# Development of a Process to Continuously Melt, Refine, and Cast High-Quality Steel

Research Conducted by:
University of Missouri-Rolla and
University of Illinois at Urbana-Champaign

Funded by US DOE DE-FC36-03ID14279

# Research Team

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  - Metallurgical Engineering Students
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- University of Illinois at Urbana-Champaign
  - Mechanical and Industrial Engineering Faculty
    - Brian Thomas, Lifeng Zhang
  - Graduate student (fluid flow modeling)
    - Jun Aoki
- Consortium of Eight Steel Companies
  - Nucor, Nucor-Yamato, Gerdau Ameristeel, SMI, TXI-Chaparral, Bayou
- Consortium of Three Engineering / Know-how Suppliers
  - Corefurnace (Techint), Proware-Metsim, Heraeus Electronite

# Overview of presentation

- General aspects of continuous steelmaking
- Examples of previous research
- Introducing a new conceptual process
  - Conceptual layout of process
  - Some information about each unit
    - Including unit that was modeled by Lifeng Zhang

# Goal of Project

- Conduct R & D to design a continuous steelmaking process that starts with scrap and delivers high quality steel to the casting mold in one process.

| FEATURES OF THE CONCEPT | => | POTENTIAL BENEFITS |
|---|---|---|
| Fully continuous | => | High productivity, maximum automation |
| Scrap-based | => | Less Refining required |
| Continuous stirring of vessels (Bottom – blowing) | => | Rapid mixing, high reaction rates near equilibrium |
| Separated vessels | => | No backflow |
| Enclosed process | => | Safer & environmentally friendly |

# Continuous Steelmaking

## Benefits/Advantages

- Lower capital cost
  - Smaller vessels
  - Less cranes
- Higher capital utilization
- Less labor
- Easier to automate
- Less conversion time
- Better energy utilization
- Less off-gas (less KO61)
- More consistent quality
- Safer & healthier work place
  - Enclosed process
  - Less batch processing

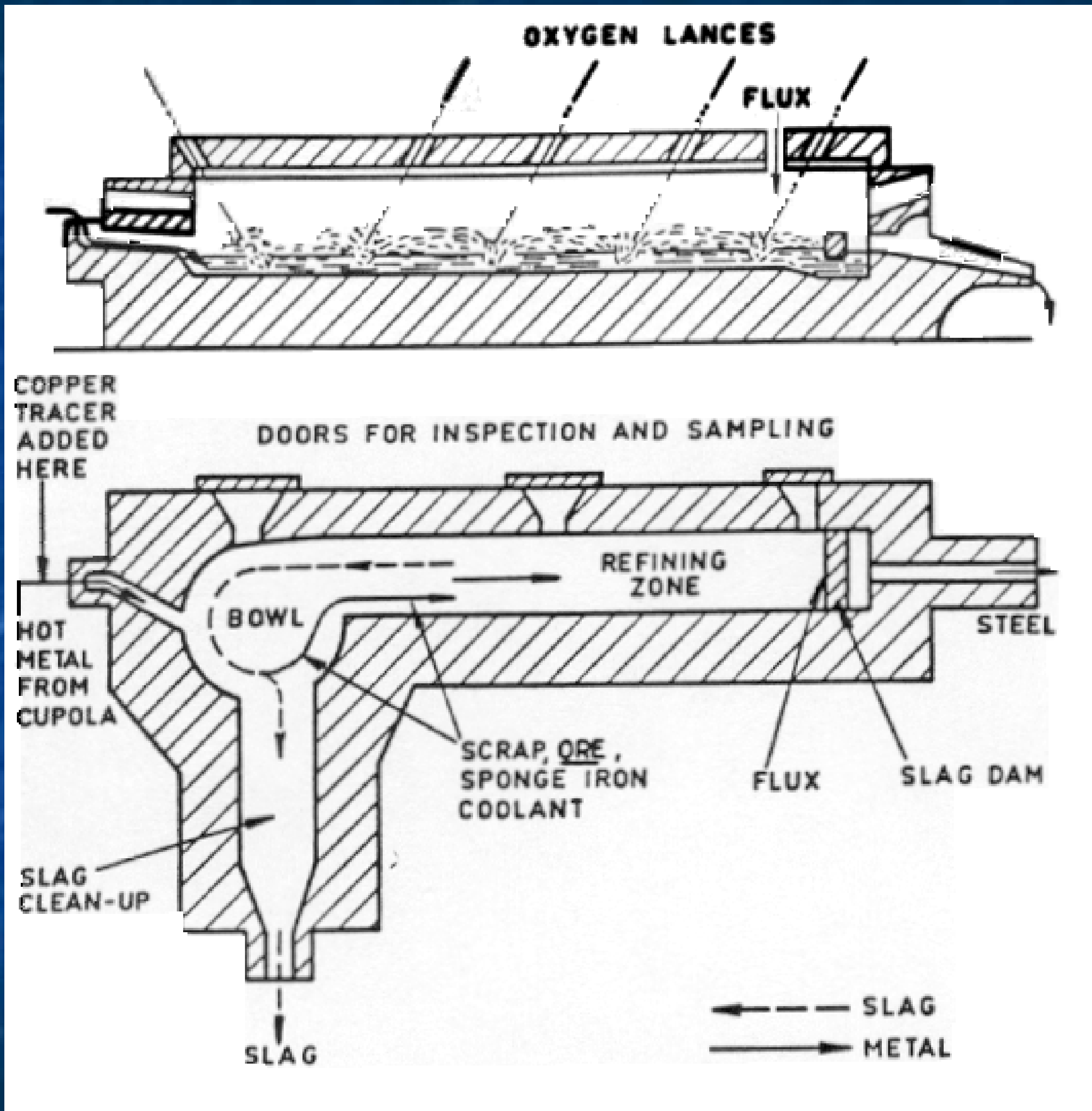
## Risks/Challenges

- Logistics
  - Start-up / Shut-down
- Matching to casting speed
- Changes or upsets to system
  - Grade change
  - Delays
  - Off-specification
- Connectors
- Deslagging
- Elevation of Vessels
- Refractories
- Previous problems
- Difficult to run a pilot plant
- Lack of real operational data

# Previous Research in Continuous Steelmaking

- Several processes were researched
  - Types of vessels:
    - CSTR - Completely Stirred Tank Reactor
    - Counter-current Reactor
    - Con-current Reactor
    - Emulsion / Spraying
  - Starting material
    - Hot metal
    - Scrap
  - Types of processes:
    - Continuous operating and periodically tapping (e.g. Consteel)
    - Continuous operating and tapping into ladle
    - Fully continuous operation (never tested)

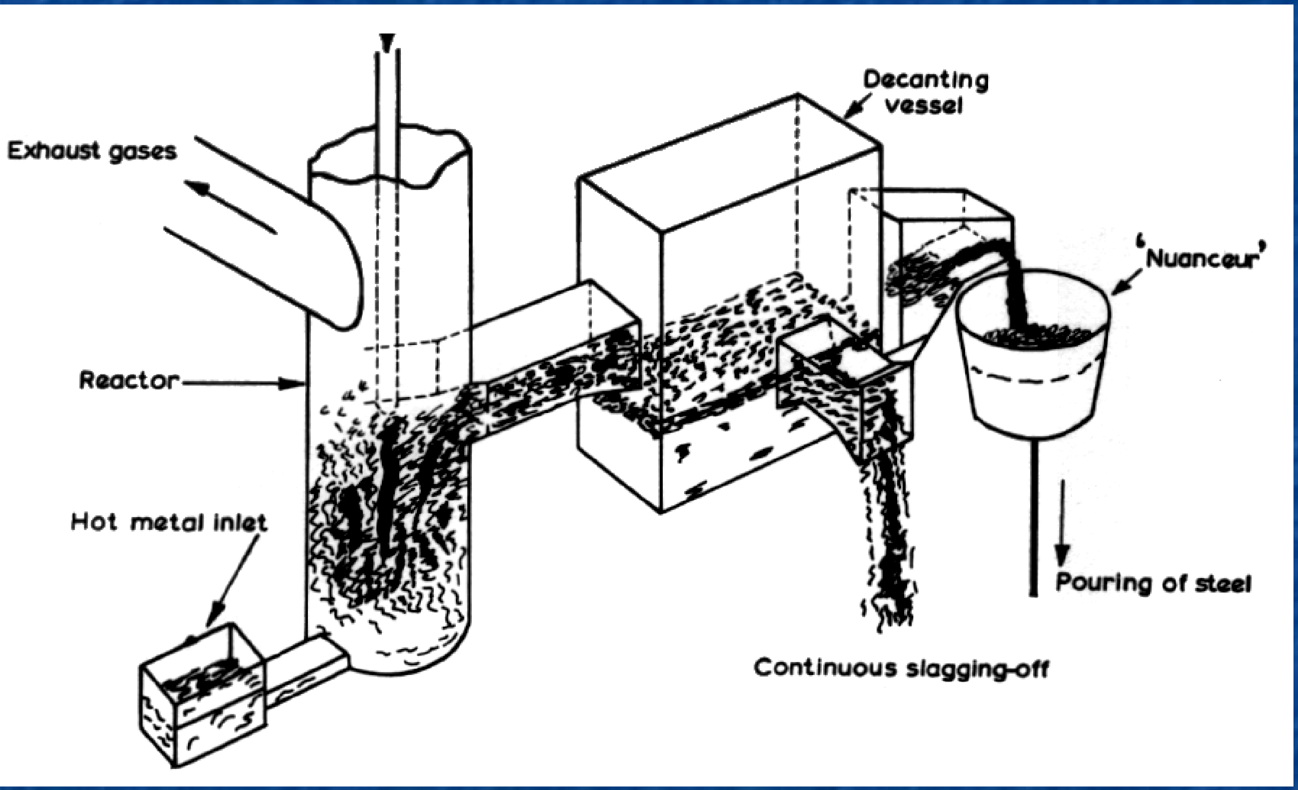
# PFR: WORCRA cont. steelmaking




- Australia, Sweden, Britain, USA
  - 1961 – 1990's
  - Countercurrent flow
  - Different versions
  - 10 tph Oregon '72
- Problems/Critics
  - Backmixing = NO CONTROL
  - Refractory wear
  - Heat loss
  - Unsatisfactory productivity


Brooks, G.A., Ross, N.G., Worner, H.K. "Continuous Steelmaking: The Balance Between Intensity and Refining" 56th Ironmaking Conference Proceedings, Chicago, April 13 – 16, 1997, pp. 695 – 701

# Emulsion CSTR: IRSID cont. st.

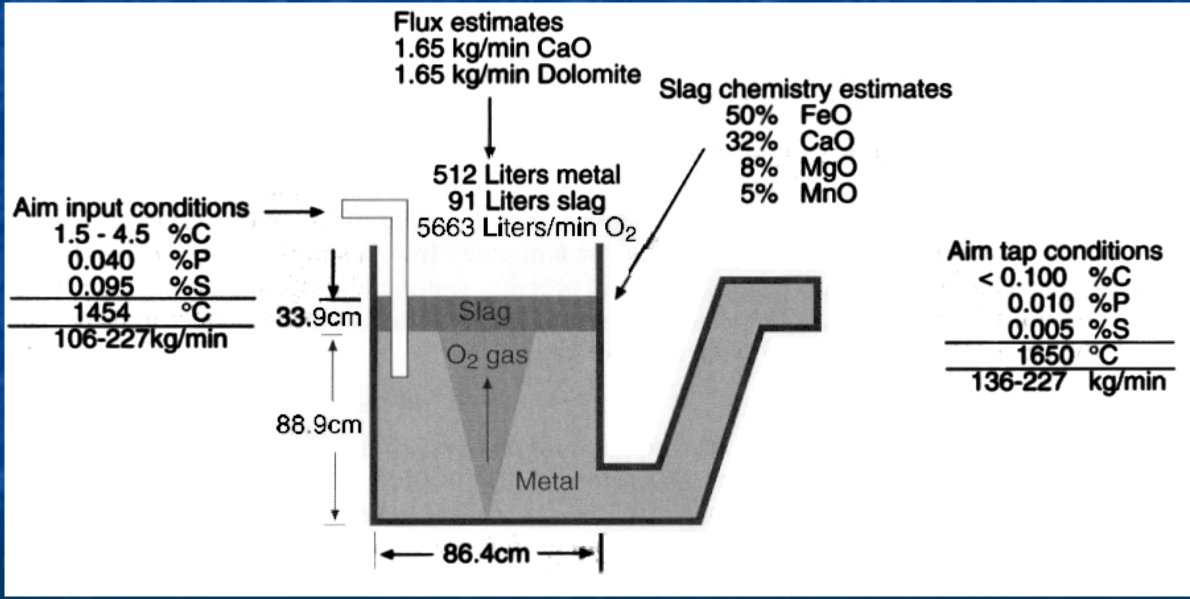



Berthet, A., Rouanet, J., Vayssiere, P., Trentin, B. "The IRSID continuous steelmaking process" Journal of The Iron and Steel Institute, June 1969, pp. 790 – 797

- France
  - 1963 – 1970's
  - Emulsion & separation
  - FAST KINETICS
- Problems/Critics
  - Unknown mechanism = NO CONTROL
  - Low iron yield
  - Long settling times
  - Refractory wear

# Equilibrium CSTR: AISI cont. st.

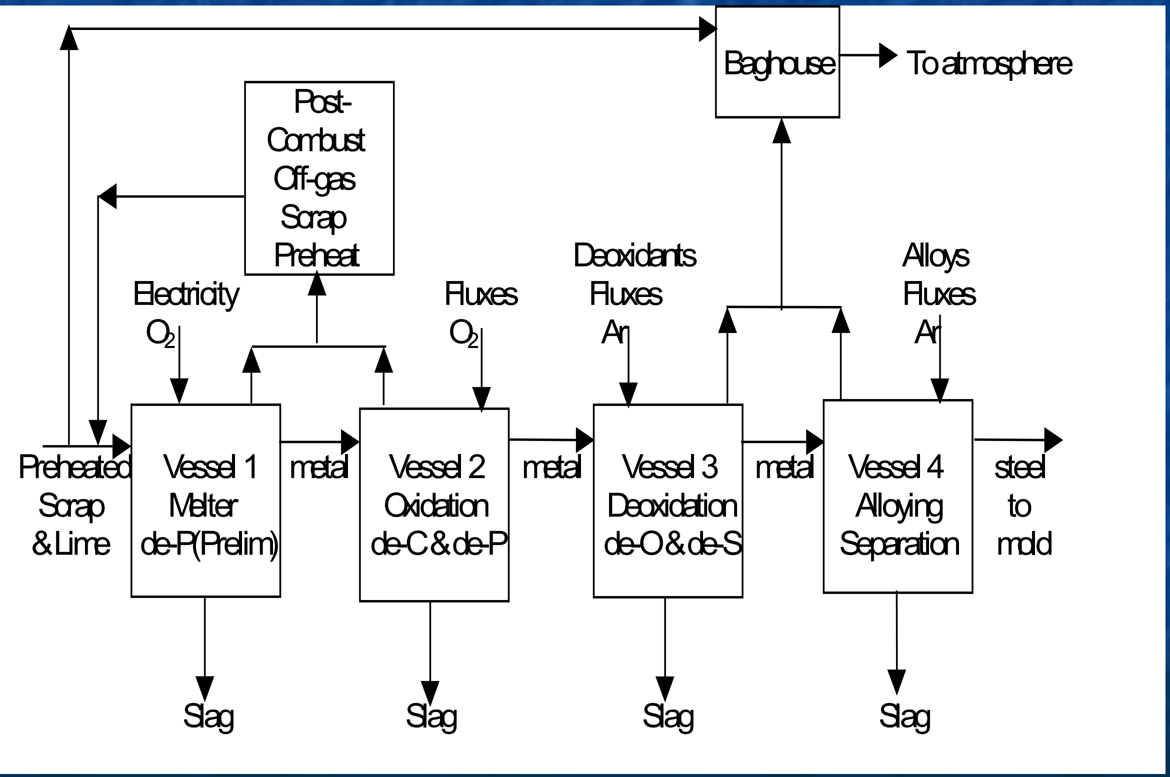
- USA
  - 1980's - 1990's
  - Equilibrium CSTR
- Problems/Critics
  - Kinetic limits
  - Low iron yield
    - High initial carbon and low final carbon
    - Clogging of connectors transporting FeO




The AISE Steel Foundation "The Making, Shaping and Treating of Steel" 11th edition, Steelmaking and Refining Volume, 1998, p. 748, Fig. 13.4

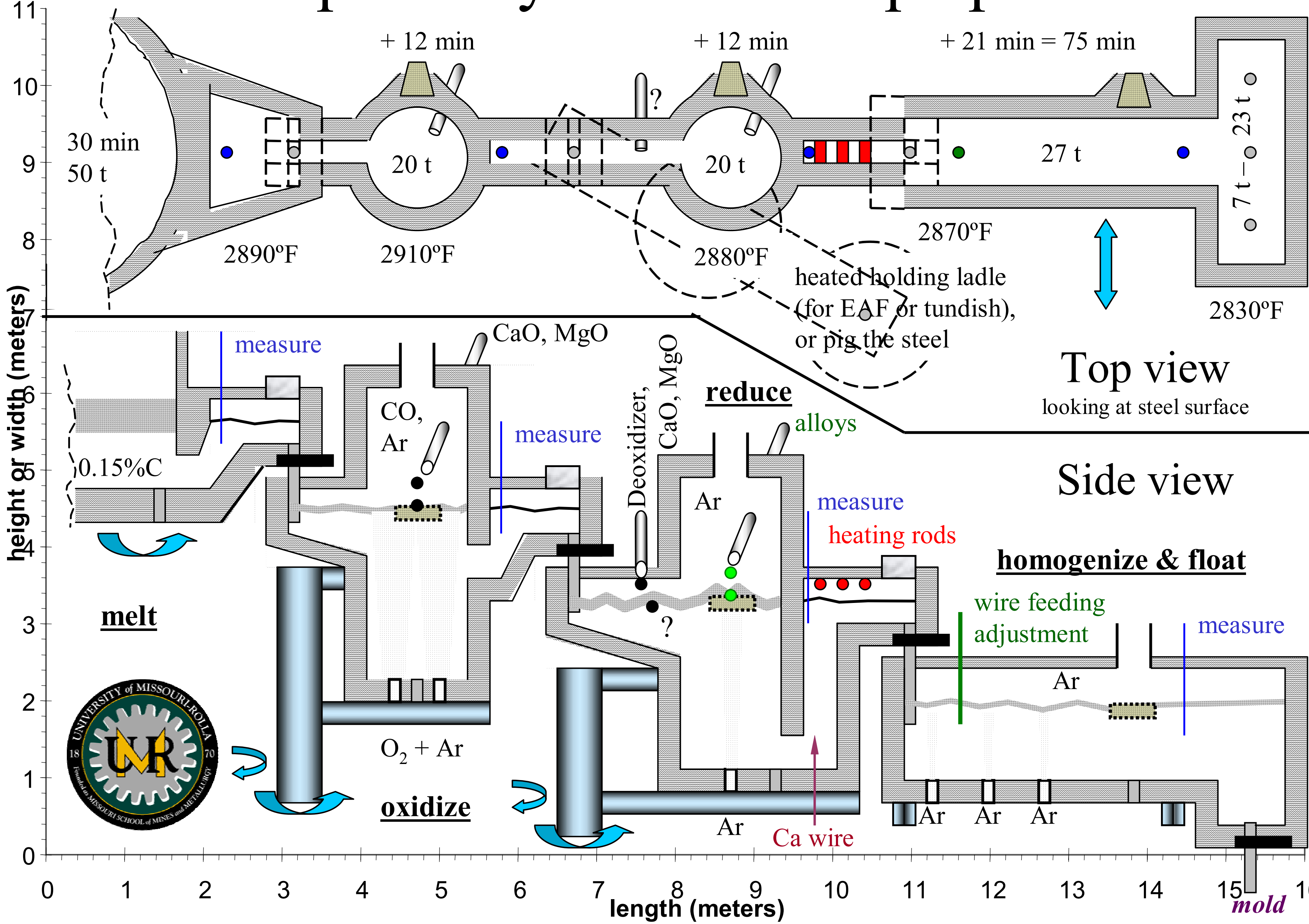
# UMR's Continuous Steelmaking Concept

- Processing time ≅ 1¼ hr
- Total liquid metal ≅ 130 t



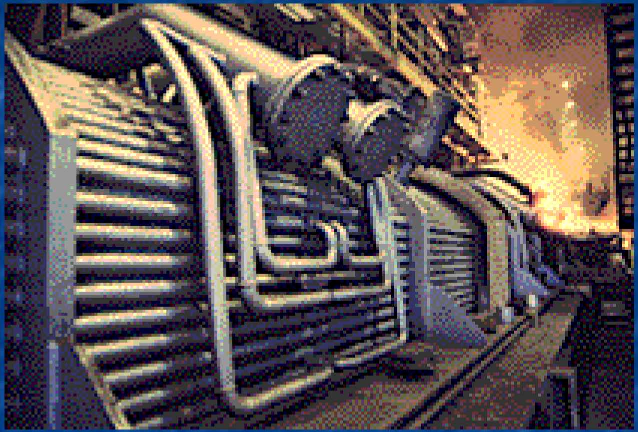

- 4 Units - 100% scrap based
- Melting Unit
  - EBT AC (or DC) EAF melting
  - Consteel preheating & continuous feed
  - Remove P
- Oxidation Unit
  - CSTR to remove C
- Reduction Unit
  - CSTR to remove O & S
  - Alloying
- Enhancement Unit
  - Homogenization
  - Flotation

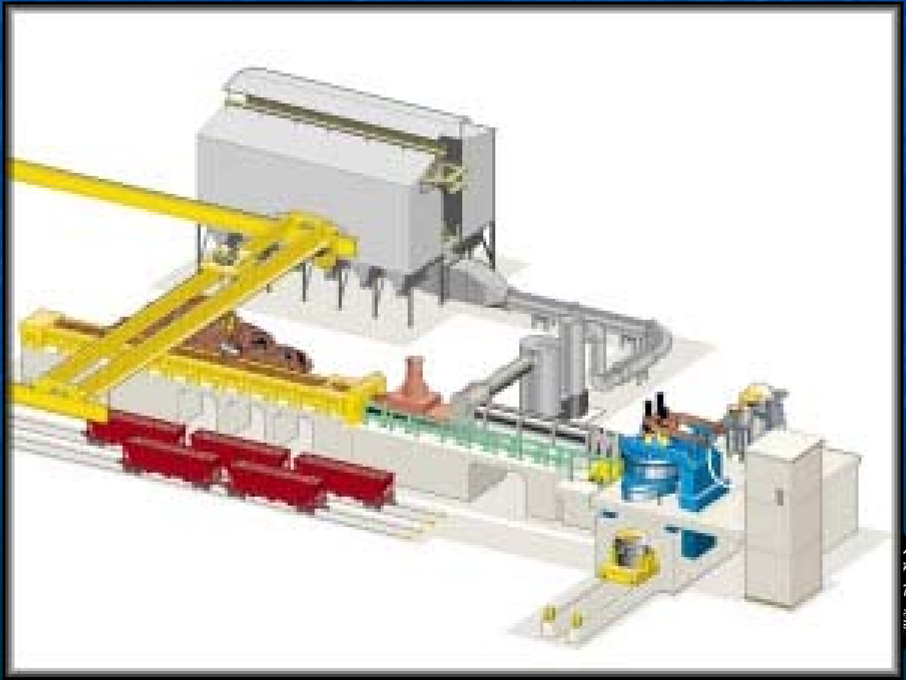
# Conceptual layout for 110 tph process



# Consteel preheater and EAF

- Preheat tunnel (~100 ft)
  - Continuously transports and preheats scrap to ~800ºF
- <u>Near-equilibrium EAF</u>
  - Less FeO in the slag, higher Fe-yield
  - Continuously foaming slag
  - Electrode heats liquid - Liquid melts scrap
- <u>Proven technology</u>





http://www.corefurnace.com/meltshop_01.html

Development of a Process to Continuously Melt,

# Preliminary Concepts – Melting Unit

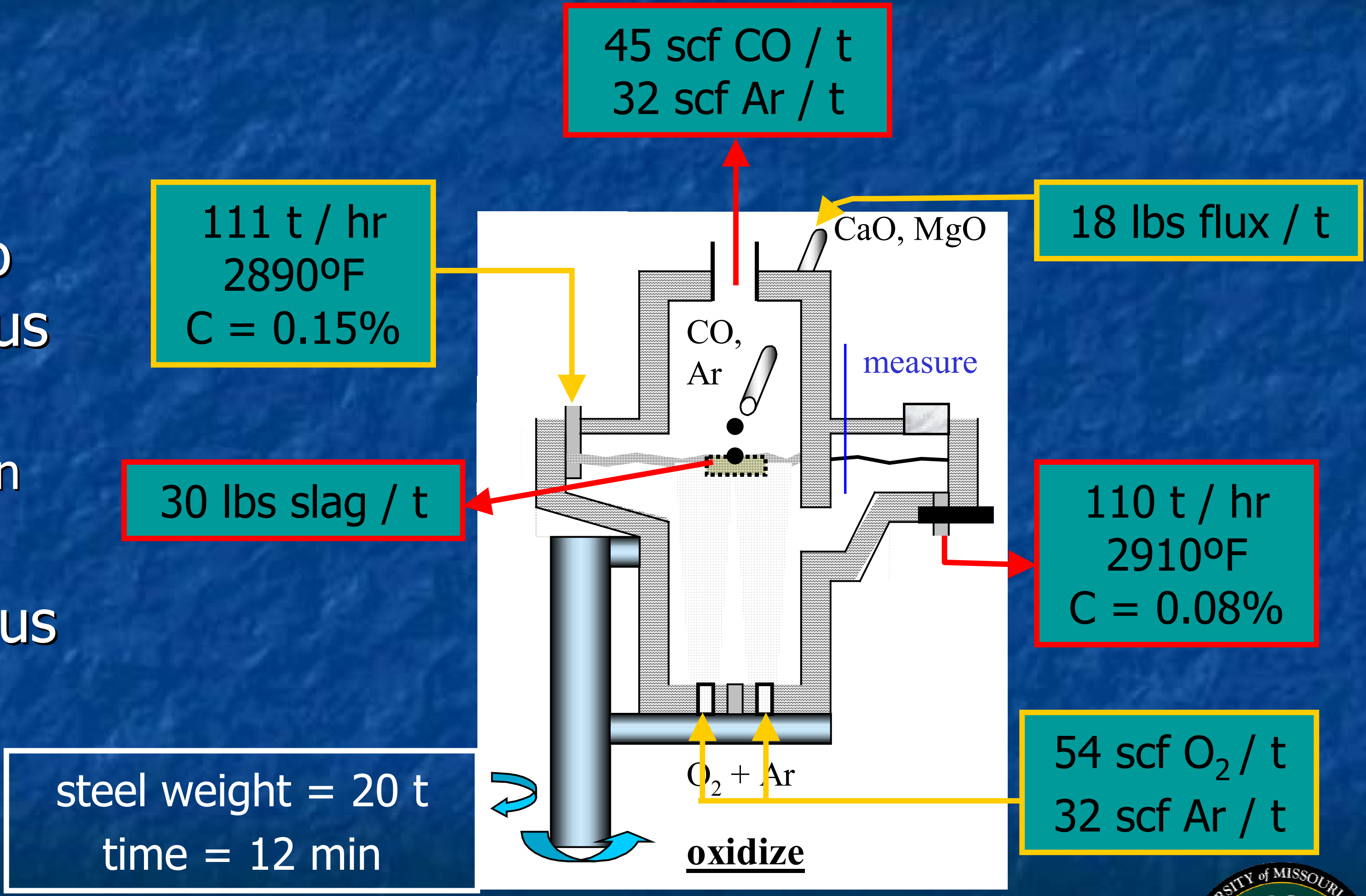
- Consteel preheater
  - Post-combustion of CO from EAF and oxidation vessel
    - More efficient = gas composition consistent
  - Estimated scrap (and lime) temperature entering unit (800ºF)

- Melting similar to current EBT AC (or DC) EAF
    - ~50 tons of metal capacity
    - 40 MW of power (50 MW transformer)
    - ~30 minutes residence time for 110 tph
  - Continuous charging and tapping
  - Continuous oxygen blow
    - De-P and De-C (below 0.15%C) continuously
  - Carbon/oxygen injection for continuous foamy slag
  - Continuous de-slagging

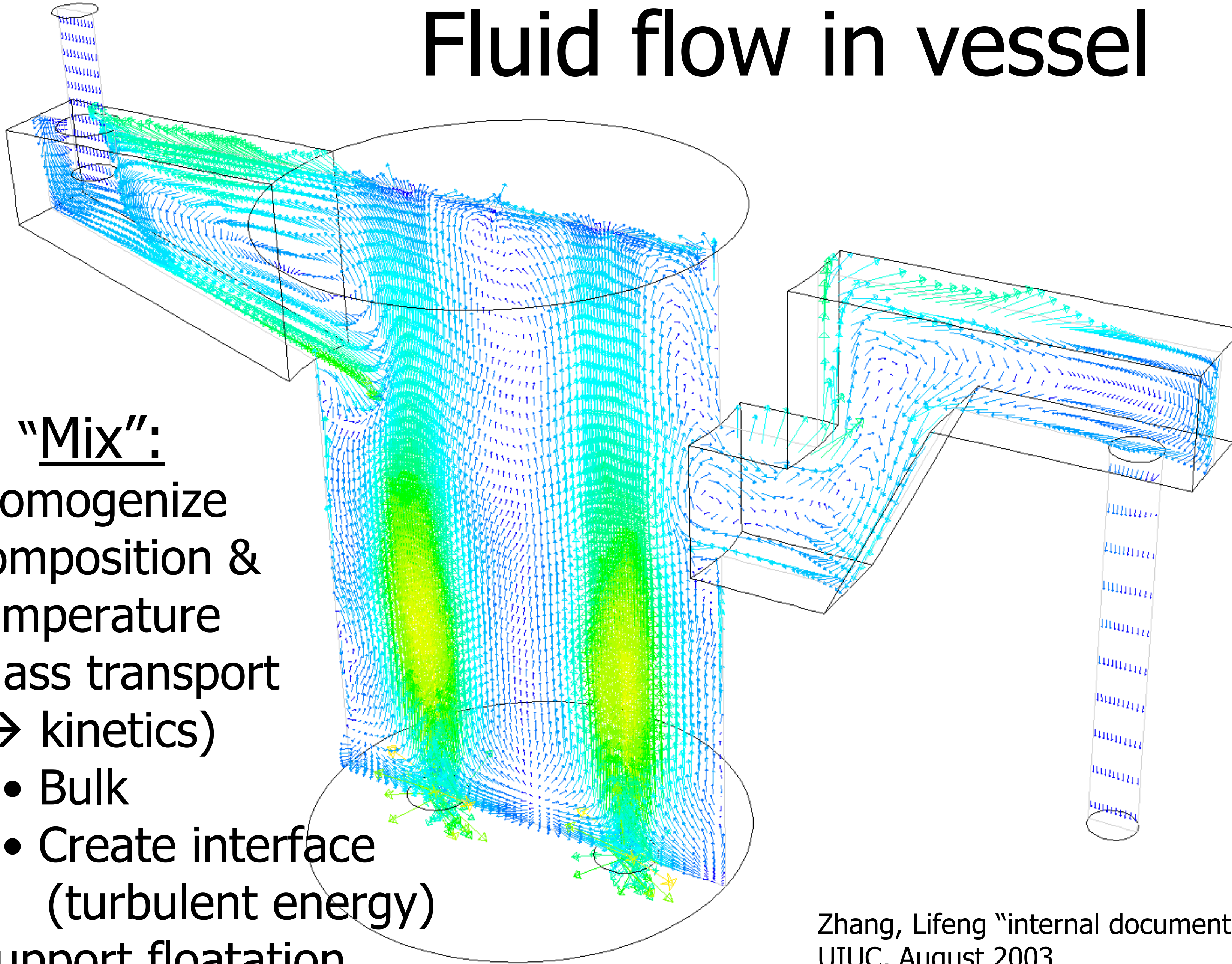
- Continuous Tapping

# Preliminary Concept for Oxidation Unit

- De-C
- Similar to continuous Q-BOP
  - Fruehan model
- Continuous de-slag



# Fluid flow in vessel



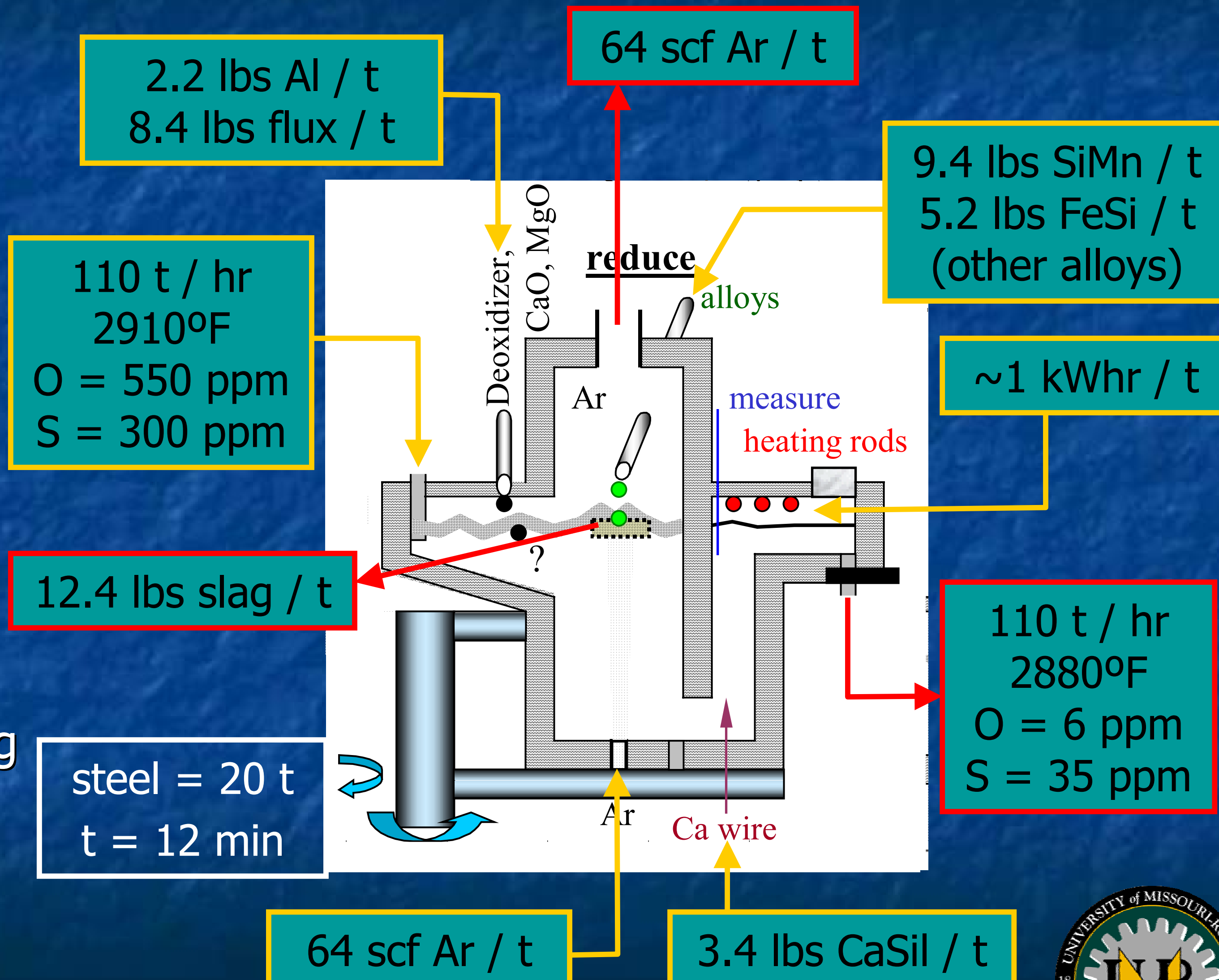
"<u>Mix</u>":

- Homogenize composition & temperature
- Mass transport (→ kinetics)
    - Bulk
    - Create interface (turbulent energy)
- Support floatation

Zhang, Lifeng "internal document"
UIUC, August 2003

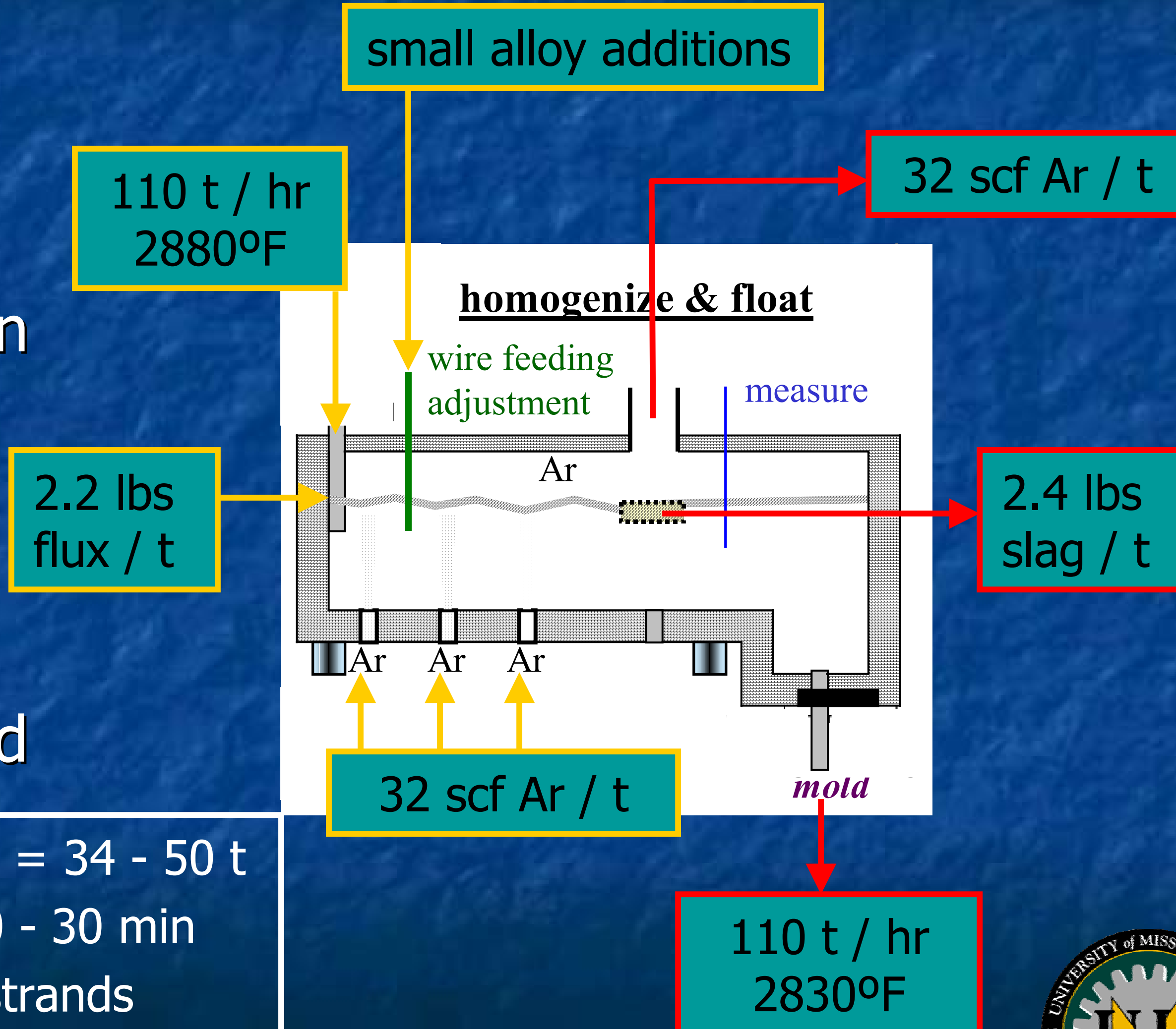
# Preliminary Concept for Reduction Unit

- De-O & De-S
- Continuous de-slag
- Alloying
  - Bulk (small pieces)
- Temperature control
  - Resistant heating
  - Avoid cooling
- Calcium treatment



# Preliminary Concept for Final Unit

- Final Alloying
  - Wire injection adjustments
- Homogenization
- Inclusion floatation
- Minimize reoxidation
- Continuous transfer to mold



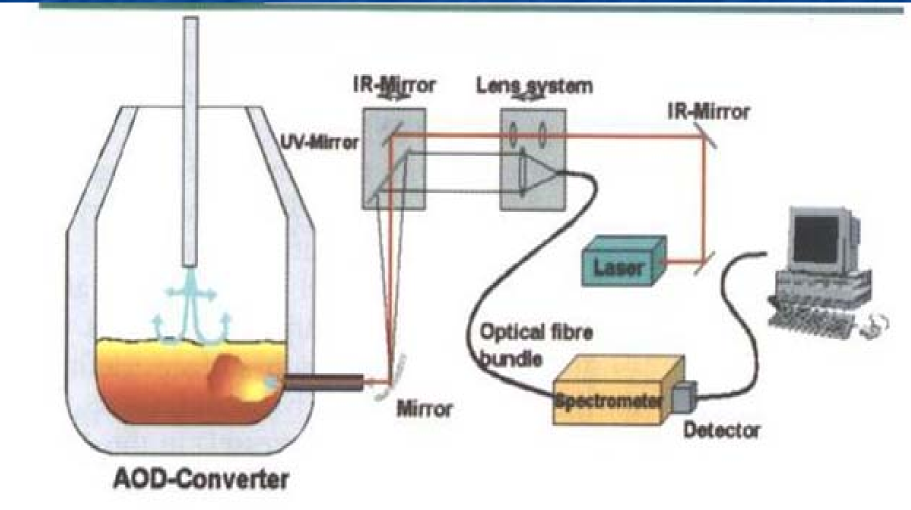

steel weight = 34 - 50 t
time = 20 - 30 min
1 – 3 strands

# Continuous Monitoring

- Con®Cept: Temperature & Chemistry
  - Laser – lens – spectrometer (LMF & EAF, etc.)
- Inclusion sensor*
  - Size & Number

Temperature

Chemistry




Elements of the continuous bath analysis system on an AOD converter.

Ramaseder et al. "Continuous chemical analysis of liquid steel" Steel Times International, Nov 02, p. 30

Pillwax et al. "VAI-ConCept – A Performance Package for AOD converters" AISE Steel Technology, Vol. 80, No. 9, Sept 03, p. 93

*International Report "SMK, Heraeus Develop Sensor" Iron & Steelmaker, Vol 30, No 11, Nov. 2003, p. 4

# Summary

- Continuous steelmaking has the potential to increase profits
- Extensive previous research exists
- New conceptual process is scrap based and fully continuous
- Fluid flow modeling is crucial during the design of the vessels