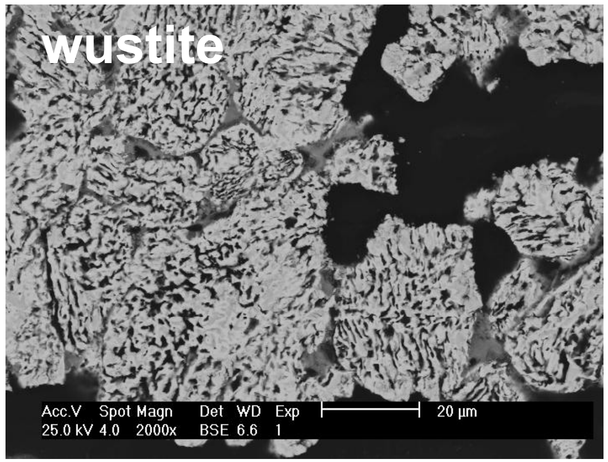




Morphological changes







- Dense grains in hematite
- Grains become porous in magnetite and wustite
- Wustite grains break up into crystallites
- Molten-like structure of iron

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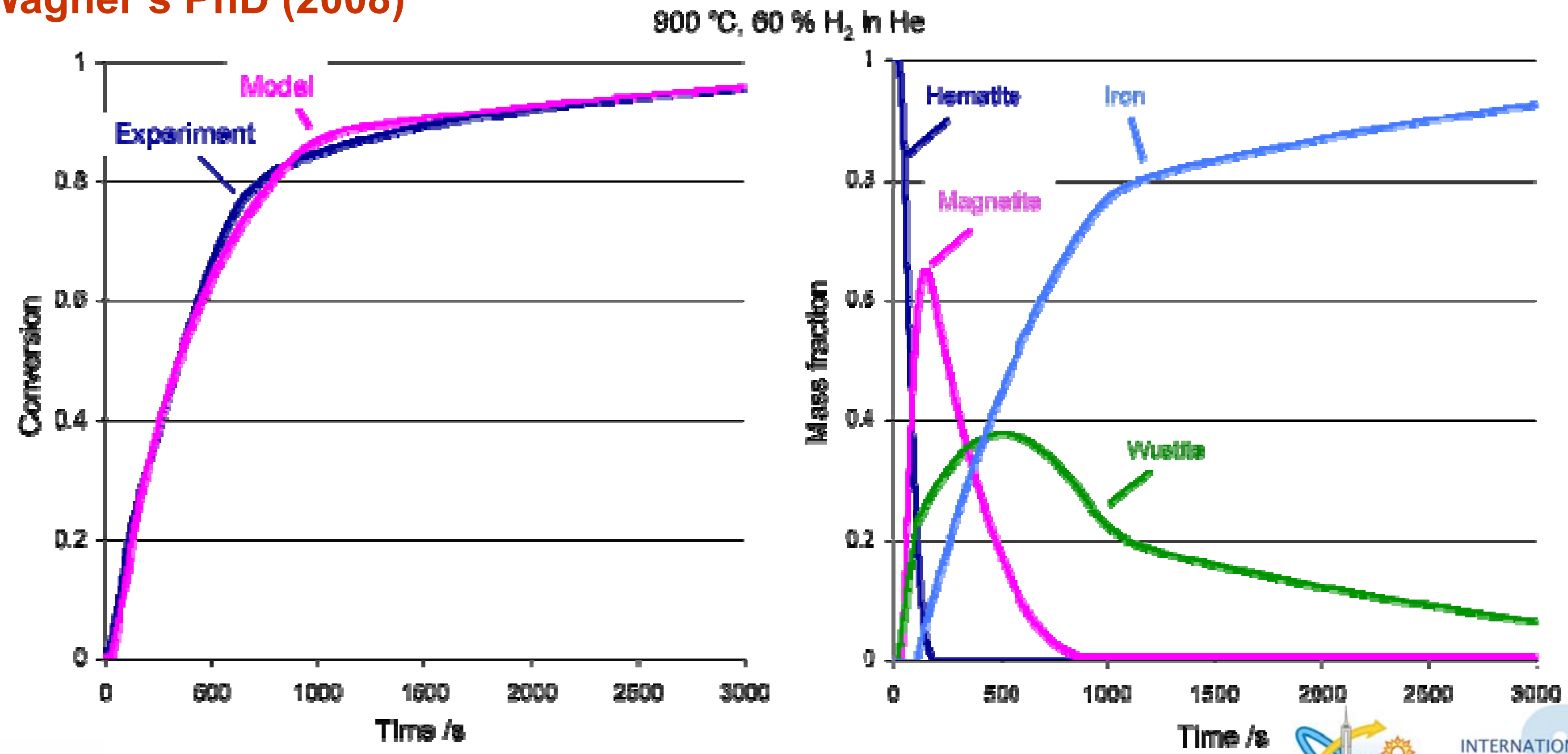
Kinetic model of a single pellet

- **3 reactions, mass transport (external transfer, inter- and intra-grain gas diffusion, solid diffusion, sintering of the iron layer)**

D. Wagner's PhD (2008)



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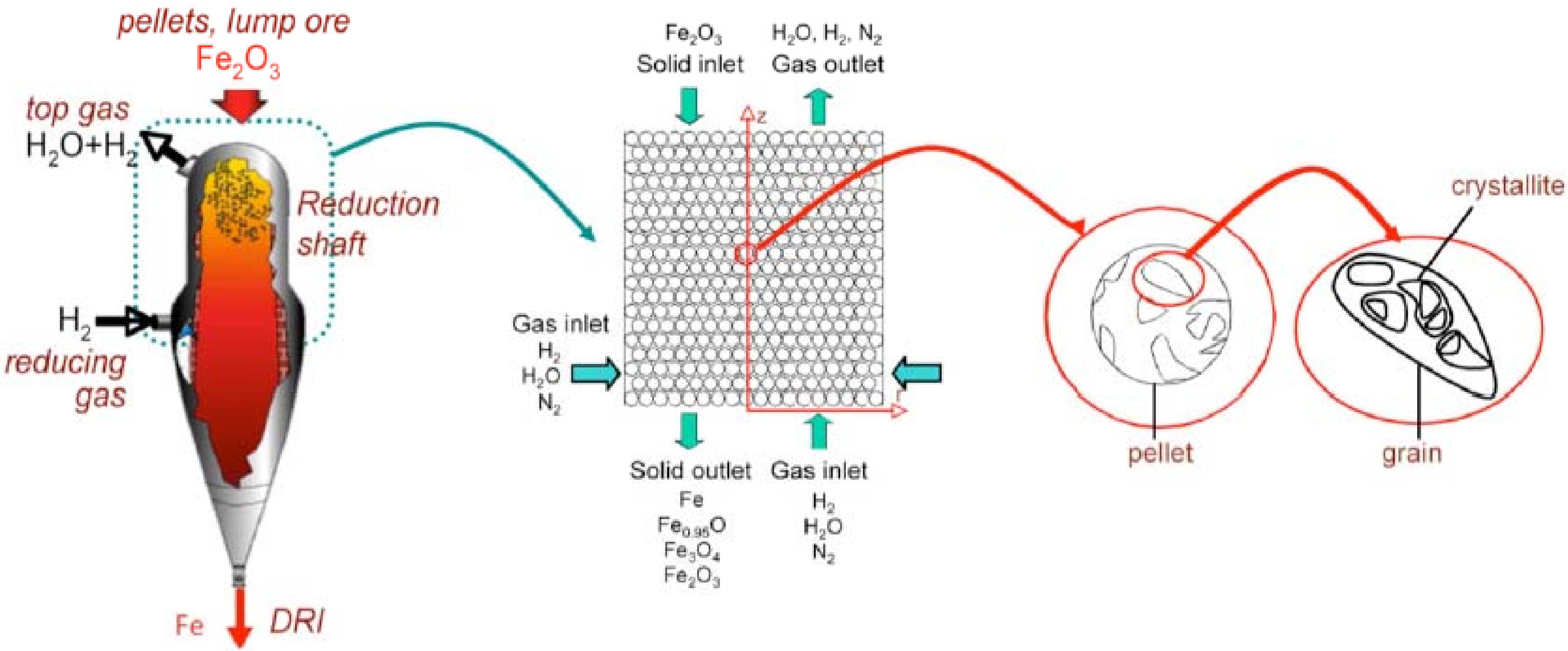
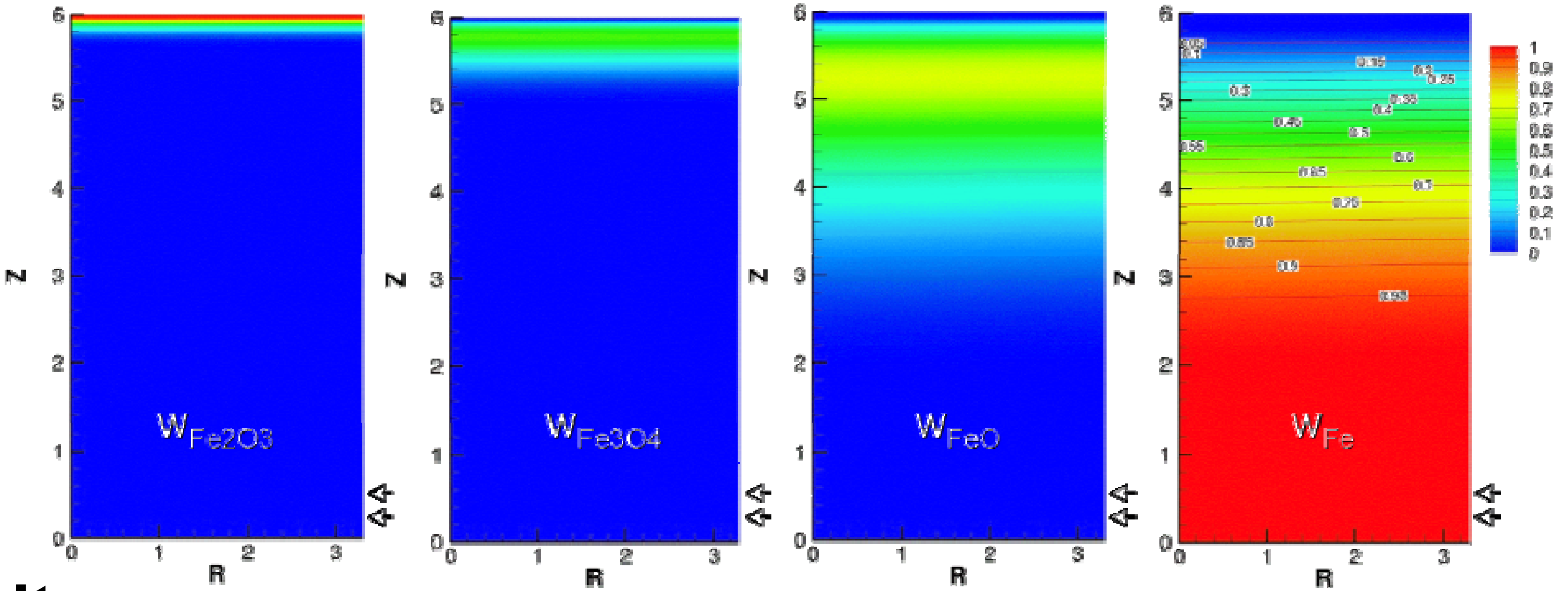
Numerical model of the H_2 shaft



- **2-D, axisymmetrical, steady-state model**
- **Written from scratch in FORTRAN 90 using the finite volume method**
- **Description of gas and solid flows, mass transfer, heat transfer, 3 reduction reactions**
- **Single-pellet sub-model included, with kinetics derived from thermogravimetry experiments**

Numerical model of the H_2 shaft

D. Wagner's
PhD (2008)



- **Main results**
  - Reaction with H_2 is faster than that with CO
  - Possible to use a more compact reactor than MIDREX and HYL shafts (e.g. 4.5 m instead of 9 m, with almost 100 % Fe^0)
  - Decreasing the pellet size clearly accelerates the process

Conclusions

- **Making steel using H_2 as a reducing gas makes sense:**
  - More than 50% reduction in CO_2 emission by several routes
  - Most of the technologies are mature
  - Social acceptability can be expected
  - Scientific problems are being studied

- **The main issues lie outside the steelmaking sector and expertise**
  - the future (2020, 2050) cost of hydrogen, which mostly depends on transport and energy policies
  - the CO_2-cost of electricity.