



Lab Curiosity to Commercial Process to (Maybe) High-valued Solar-thermal Products

Alan(Al) W. Weimer
Chemical and Biological Engineering
University of Colorado at Boulder

HelioCon Presentation
(September 3, 2026)

Objectives



- A true story about new (lab curiosity) processing technology and navigating the headwinds associated with financial barriers and people so that all win; a focus on mid/early career researchers and recognizing opportunities - with pitfalls;
- A real opportunity for a near perfect fit CSP reaction engineering project to synthesize materials that are of interest today – like B_4C , SiC , TiB_2 , and WC ,

Company Objective



In 1983, The Dow Chemical Company intended to be the low-cost producer in the world of high-quality non-oxide ceramic powders

- B_4C , SiC , Si_3N_4 , AlN , WC , ...

Which Path?



In 1983, The Dow Chemical Company intended to be the low-cost producer in the world of high-quality non-oxide ceramic powders
- B_4C , SiC , Si_3N_4 , AlN , WC , ...

This was a great opportunity for a young engineer 4 years out from their Ph.D.!



Technically exciting – radiation heat transfer, solids reacting together at near $2000^{\circ}C$, non-steel reactor, 1st process engineer to work with ~ 30 “white glove” scientists

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Recommendations

- Do something else like polymers, this is a fad and will be gone in 10 years
- Take the double promotion to group leader
- Focus on particle technology throughout the company
- **Don't do this!**

Understand the Market Opportunity



In 1983, The Dow Chemical Company intended to be the low-cost producer in the world of high-quality non-oxide ceramic powders - B_4C , SiC , Si_3N_4 , AlN , WC , ...



B_4C Body Armor



Armor Plating



Helicopter Seats

Targeted Market - Military Applications for Boron Carbide (B_4C)

Know the Competition



Commercial Silicon Carbide Powders

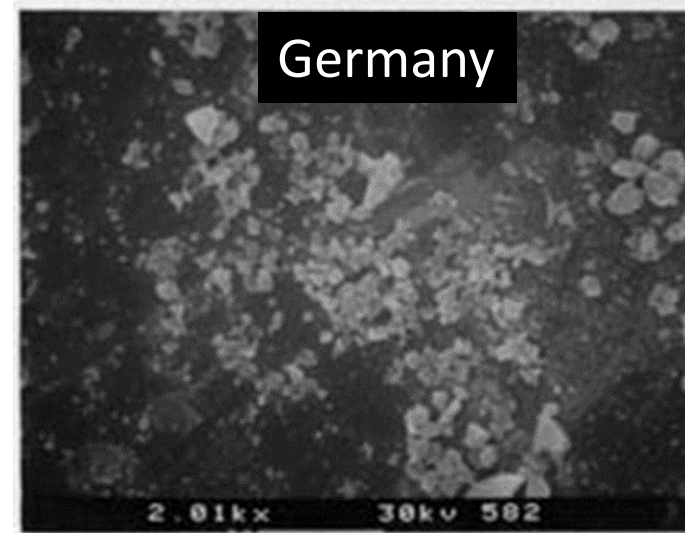
Preferred Properties to make high-quality fabricated parts

- Submicron particle size
- High purity
- Non-agglomerated

Agglomerated Powders

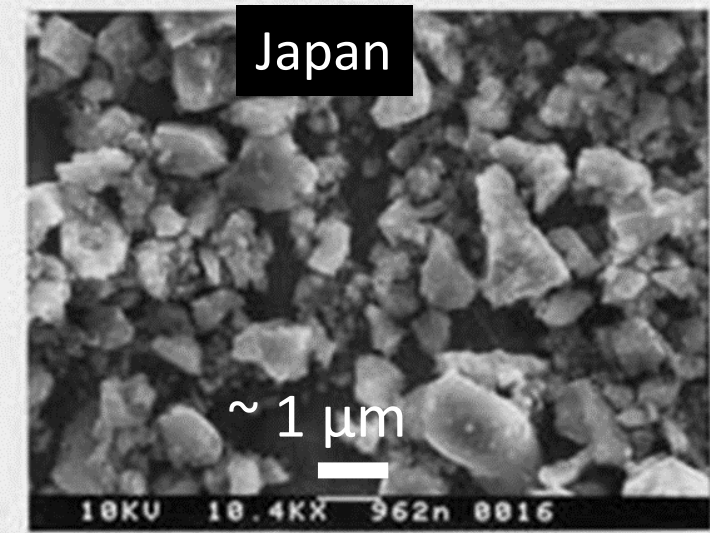
These commercial SiC powders typically produced by carbothermal reduction chemistry:

$(3C + SiO_2 \rightarrow SiC + 2CO)$,
grinding, and screening



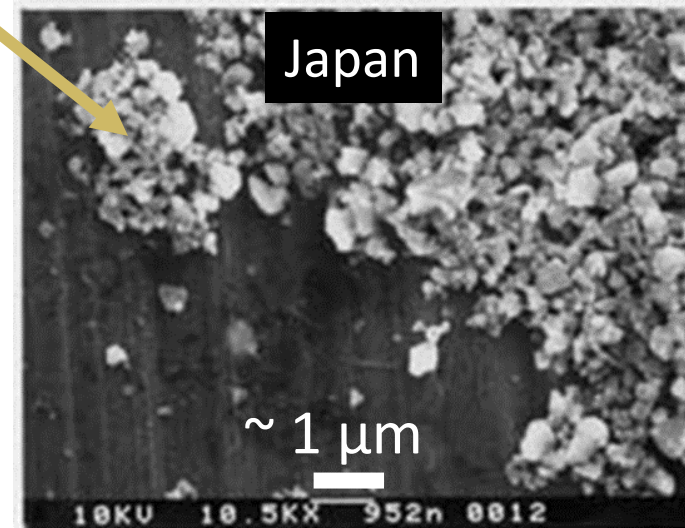
Germany

Starck B-10



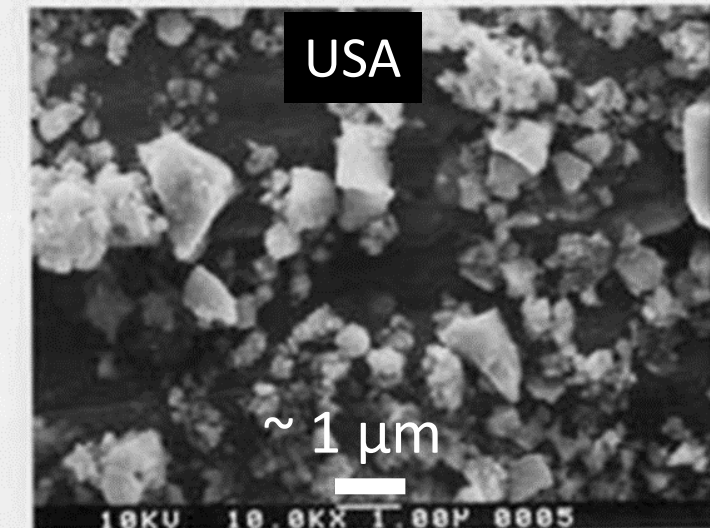
Japan

Ibiden Ultrafine



Japan

Showa Denka B-1



USA

Superior Graphite HSC

Know the Competition

Commercial Boron Carbide Powders



Preferred Properties to make high-quality fabricated parts

- Submicron particle size
- High purity
- Non-agglomerated

Angular edges from grinding the 2nd hardest material known

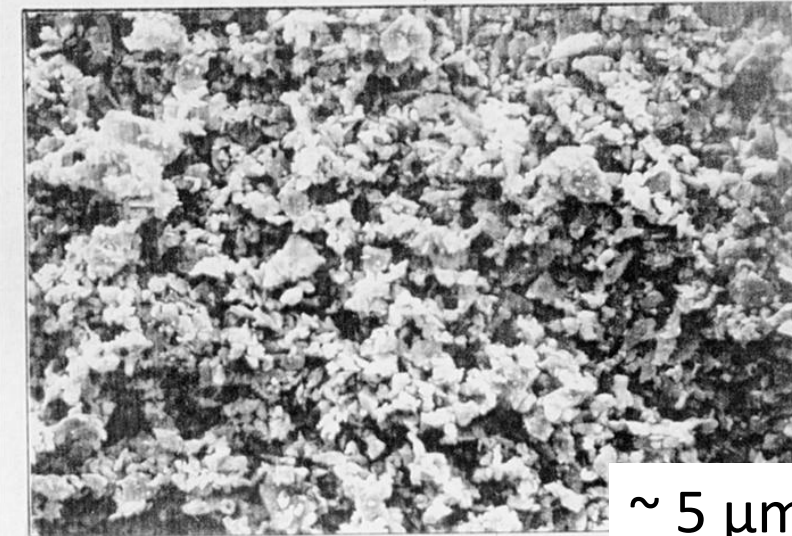
Germany



~ 5 μm 5.00 μm

Medium Grade
(~\$15/lb)

Germany



~ 5 μm

4.98 μm

These commercial B_4C powders typically produced by carbothermal reduction chemistry:

$(7\text{C} + 2\text{B}_2\text{O}_3 \rightarrow \text{B}_4\text{C} + 6\text{CO})$,
grinding, and screening

(1985 pricing)

Fine Grade
(~\$150/lb)

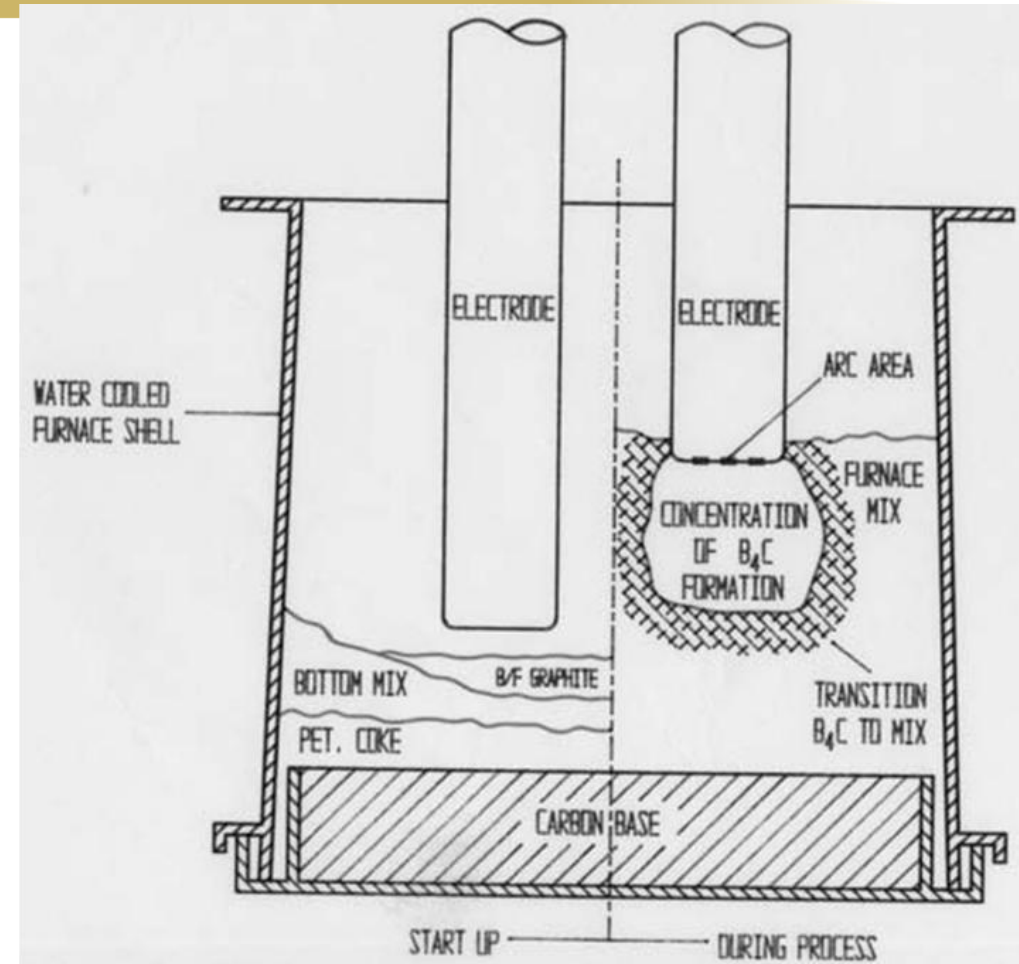
Commercial ESK Boron Carbide (B_4C) Powders

(ESK = Elektroschmelzwerk Kempten)

Commercial Reactors at the Time (know competition)



Acheson - SiC



Electric Arc – B₄C

Reactions carried out for days at extremely high temperature and then product is ground using **extensive grinding, sieving, separating, acid leaching to purify,...**

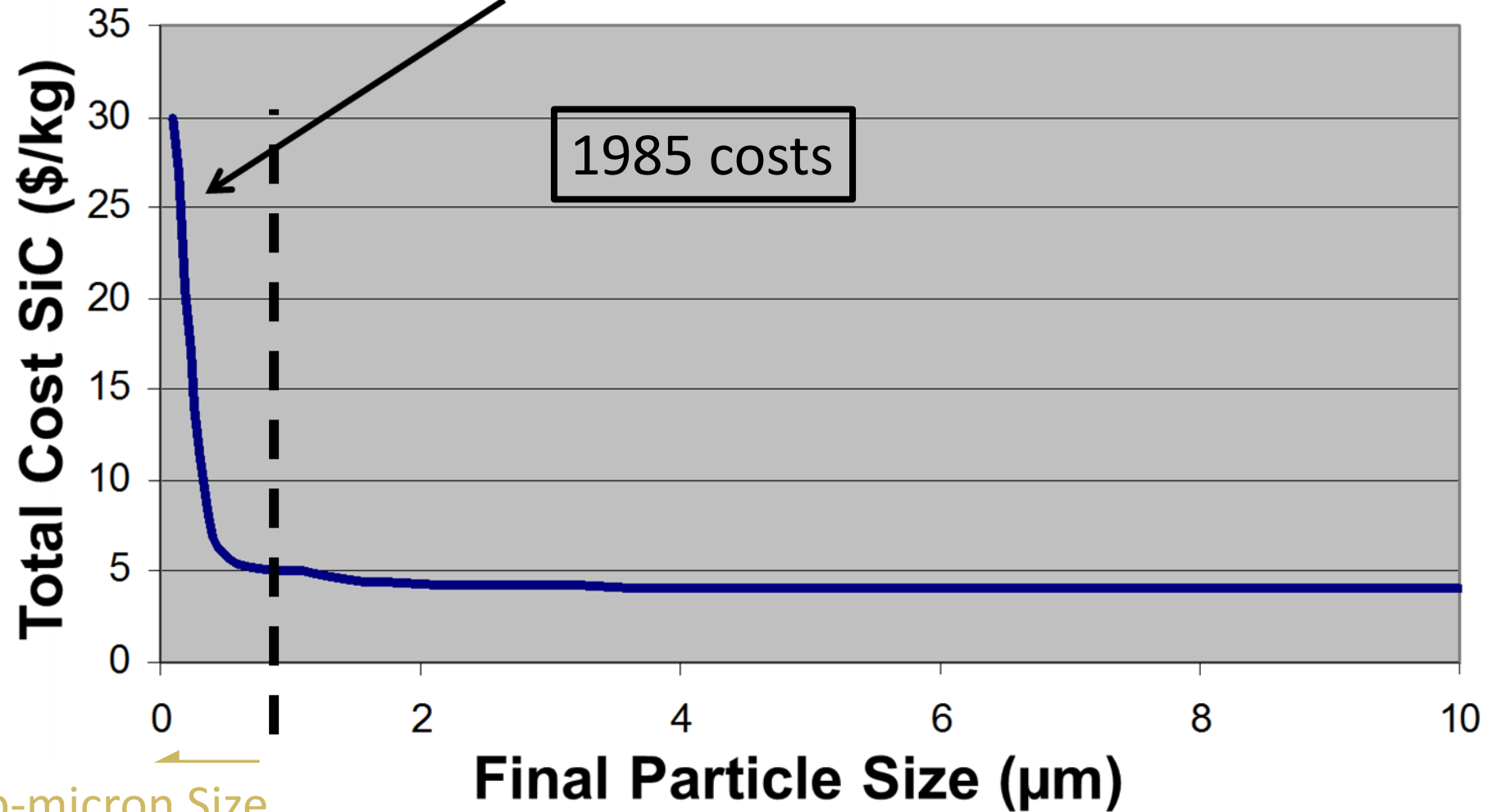


Understand the Opportunity – Cost

High-cost is the result of grinding, acid leaching out metal impurities, classifying to separate by particle size, recycling back to grinding

Note: smallest flaw size is related to the largest grain (particle) size

Exponential increase in cost for submicron powders



Which Path do We Take?



What will be the low-cost route to high-quality non-oxide ceramic powders?



- Technology Decisions
- Needs to Overcome Key Barriers
 - IP
 - \$
 - technology that actually works
 - viable market
 - know competition
 - working team
 - lowest cost
 - scalable process
 - bit of luck
 - convergence

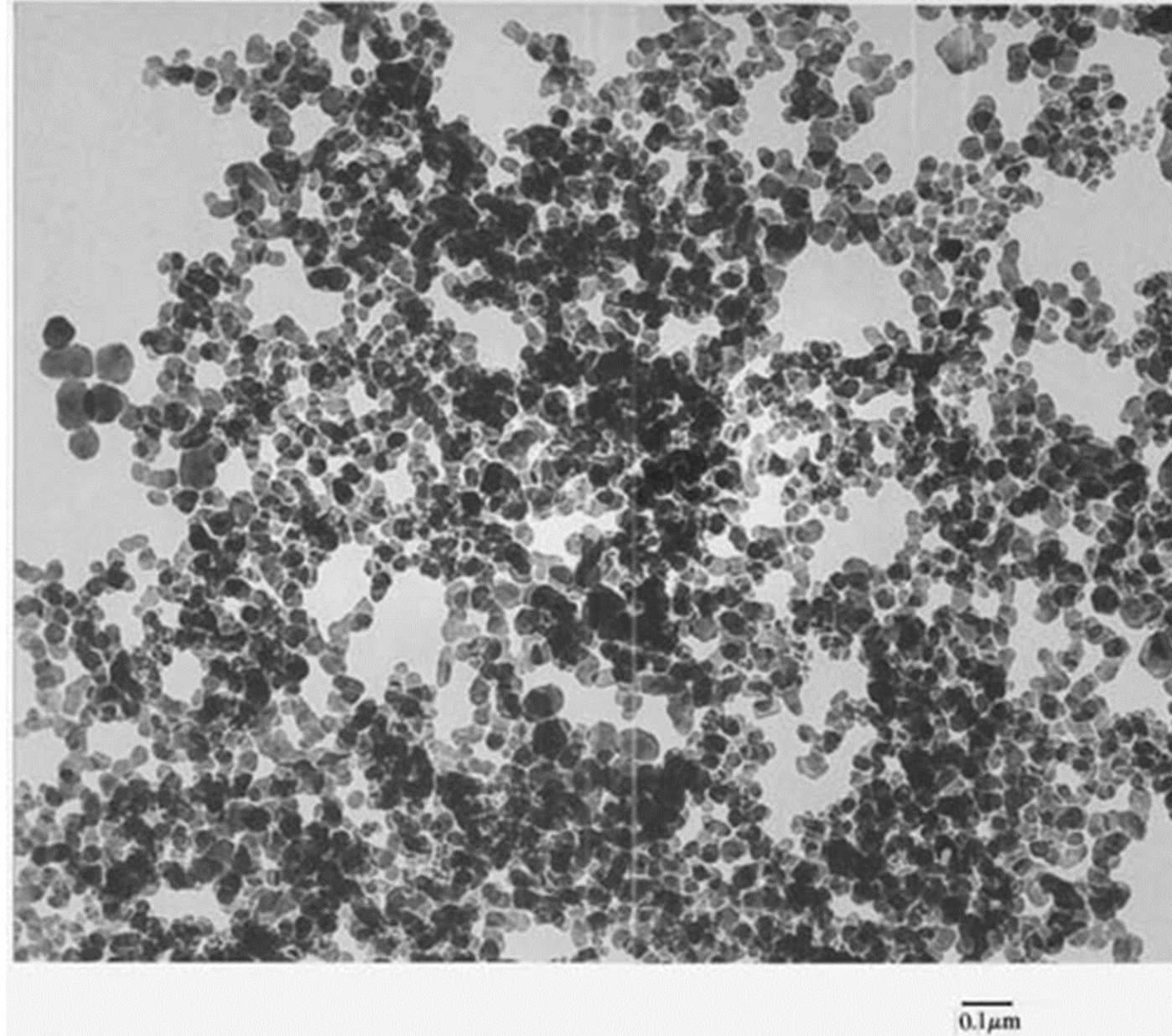
Understand the Opportunity - Technologies



Let's avoid the cost of grinding
and see if we can make submicron
particles directly!

Knudsen, A.K. and W. Rafaniello, US Patent 4,957,884

Laser-driven reaction using BCl_3
gaseous reactant



Understand the Opportunity - Technologies

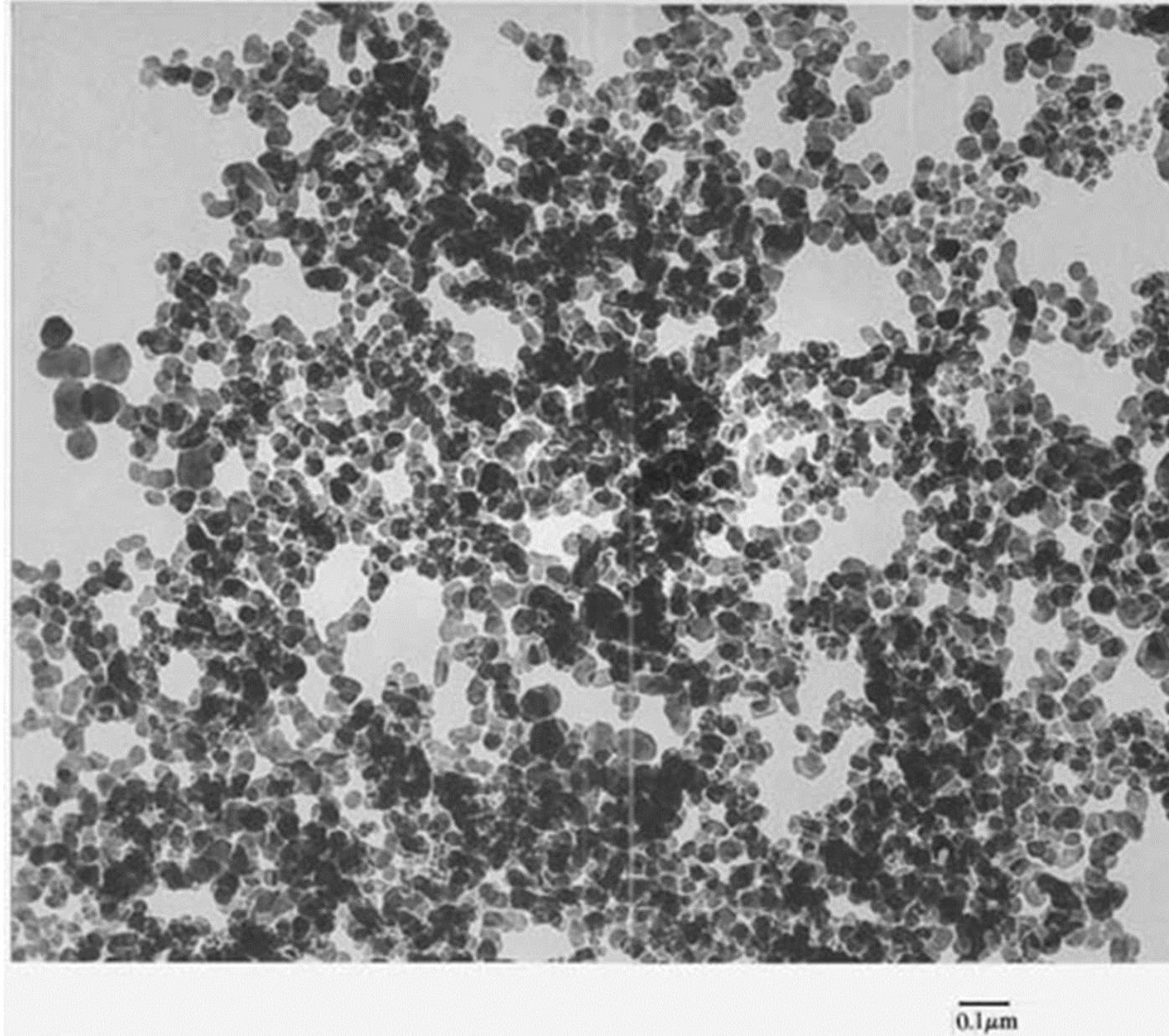


Let's avoid the cost of grinding
and see if we can make submicron
particles directly!

Do we go with the laser process? →
(this is a cost/performance and
business decision)

Knudsen, A.K. and W. Rafaniello, US Patent 4,957,884

Laser-driven reaction using BCl_3
gaseous reactant

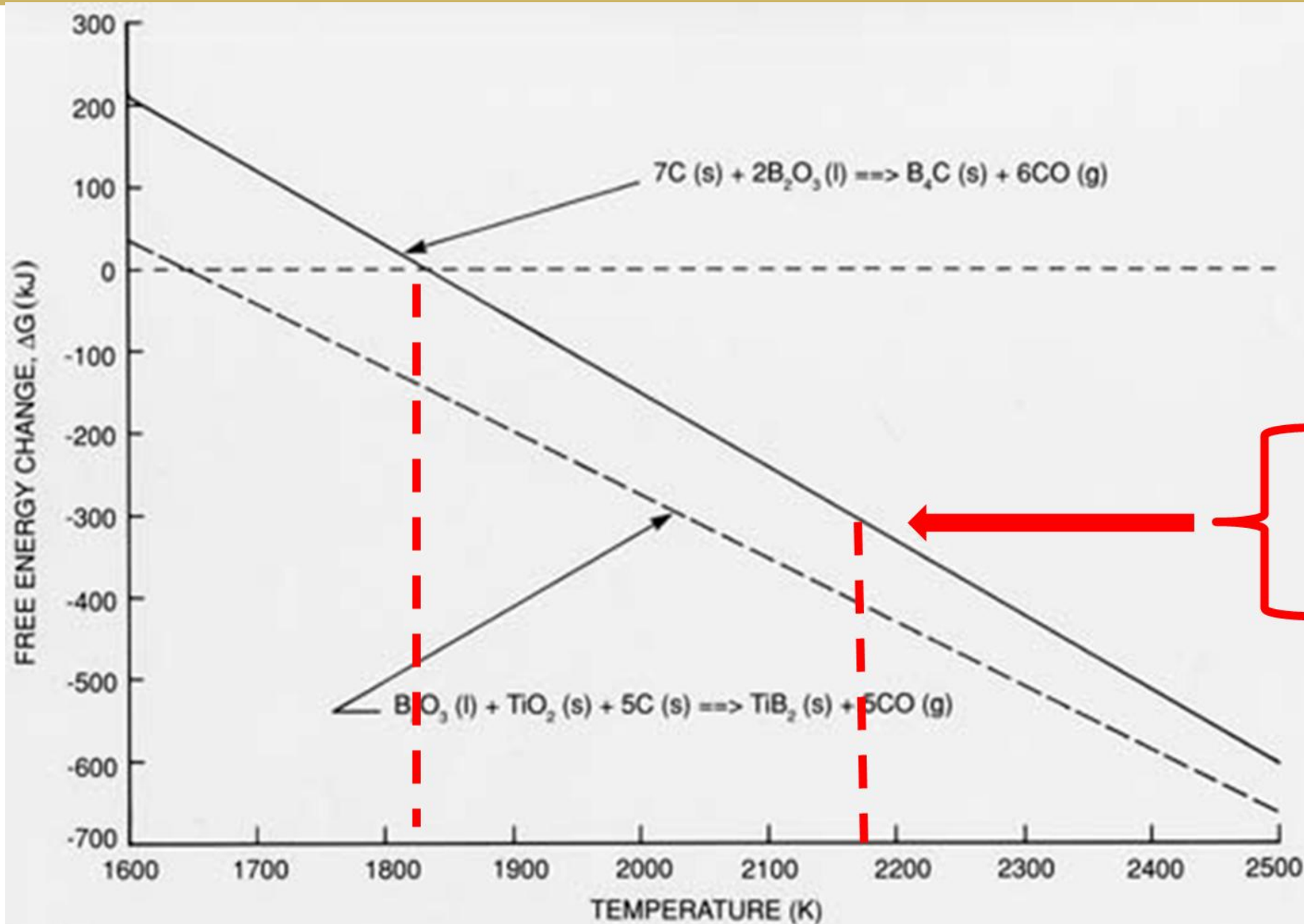




Develop a continuous process for producing submicron ceramic powders with properties similar to laser product, but at a substantially reduced cost

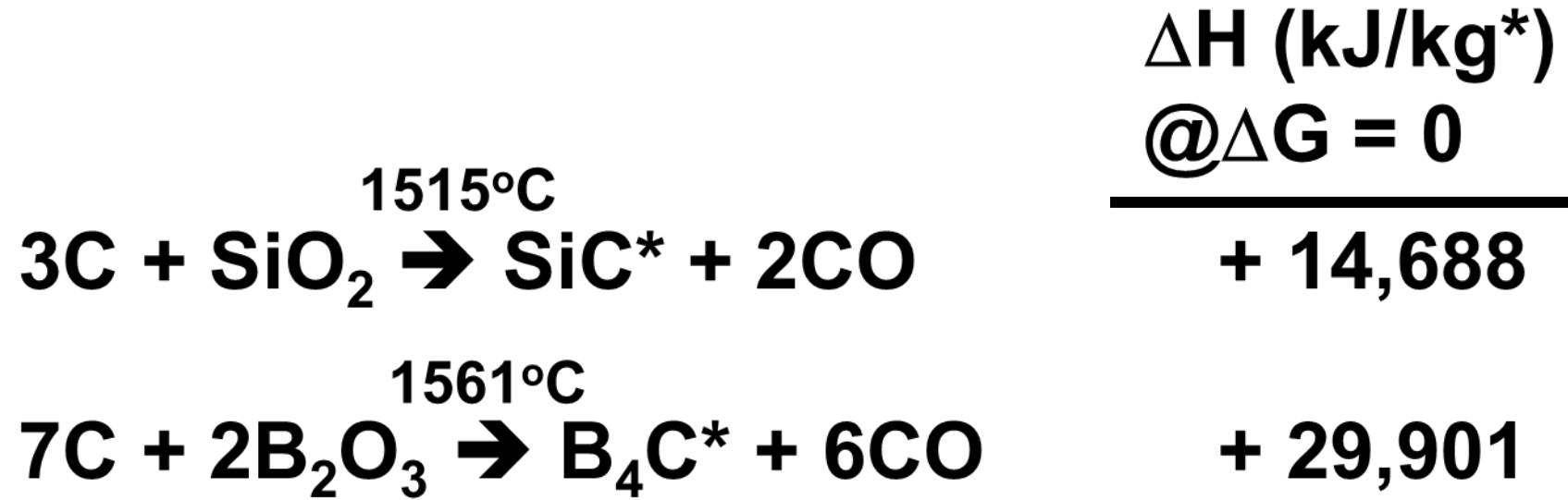
- Direct synthesis of submicron powders**
- Use carbothermal reduction chemistry**
 - ✓High purity, low-cost raw materials**
 - ✓Develop continuous reactor technology**

Understanding Fundamentals – Free Energy



In order to drive this reaction to the right in the presence of CO, we need to operate at around 1900°C, or higher

Understanding Fundamentals – Enthalpy



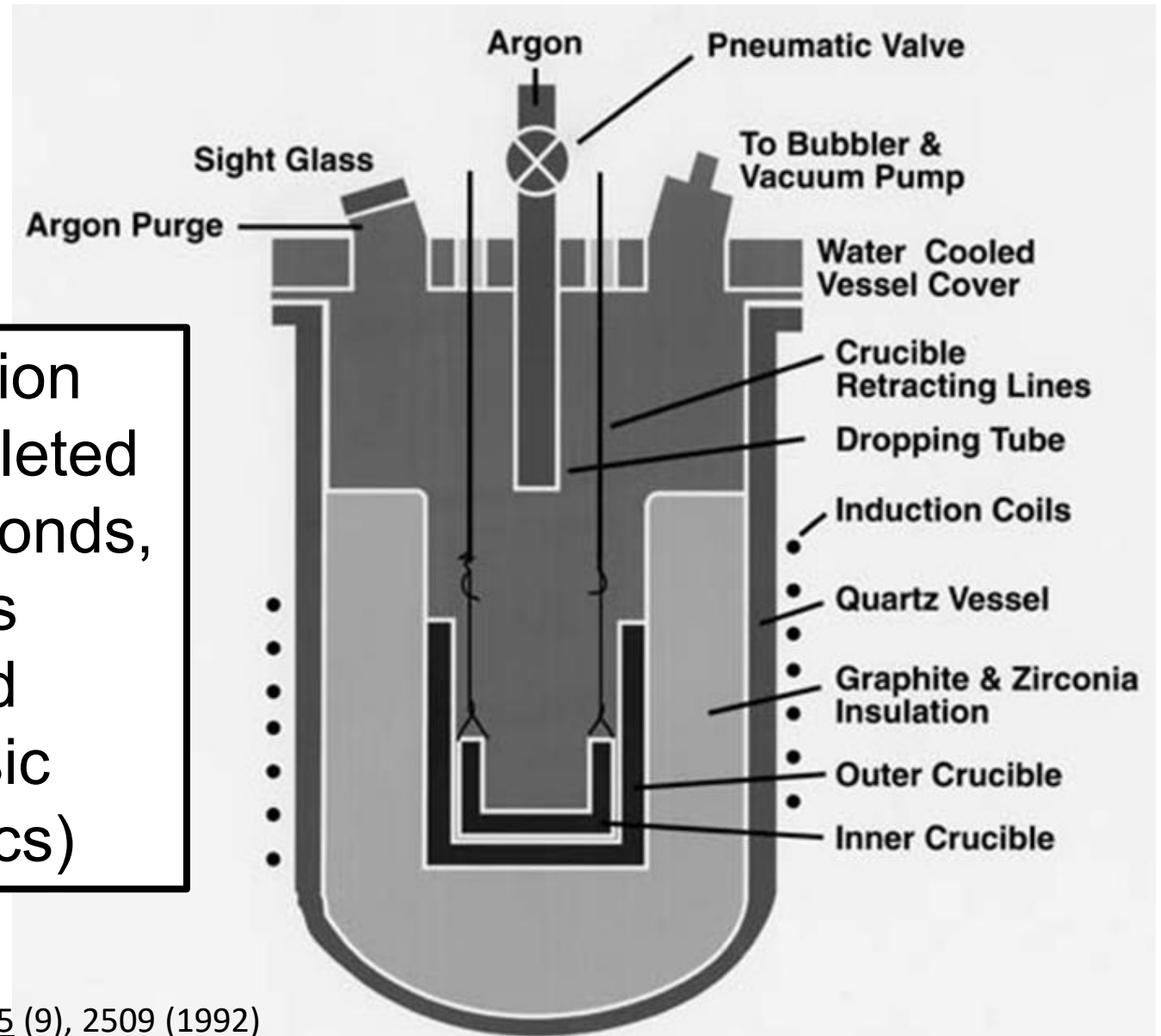
An incredible amount of energy is required to drive the reaction (~30,000 kJ/mole)!

Understanding Fundamentals – Kinetics



Induction
Heated
Laboratory
Reactor

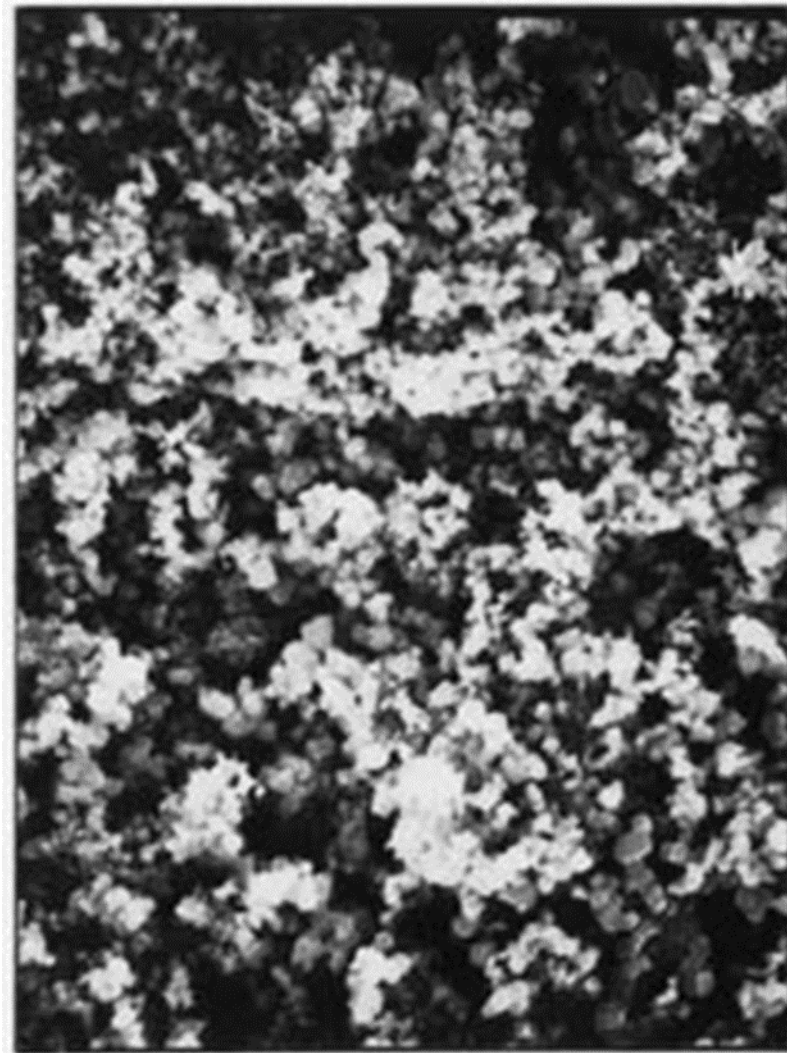
Reaction
Completed
in seconds,
or less
(Rapid
Intrinsic
Kinetics)



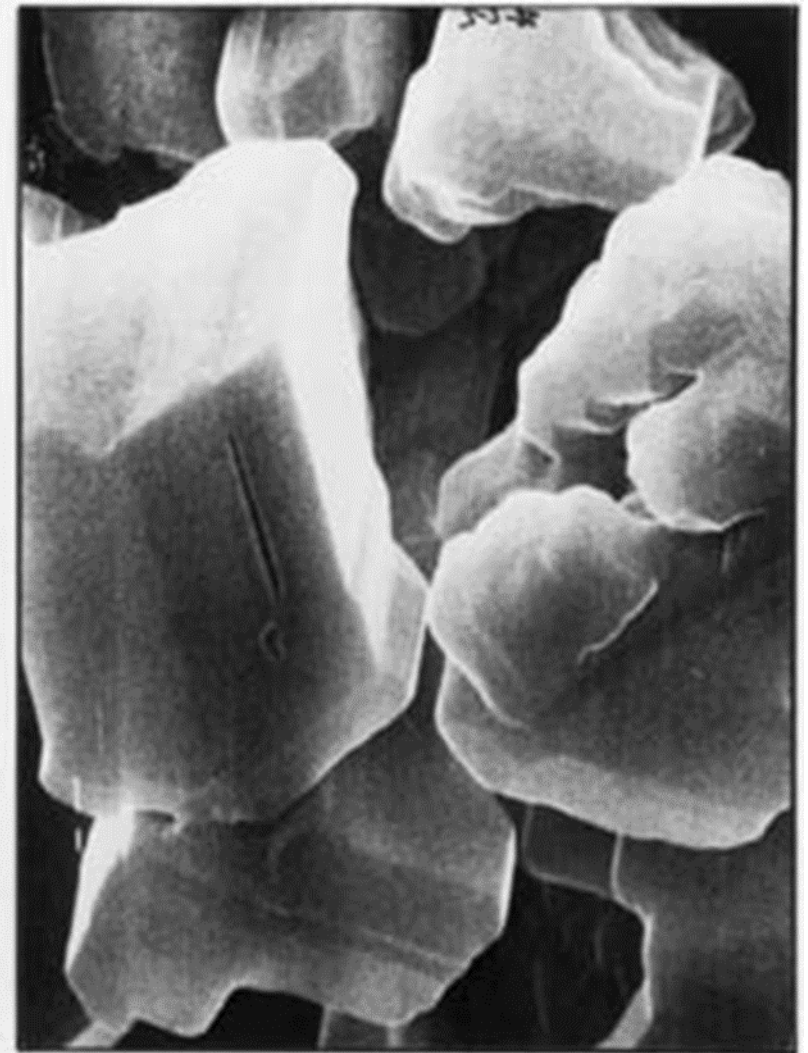
Understanding Fundamentals – Particle Growth



The rate of heating has a substantial influence on the rate of nucleation to generate fine submicron particles directly



Rapid Heating



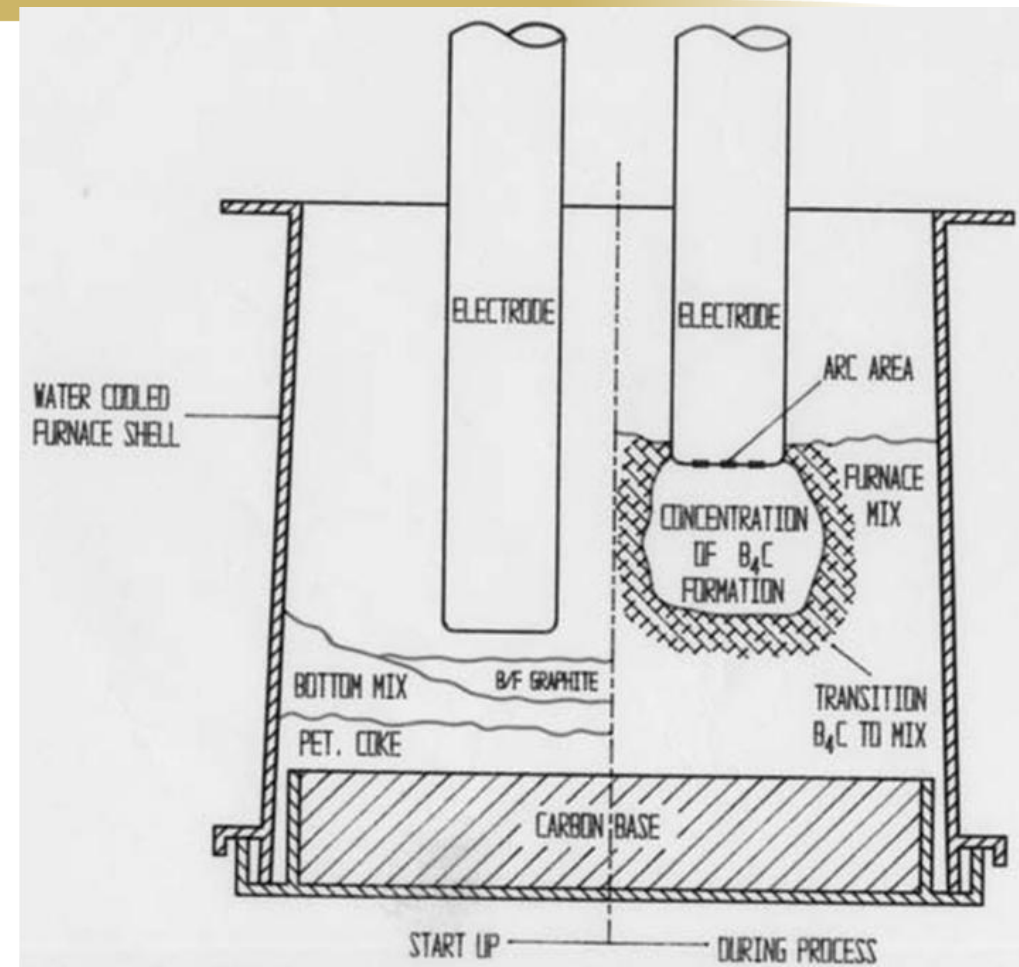
Conventional Heating

3 μ m

Commercial Reactors at the Time (know competition)



Acheson - SiC



Electric Arc – B₄C

Based on our fundamental understanding, what is reaction rate limiting for these two commercial reactors – i.e. limiting productivity?

Understanding Fundamentals – Summary



- **T ~ 1900°C**
- **Highly endothermic (requires a lot of energy)**
- **Rapid intrinsic kinetics**
- **Rapid grain growth**

Xiong, Y., S. et al. AIChE Journal, 38 (11), 1685 (1992).

If you understand the fundamentals, you can withstand the adversity – but it may take time since you are dealing with other very smart people who need to approve & may have different ideas (know this and **maintain your cool**)!

Which Path do I Take?

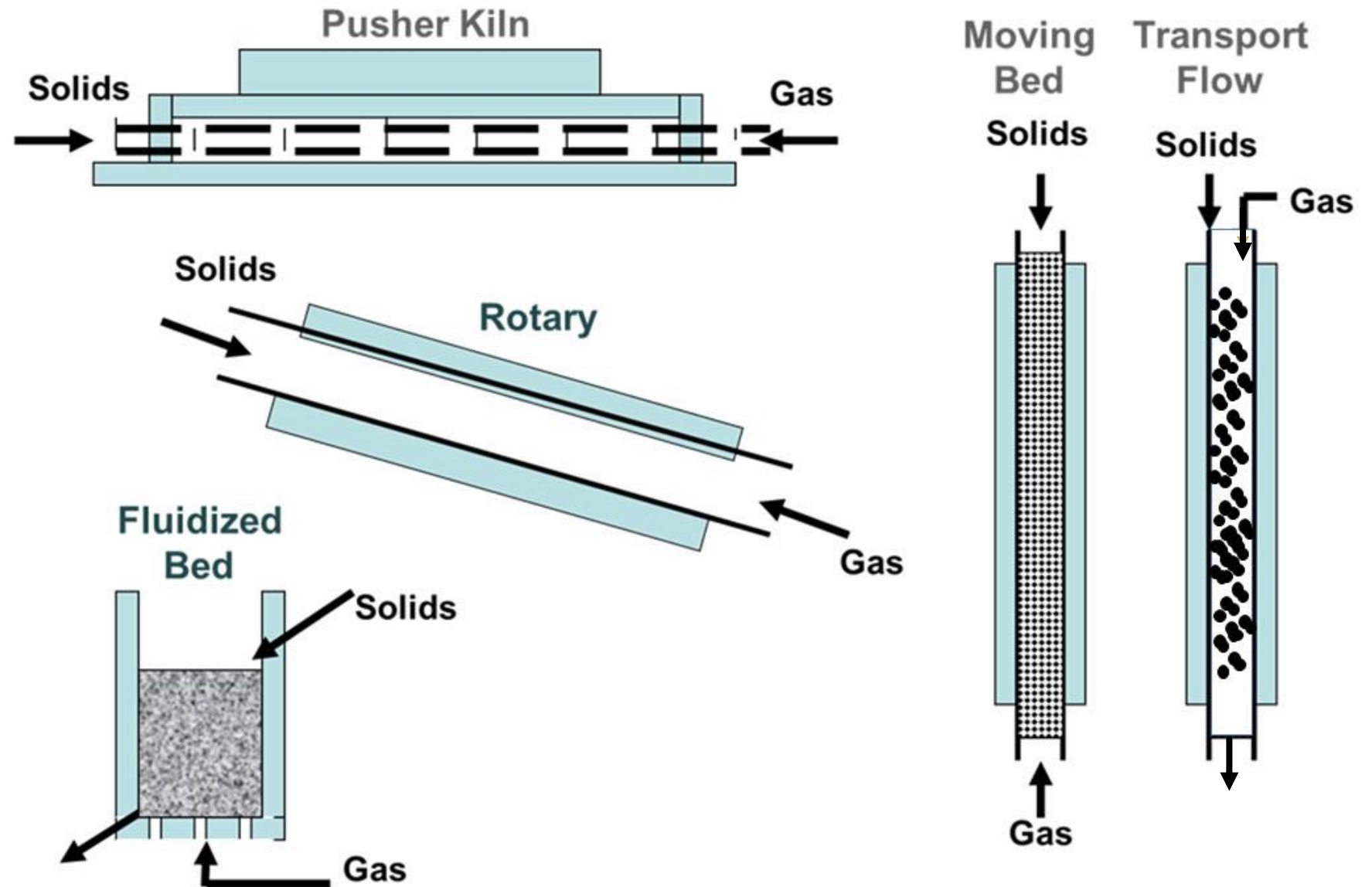


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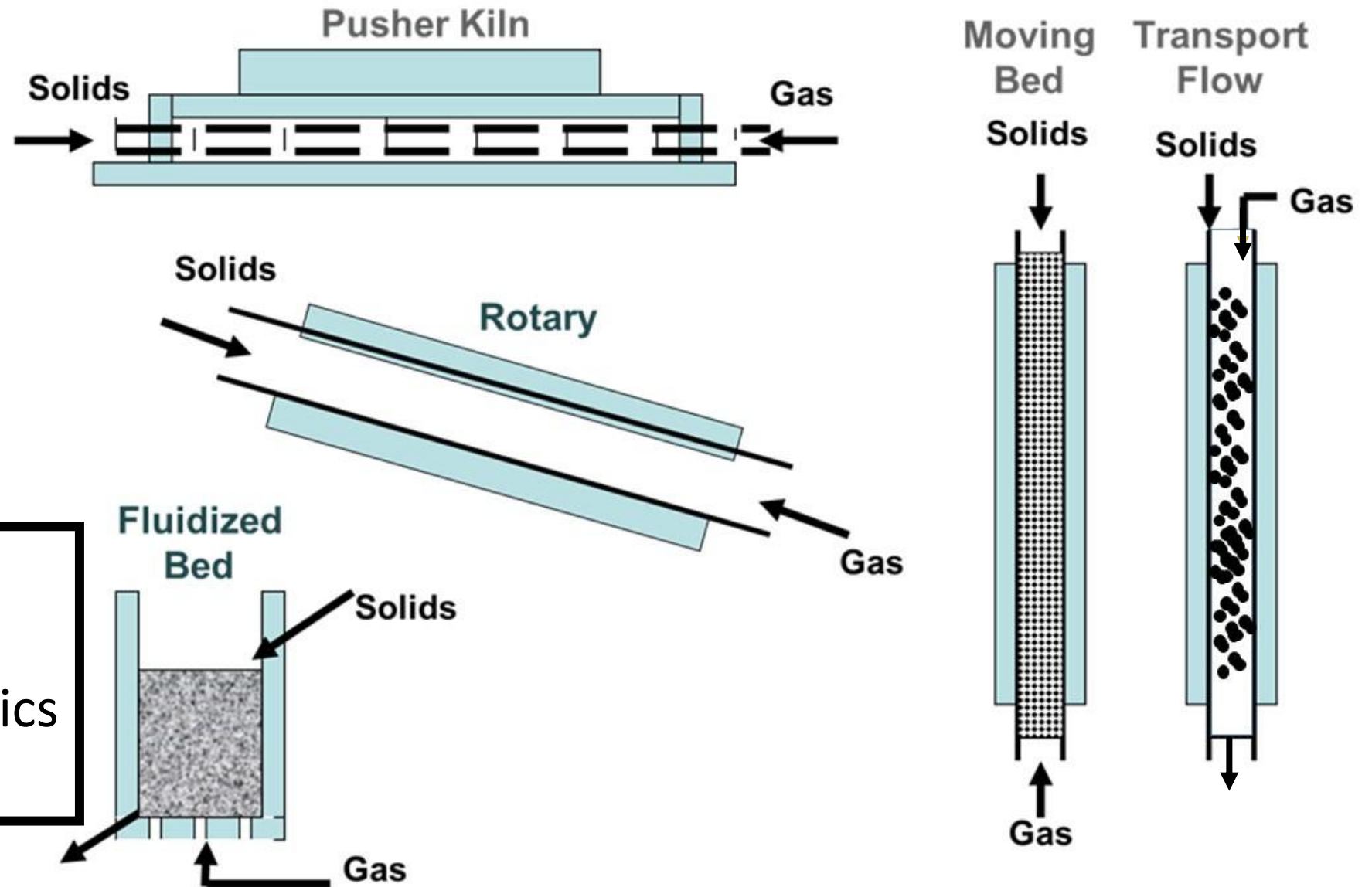
Decision Time – Solids Reactor Process Options



Decision Time – Solids Reactor Process Options

Based on your understanding of the reaction fundamentals, which do you select and why?

- $T \sim 1900^{\circ}\text{C}$
- Highly endothermic
- Rapid intrinsic kinetics
- Rapid grain growth



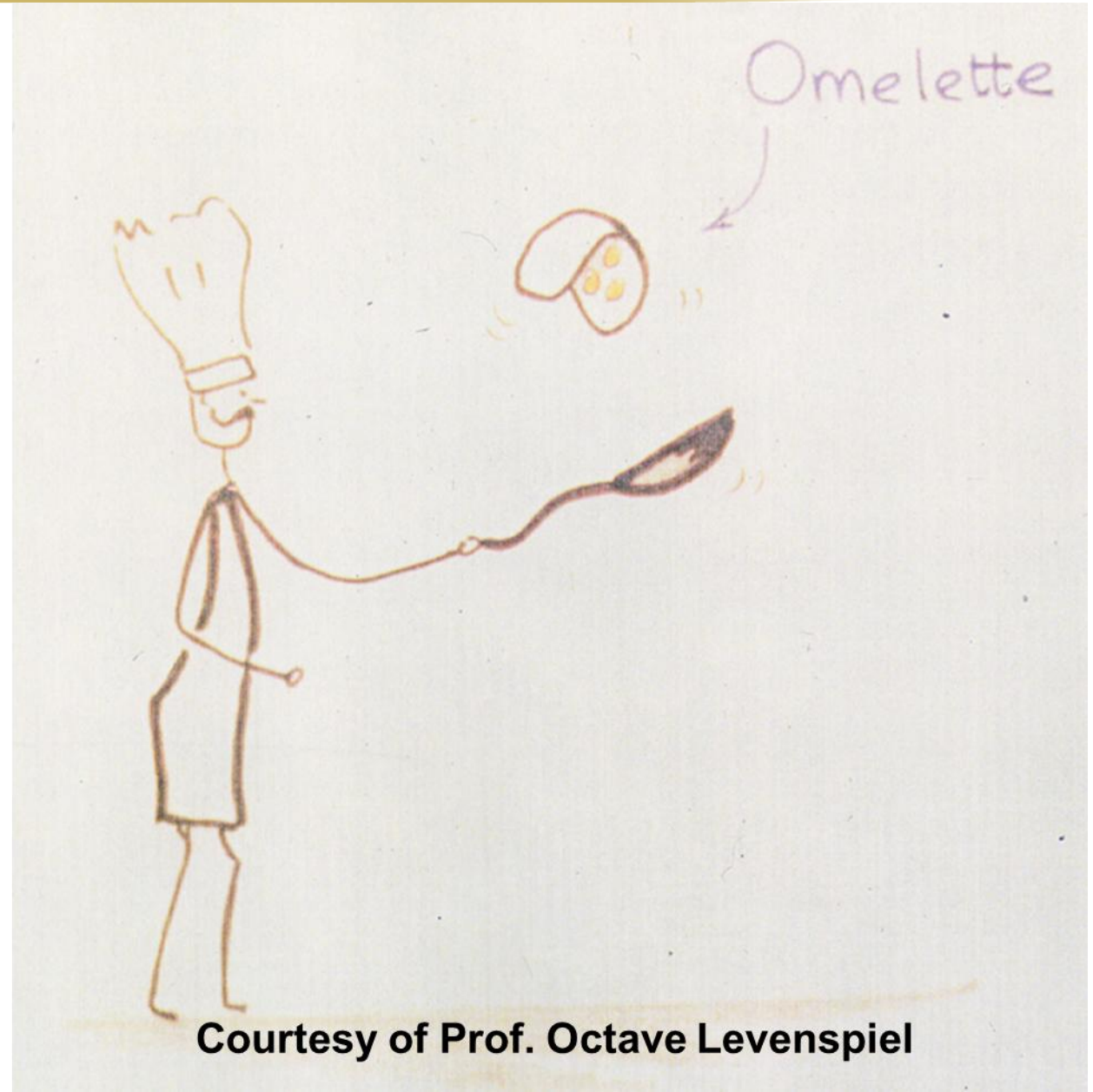
Let's Look at some Optimal Chemical Reactors



Some Optimal Reactors for Their Reaction Processes



The optimized
French reactor

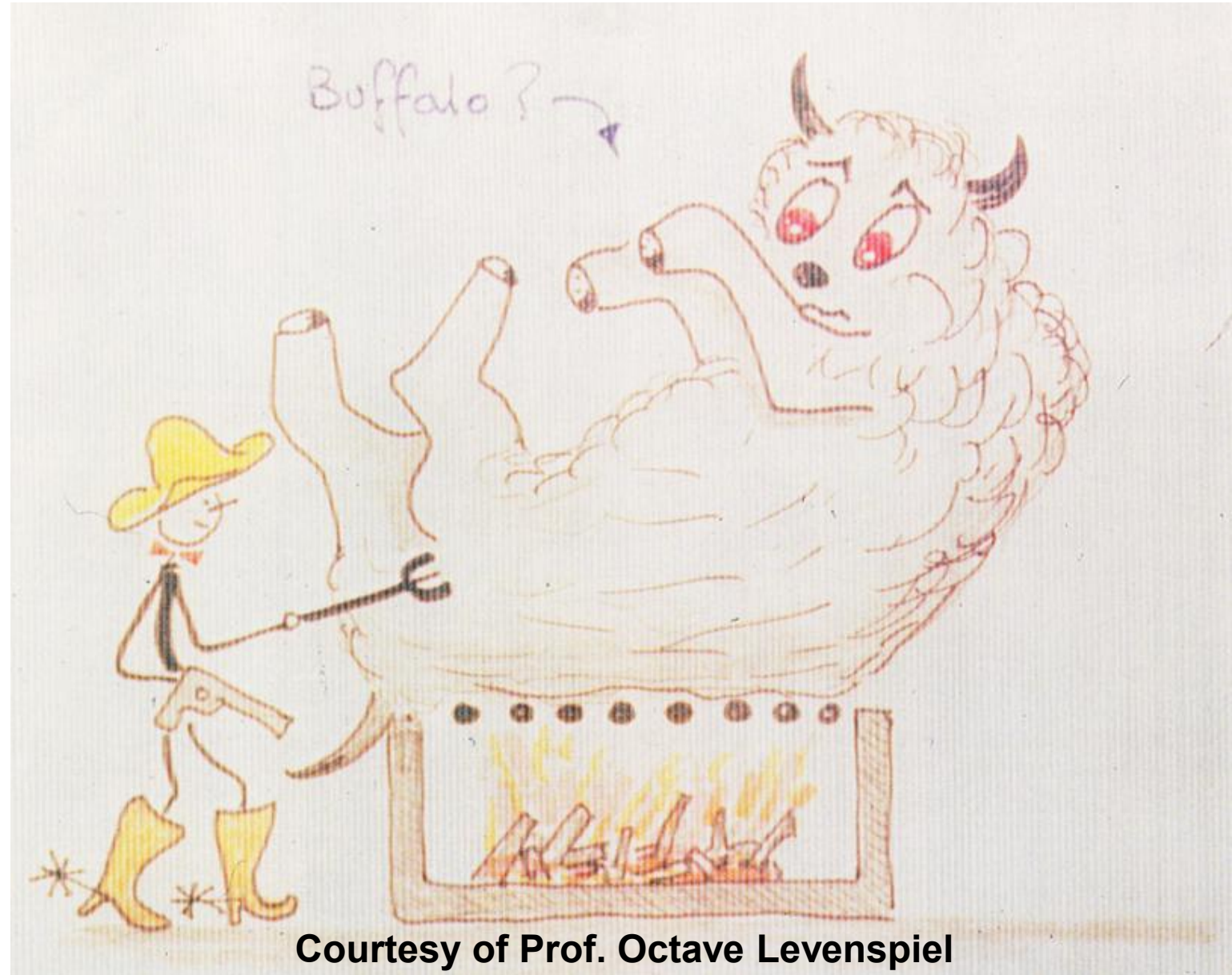


Courtesy of Prof. Octave Levenspiel

Some Optimal Reactors for Their Reaction Processes



The optimized
Texas (UT-Texas)
reactor

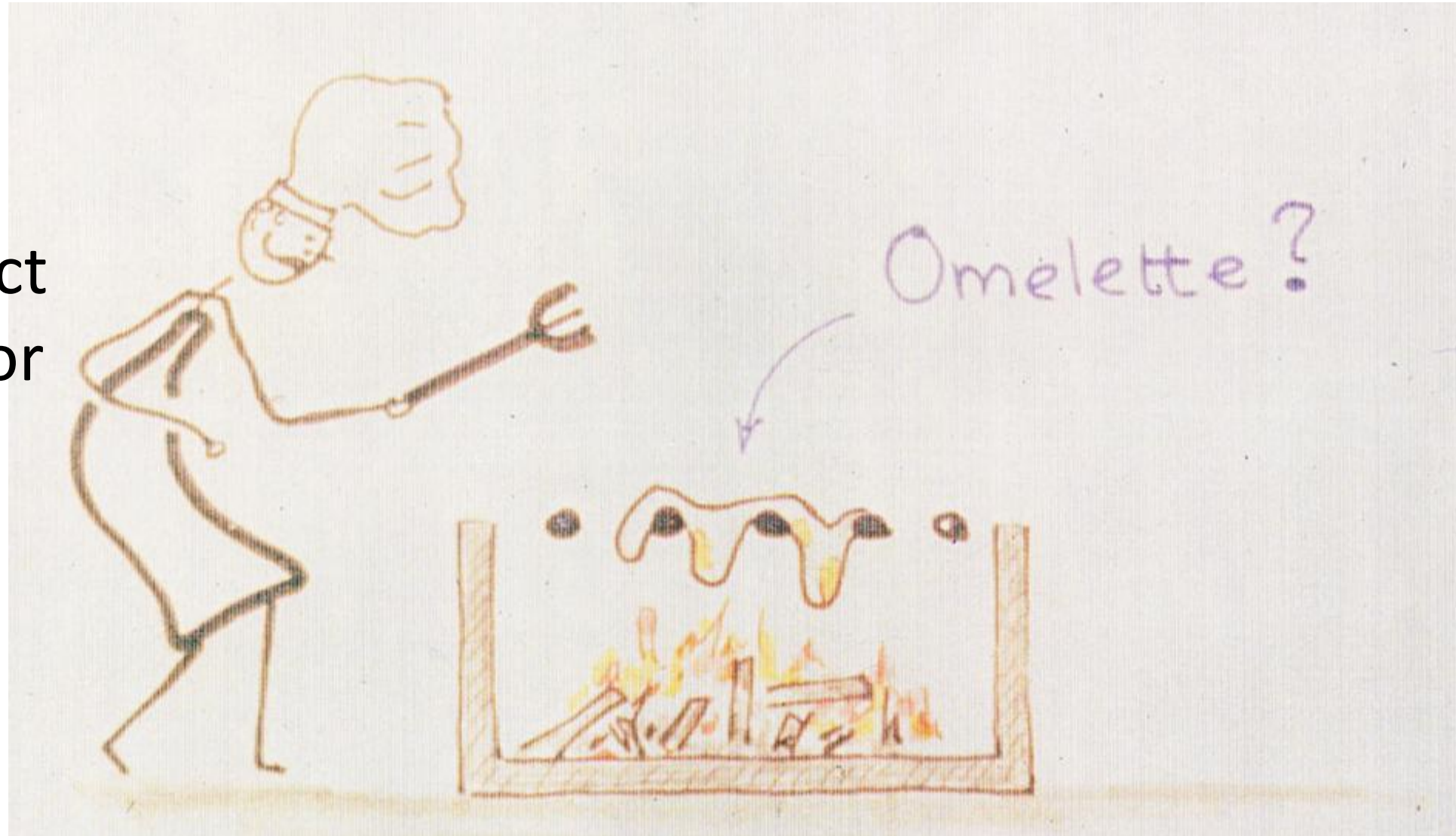


Courtesy of Prof. Octave Levenspiel

Some Optimal Reactors for Their Reaction Processes



Be sure to select
the right reactor
for the process



Courtesy of Prof. Octave Levenspiel

Some Optimal Reactors for Their Reaction Processes



The wrong
selection could
be downright
dangerous!

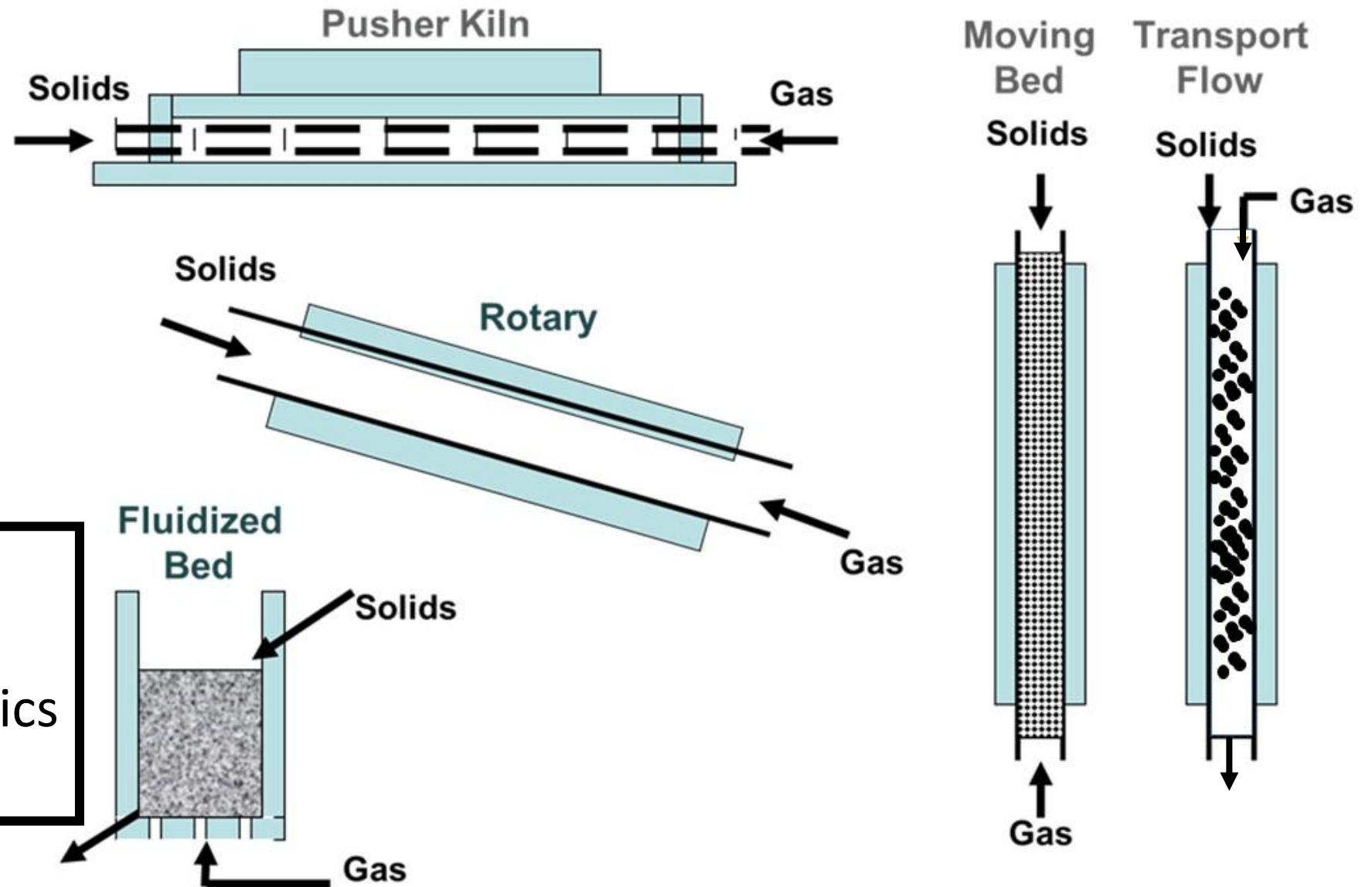


Courtesy of Prof. Octave Levenspiel

Decision Time – Solids Reactor Process Options

Let's review our fundamental understanding

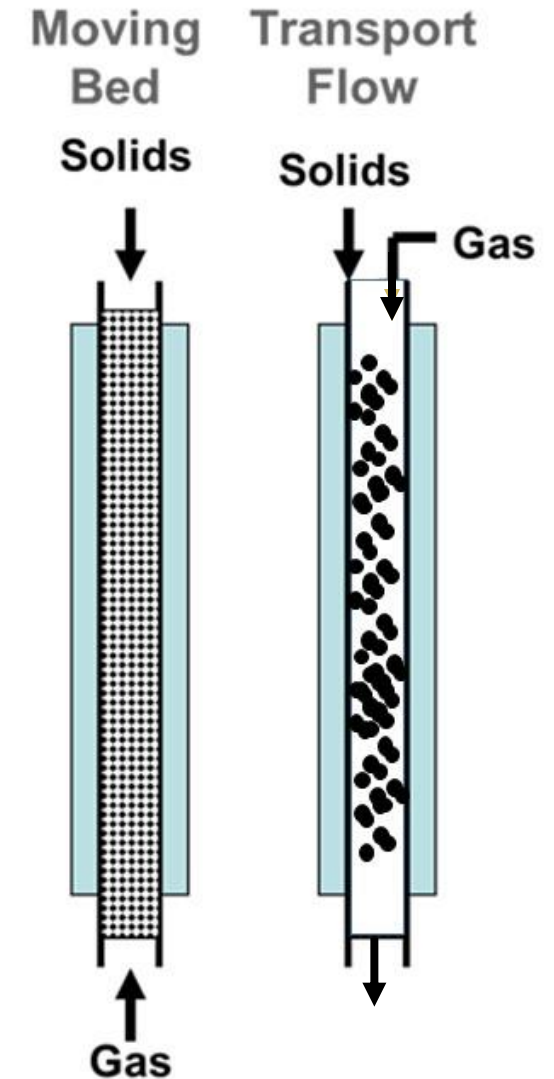
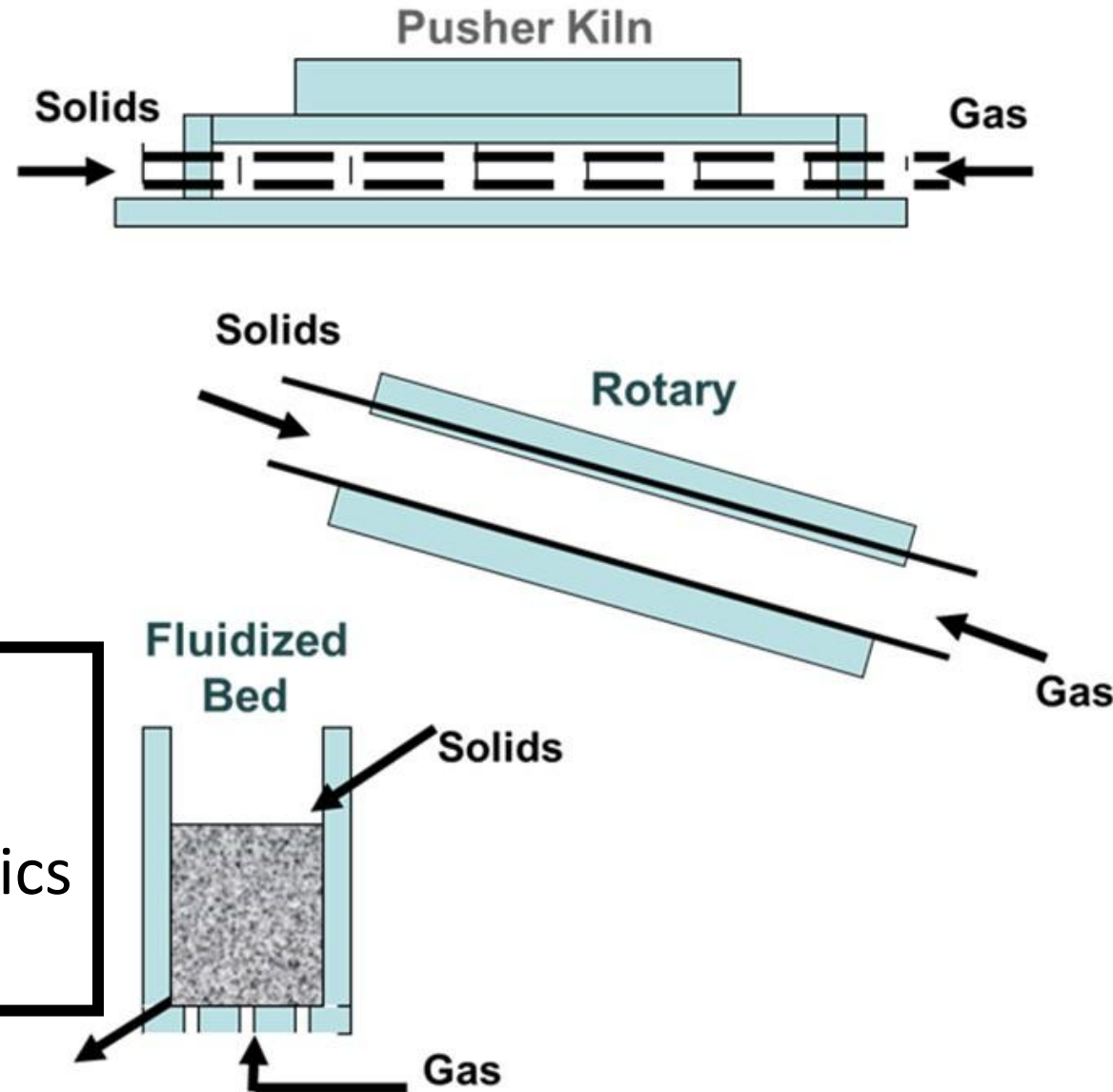
- $T \sim 1900^{\circ}\text{C}$
- Highly endothermic
- Rapid intrinsic kinetics
- Rapid grain growth



Which Reactor do you “bet” ~\$25M (today) on?



Let's review our fundamental understanding



- $T \sim 1900^{\circ}\text{C}$
- Highly endothermic
- Rapid intrinsic kinetics
- Rapid grain growth

Navigating the foggy fork in the road

Engineers solve difficult problems that don't have an obvious clear solution

1. Consider alternatives.
2. Weigh pros and cons.
3. **Examine options *through the lens of your strengths.***
4. Talk it over with others.
5. Consider personal values
 - **don't do anything you consider unethical.**

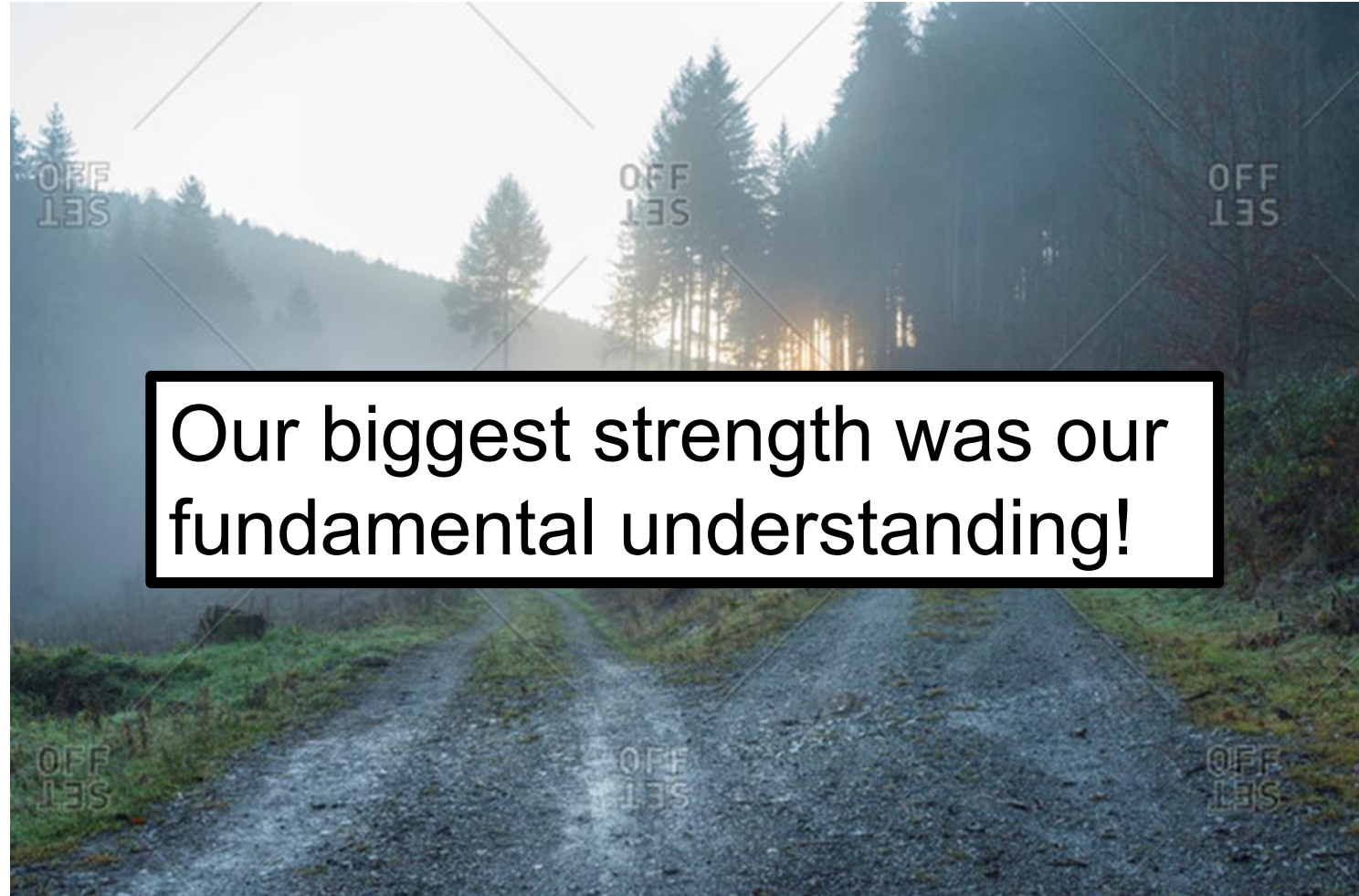


<https://www.offset.com/search/fork+in+the+road>

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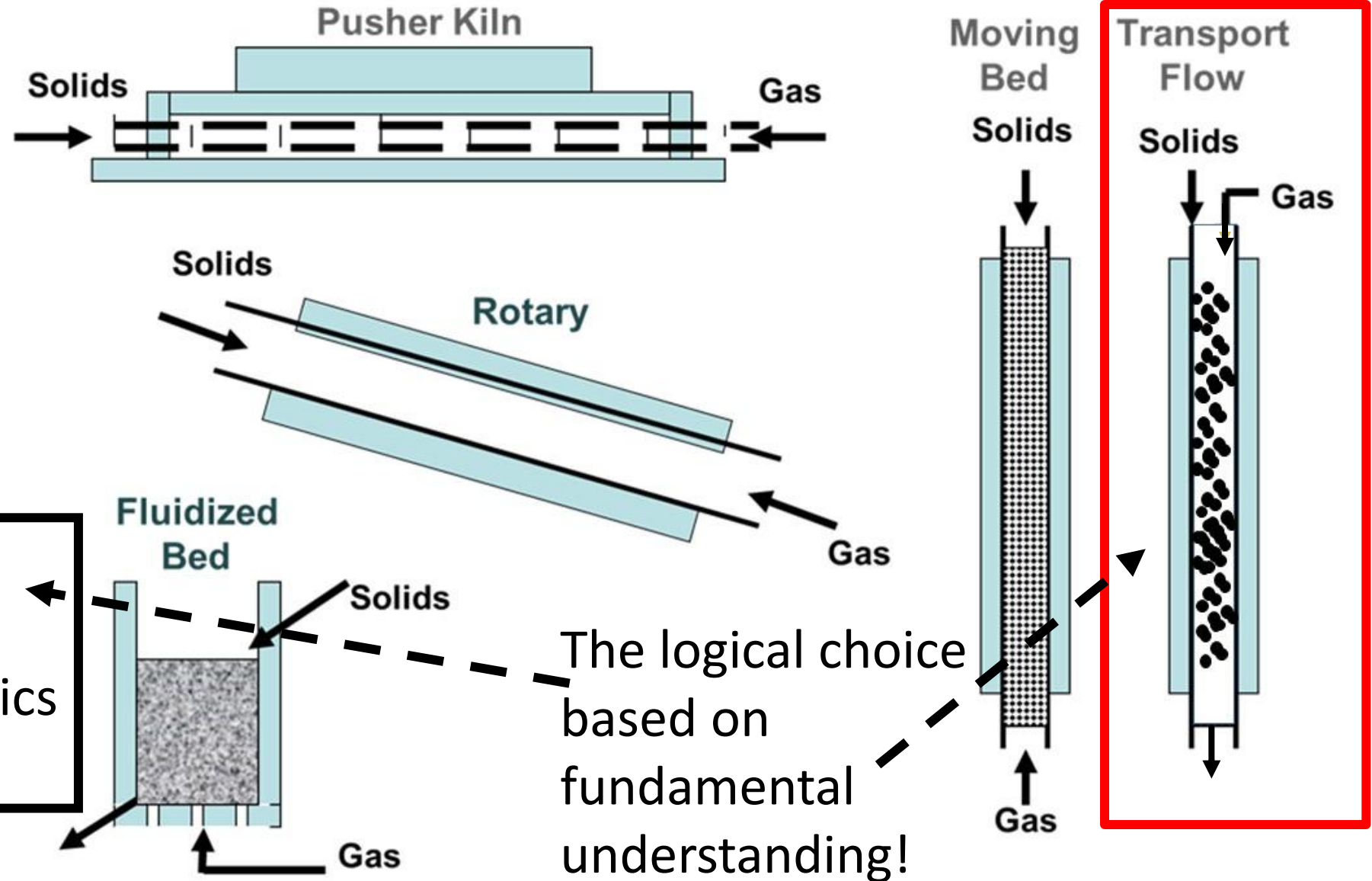


<https://www.offset.com/search/fork+in+the+road>

Which Reactor do you “bet” ~\$25M (today) on?



Let's review our fundamental understanding



- $T \sim 1900^{\circ}\text{C}$
- Highly endothermic
- Rapid intrinsic kinetics
- Rapid grain growth

The logical choice based on fundamental understanding!

What !



“Nobody does that!”



This created major internal controversy

Convince the Skeptics that it works



Your great idea is worth nothing if you can't convince people that it is worth something – work on communication skills

Management Change – Getting Serious!



dreamstime.com

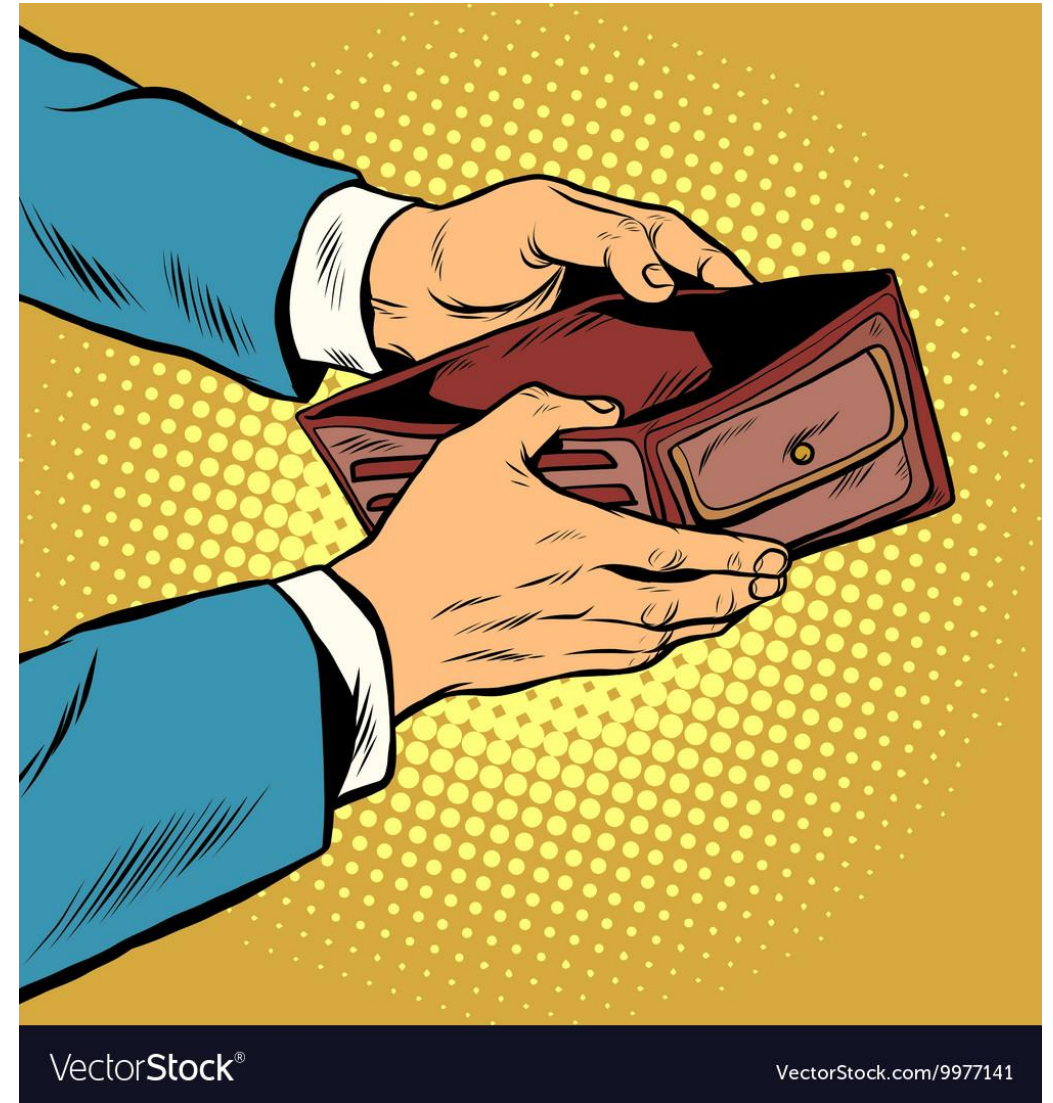
ID 174812758 © Photosvit



Demonstrate that you can Scale this Up!



“You have 6 months”



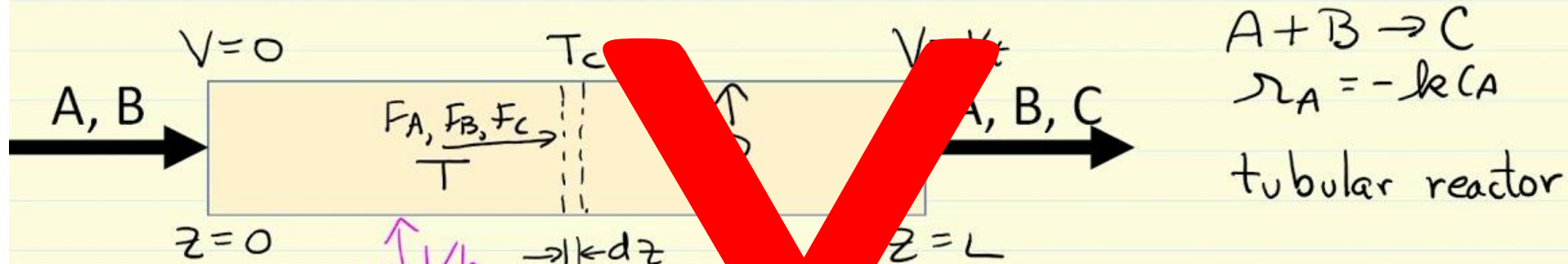
“No \$ to build anything”

"I don't want any xxxx-ing Math Model"!



Introduction to energy balances for plug flow reactors

Objective: explain the terms in steady-state energy balance for a plug flow reactor



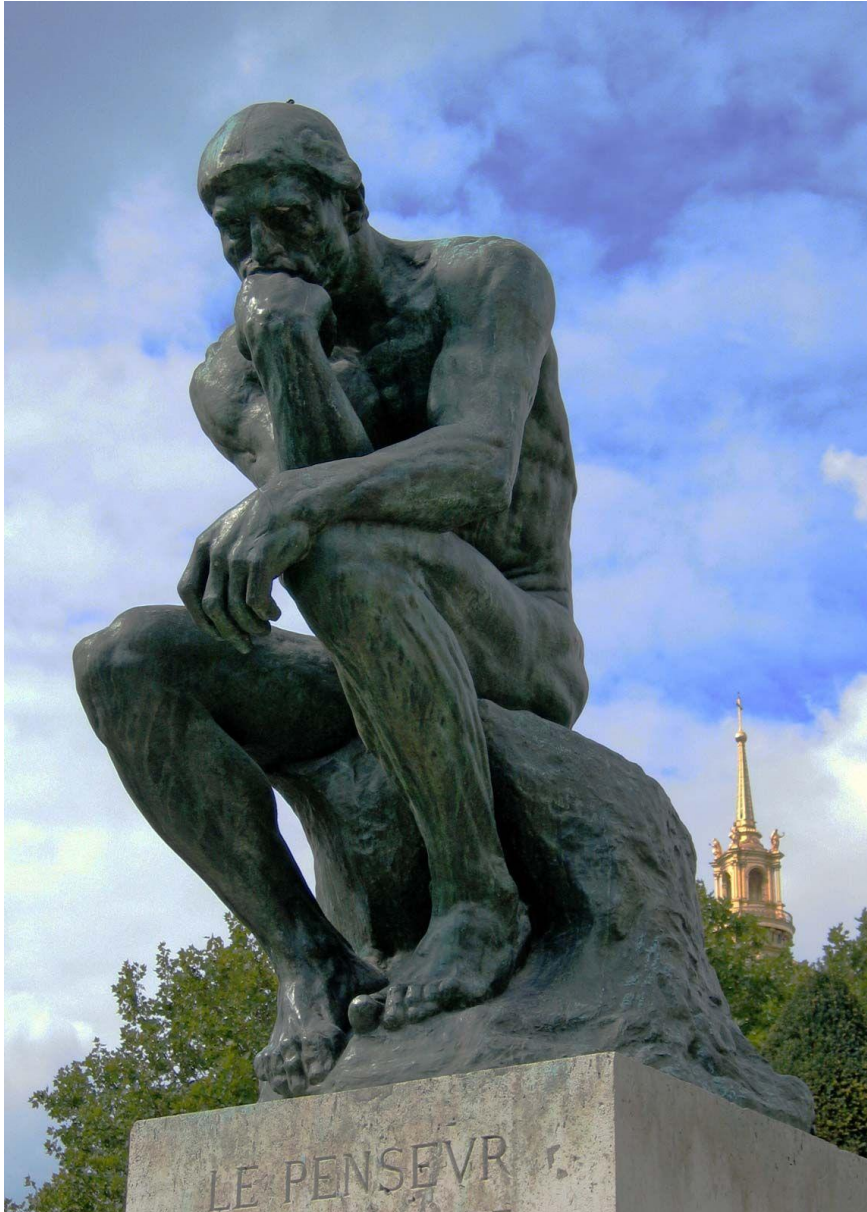
$$\sum F_i C_{p,i} dT = \Delta H_R \underbrace{r_A}_{\frac{kJ}{mol \text{ of } A}} \underbrace{A_x dz}_{\text{heat transfer area}} - \underbrace{U \pi D dz}_{\text{heat transfer coefficient}} (T - T_c)$$

$$\sum F_i C_{p,i} \frac{dT}{A_x dz} = \Delta H_R \underbrace{(-k C_A)}_{\text{heat transfer coefficient}} - U \frac{4 \pi D}{\pi D^2} (T - T_c)$$

“We have to move on this!”



What would you do?



- No Web of Science
- No Google Scholar
- No Smart Phones
- No Email
- No Internet
- No Artificial Intelligence (AI)!

Go Look in the Library!



Times Beach, MO

Times Beach is a ghost town in St. Louis County, Missouri, United States, 17 miles (27 km) southwest of St. Louis and 2 miles (3 km) east of Eureka. Once home to more than two thousand people, the town was completely evacuated early in 1983 due to a dioxin contamination that made national headlines. It was the largest civilian exposure to dioxin in the country's history.

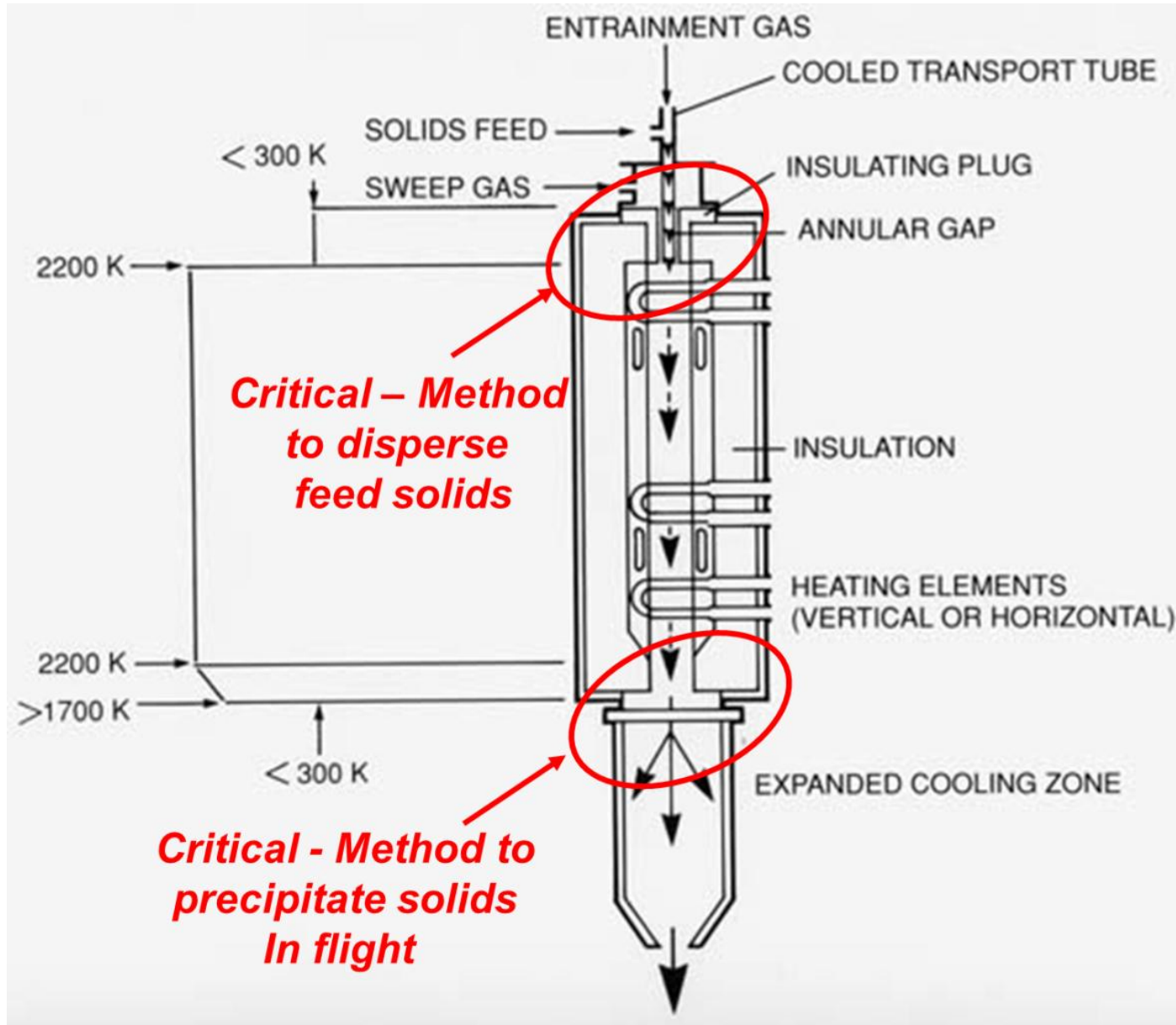


Attend Professional Meetings



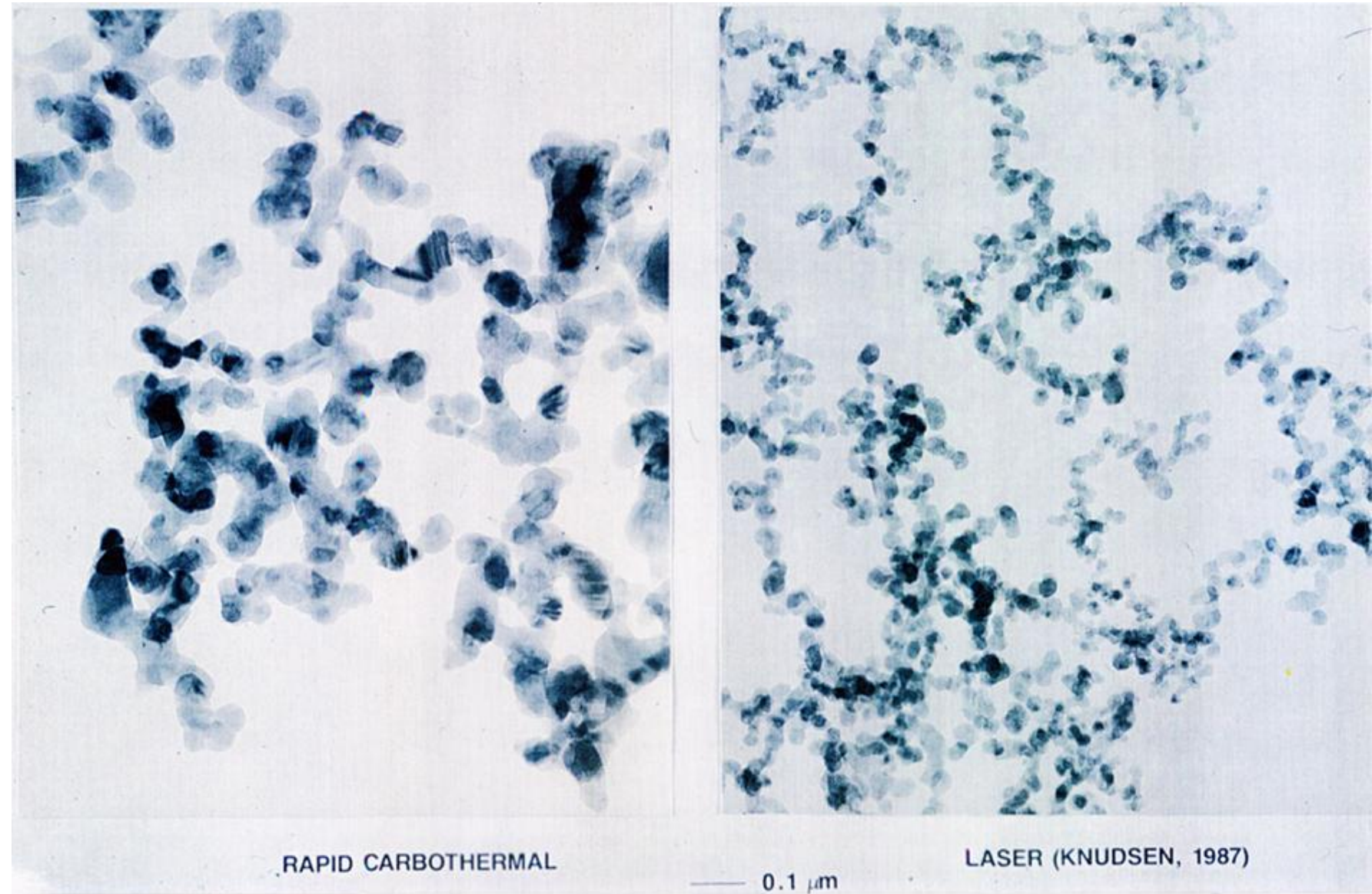
Annual AIChE Meeting (San Francisco)

Thagard Fluid-wall Pilot Reactor (Hercules, CA)



RCR vs. Laser-produced B_4C

Develop a continuous process for producing submicron ceramic powders with properties similar to laser product, but at a substantially reduced cost

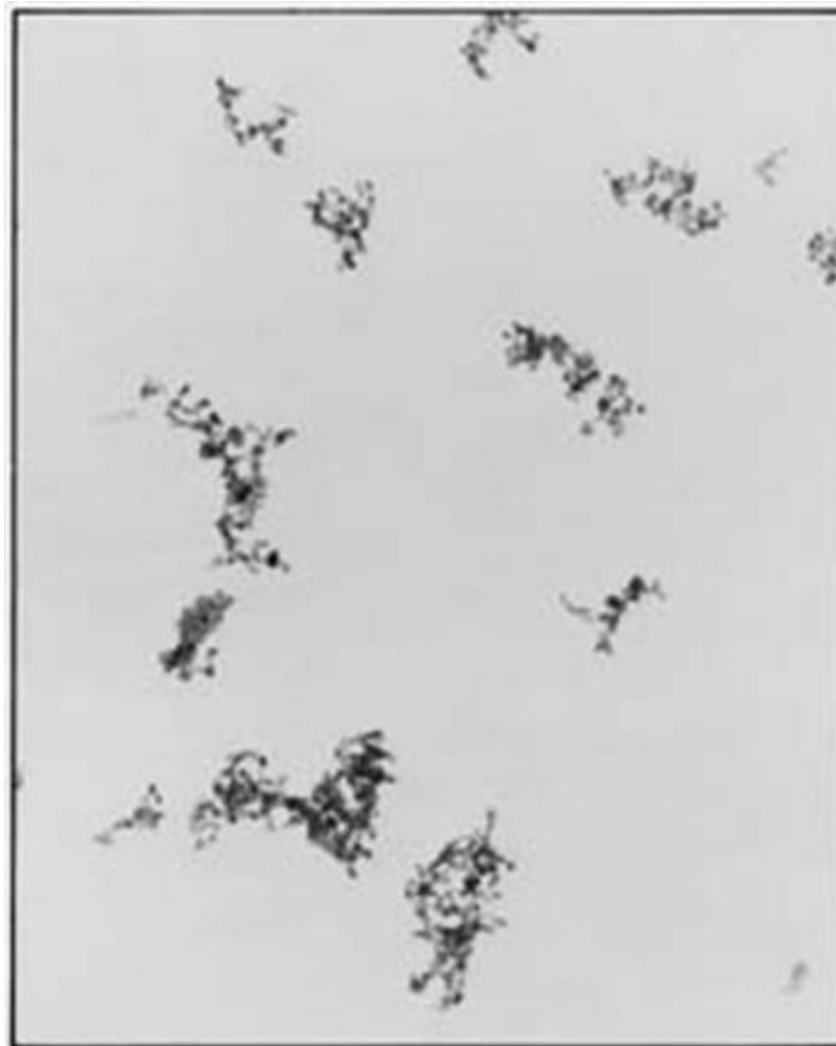


Weimer, A.W., et al., *AIChE Journal*, 37, 759 (1991)

Weimer, A.W., et al, U.S. Patent 5,110,565 (1992)

RCR vs. High-quality Commercial

Rapid
heating
with
limited
reaction
time



Rapid Carbothermal



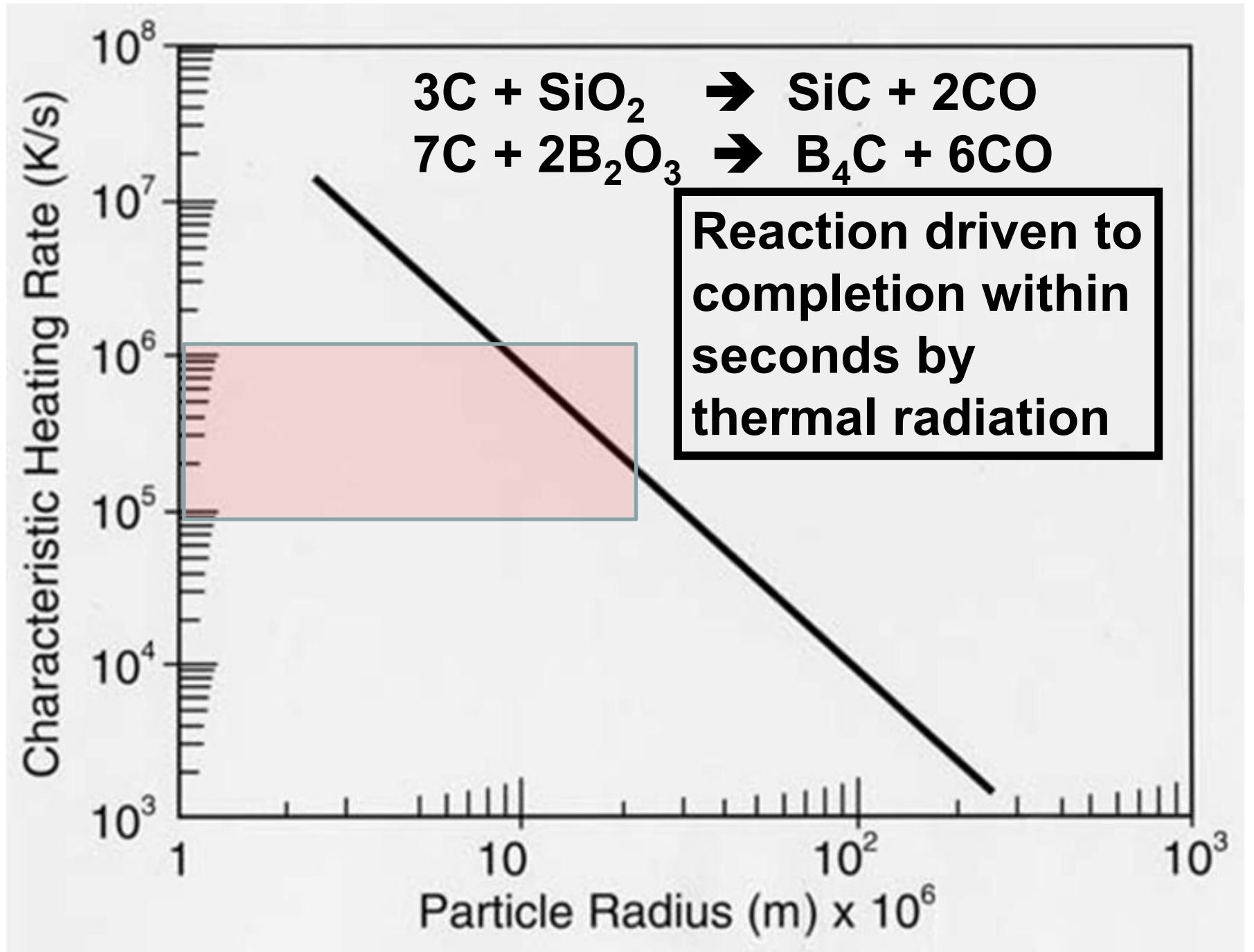
Tetrabor™ 1500

Milled and
sieved
through a
1500
mesh
screen

— 1 μ m

Rapid
Carbothermal
Reduction(RCR)

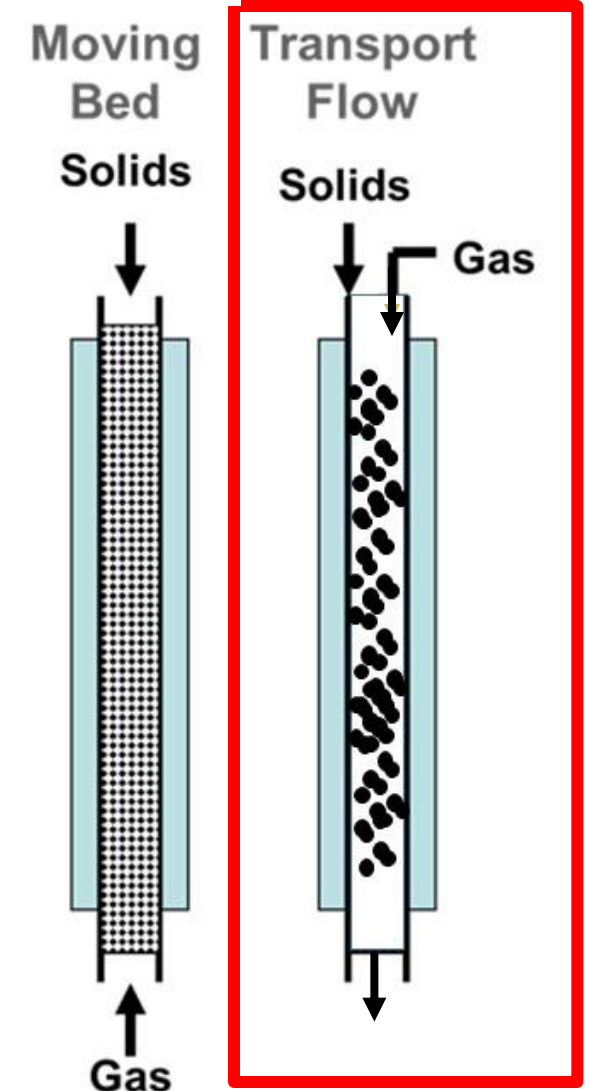
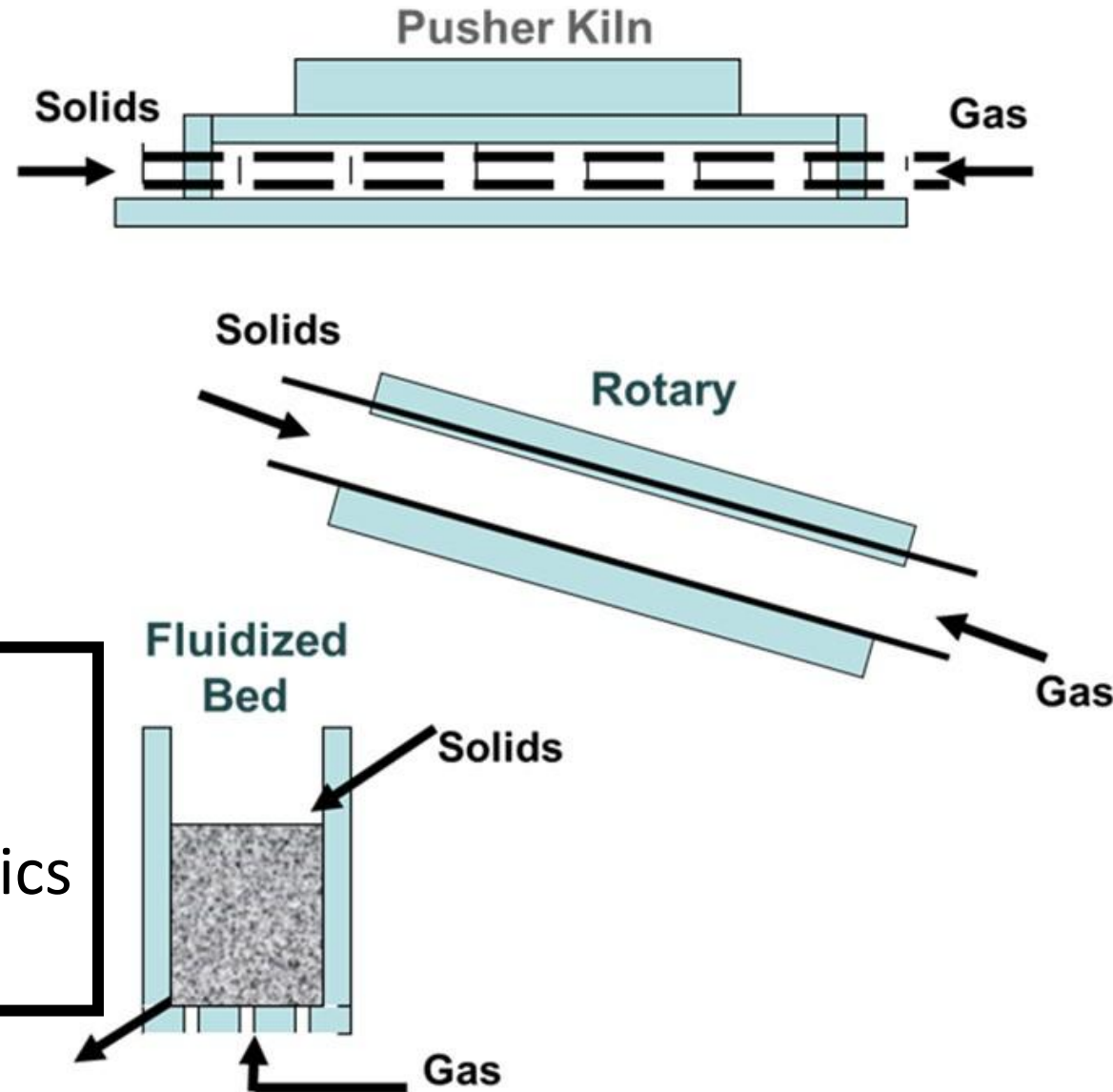
Particle Heating
Rate:
($\sim 10^5$ to 10^6 K/s



Need \$6M for the “bet” (~\$25M today) to get over the proverbial “Valley of Death”?

Let's review our fundamental understanding

- $T \sim 1900^{\circ}\text{C}$
- Highly endothermic
- Rapid intrinsic kinetics
- Rapid grain growth



Be well -prepared to get your \$



One on one meeting with
“The Decider”



Be well -prepared to get your \$



One on one meeting with
“The Decider”

**Very Important -
Know what type of
personality “The
Decider” is (could
be a customer)!**



What is the expected Personality Type for R&D VP?



- (a) Driver – Driver
- (b) Expressive – Driver
- (c) Amiable – Driver
- (d) Analytical – Driver
- (e) Analytical - Analytical

EXPRESSIVE

Unstructured
Wants Recognition
Impulsive
Outgoing

PEOPLE-ORIENTED

AMIALE

Agreeable
Wants to be Liked
Values feedback
Artistic

OUTGOING

DRIVER

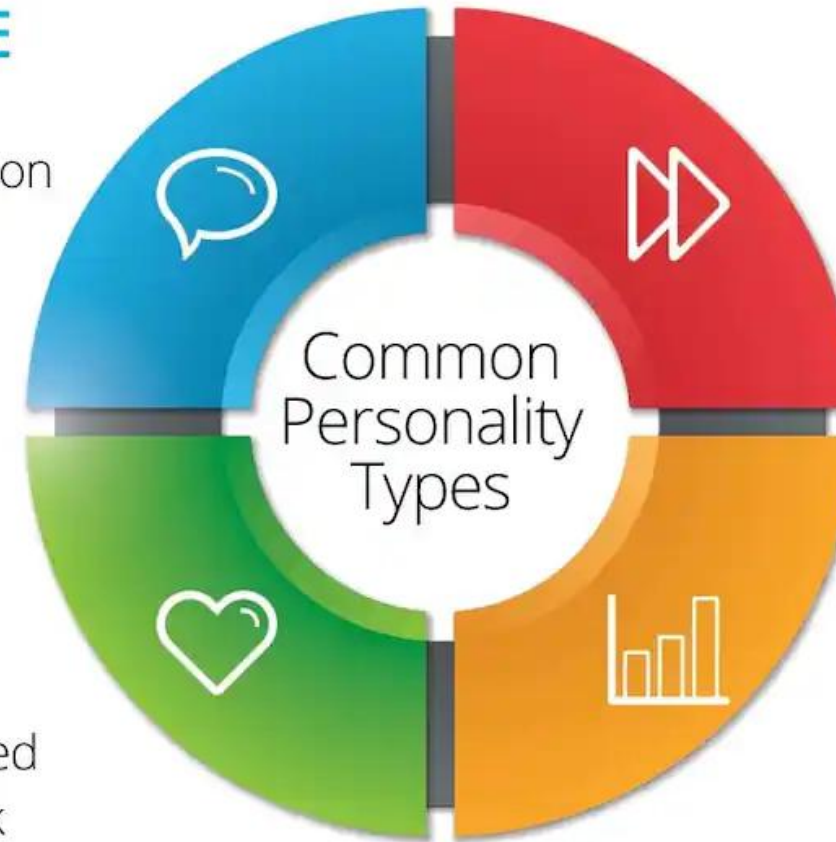
Results-oriented
Wants to Win
Calculated risks
Impatient

TASK-ORIENTED

ANALYTICAL

Logical
Wants to Be Right
Careful
Formal

RESERVED



What personality type is the Dow Chemical R&D VP?



- (a) Driver – Driver
- (b) Expressive – Driver
- (c) Amiable – Driver
- (d) Analytical – Driver
- (e) Analytical - Analytical

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DRIVER

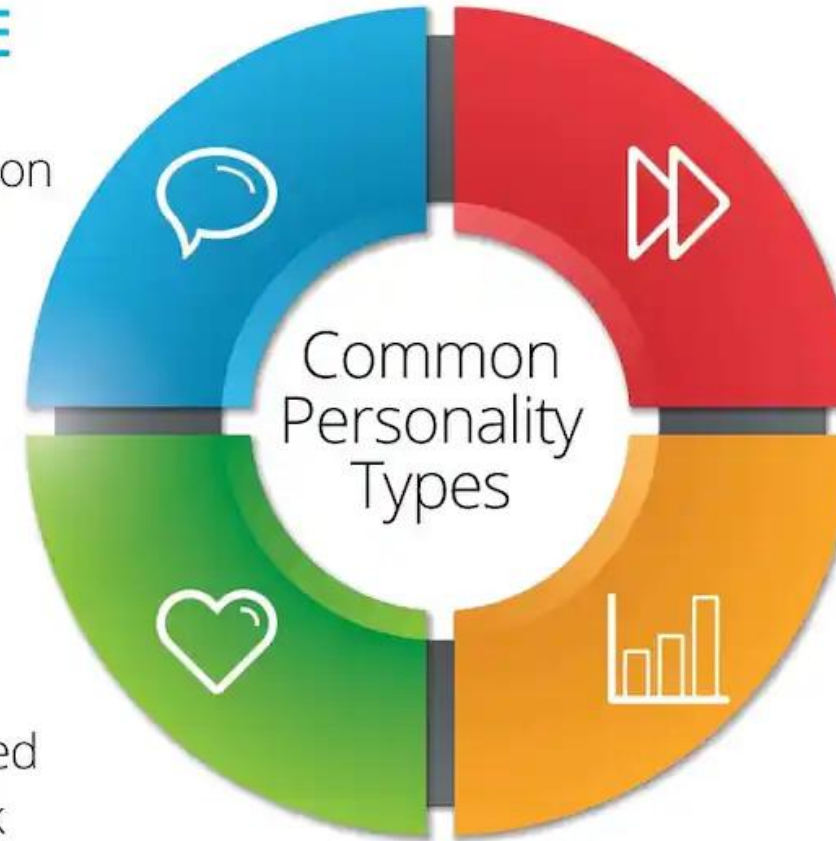
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RESERVED



What is the expected Personality Type for R&D VP?



Dow's R&D VP

- (a) Driver – Driver
- (b) Expressive – Driver
- (c) Amiable – Driver
- (d) Analytical – Driver
- (e) Analytical - Analytical

It took all day, then several months to get the ~ 100 answers, and another half-day!

EXPRESSIVE

Unstructured
Wants Recognition
Impulsive
Outgoing

PEOPLE-ORIENTED

AMIABLE

Agreeable
Wants to be Liked
Values feedback
Artistic

OUTGOING

DRIVER

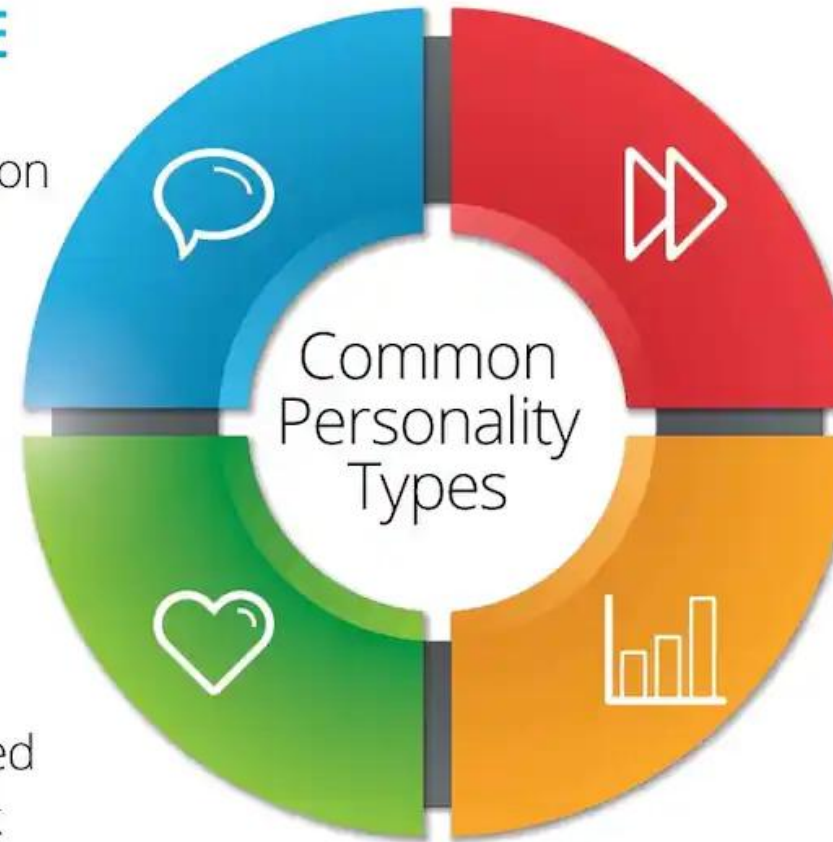
Results-oriented
Wants to Win
Calculated risks
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ANALYTICAL

Logical
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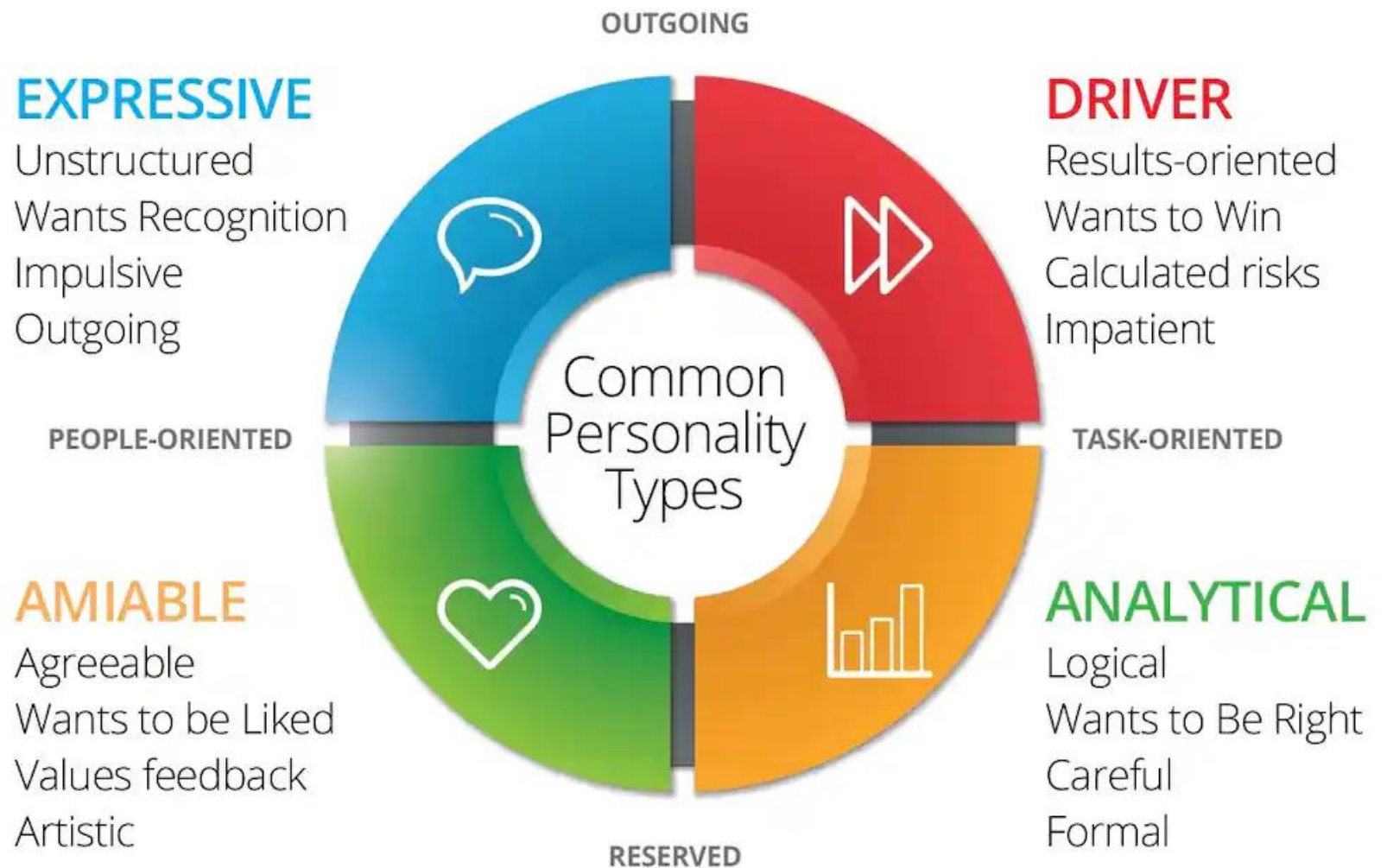
RESERVED



What is the expected Personality Type for R&D VP?



Dow's R&D VP was
an Analytical –
Analytical!



That's why Dow Trusted him with their Money!

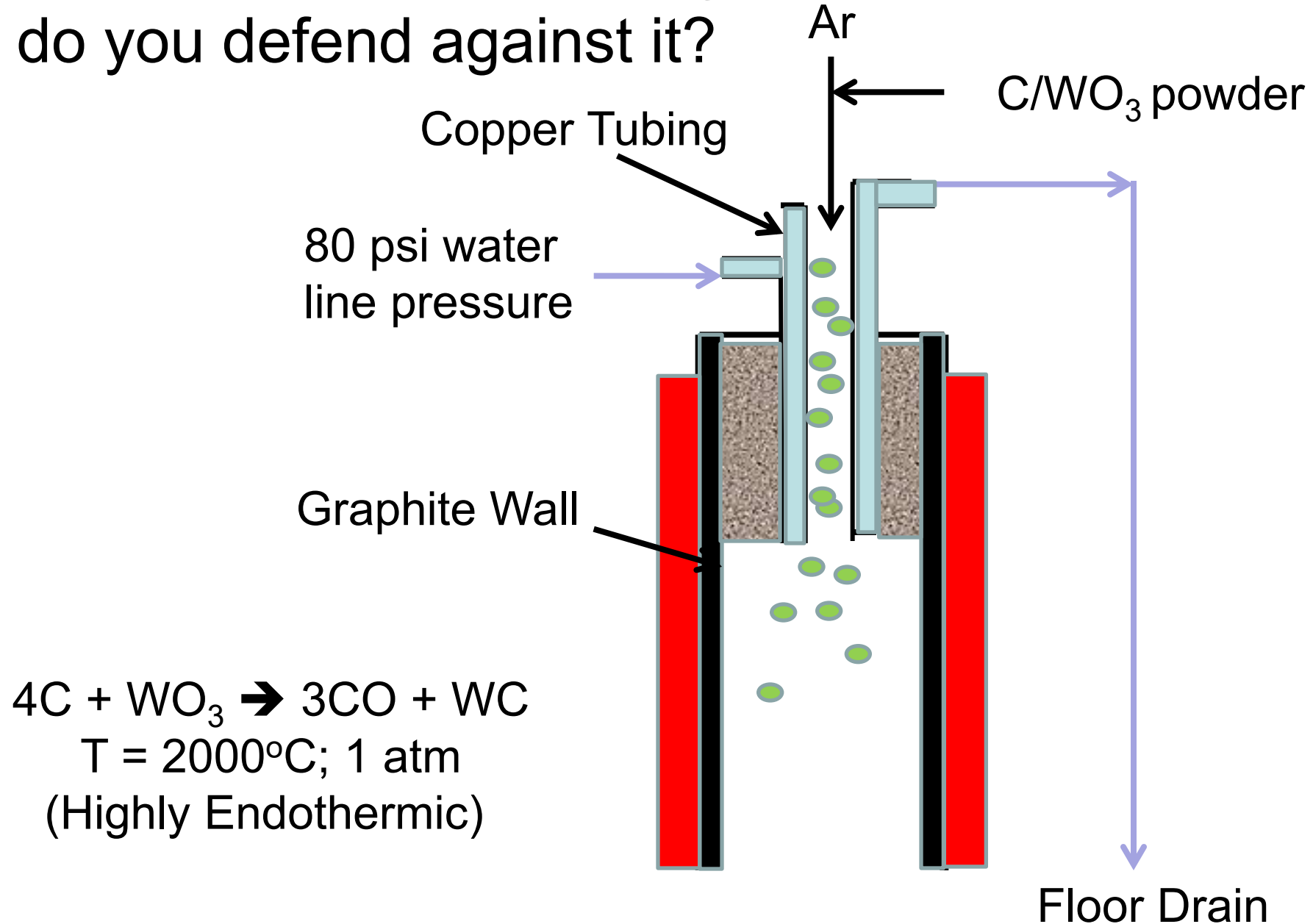
Need to Operate Safely, or, Not at all!



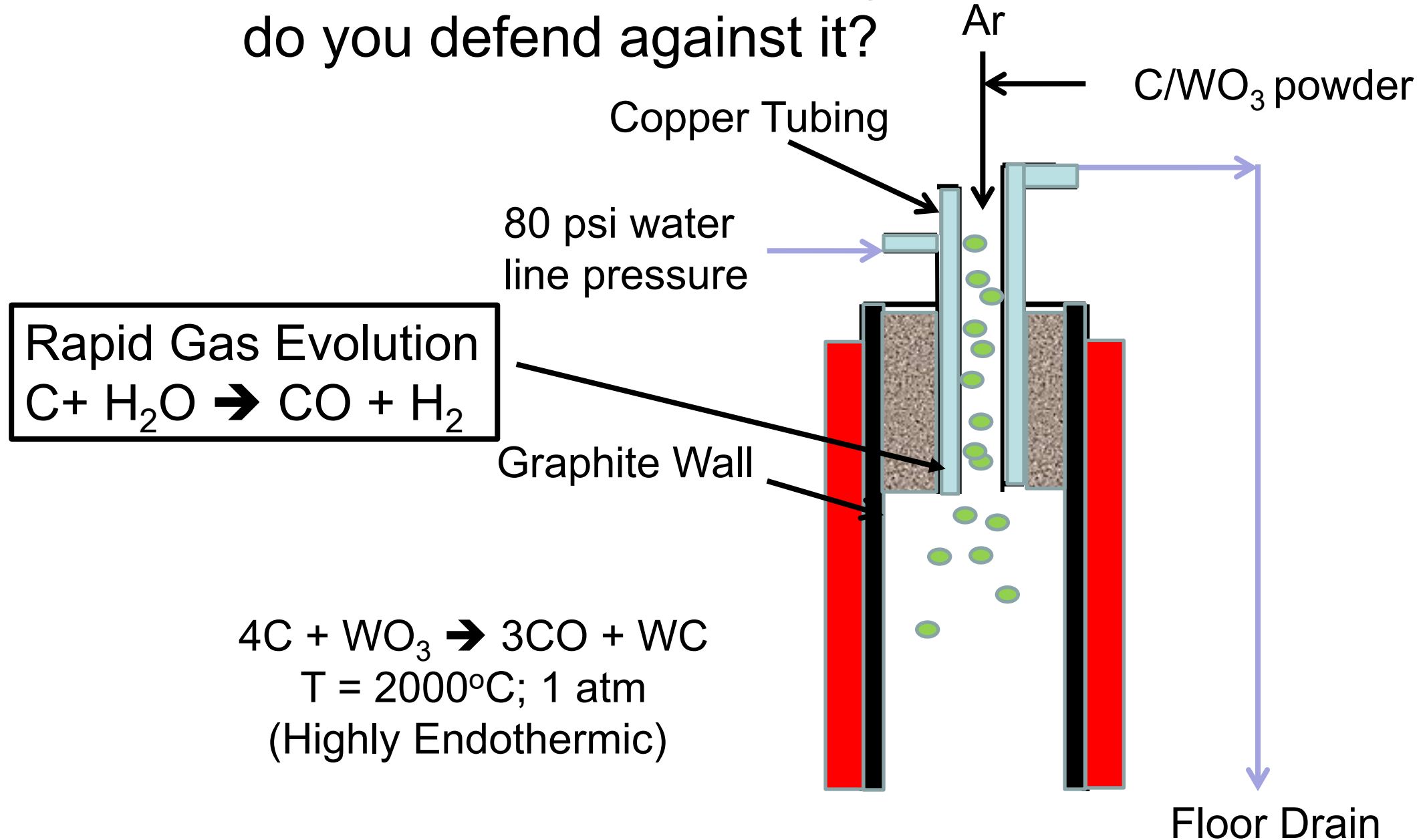
Dow Chemical would not authorize funds until a corporate safety review was passed



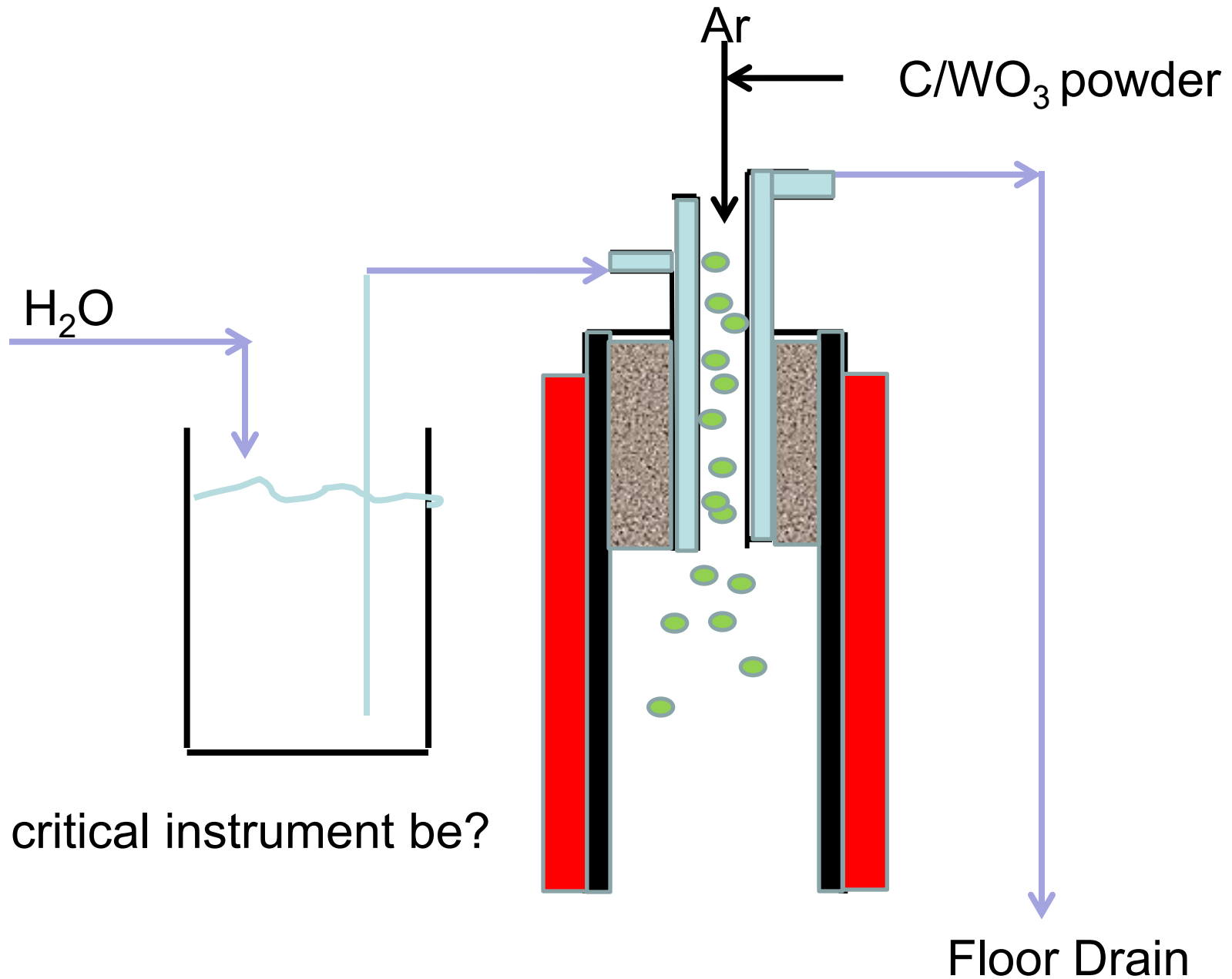
Worst Case Scenario might be what, and how do you defend against it?



Worst Case Scenario might be what, and how do you defend against it?



Construct a Natural Siphon



What might a critical instrument be?

Yes!



Great Technology, but Business-People Dominate

“The B₄C market is only worth \$7M/yr. We’re The Dow Chemical Company and we make \$18B/yr (~ 1988). Go find a product that will make at least \$500M/yr. Come back then.”

- The massive armor market had not yet developed at that time
- When technical meets business, who do you think wins?



B₄C Body Armor



Armor Plating

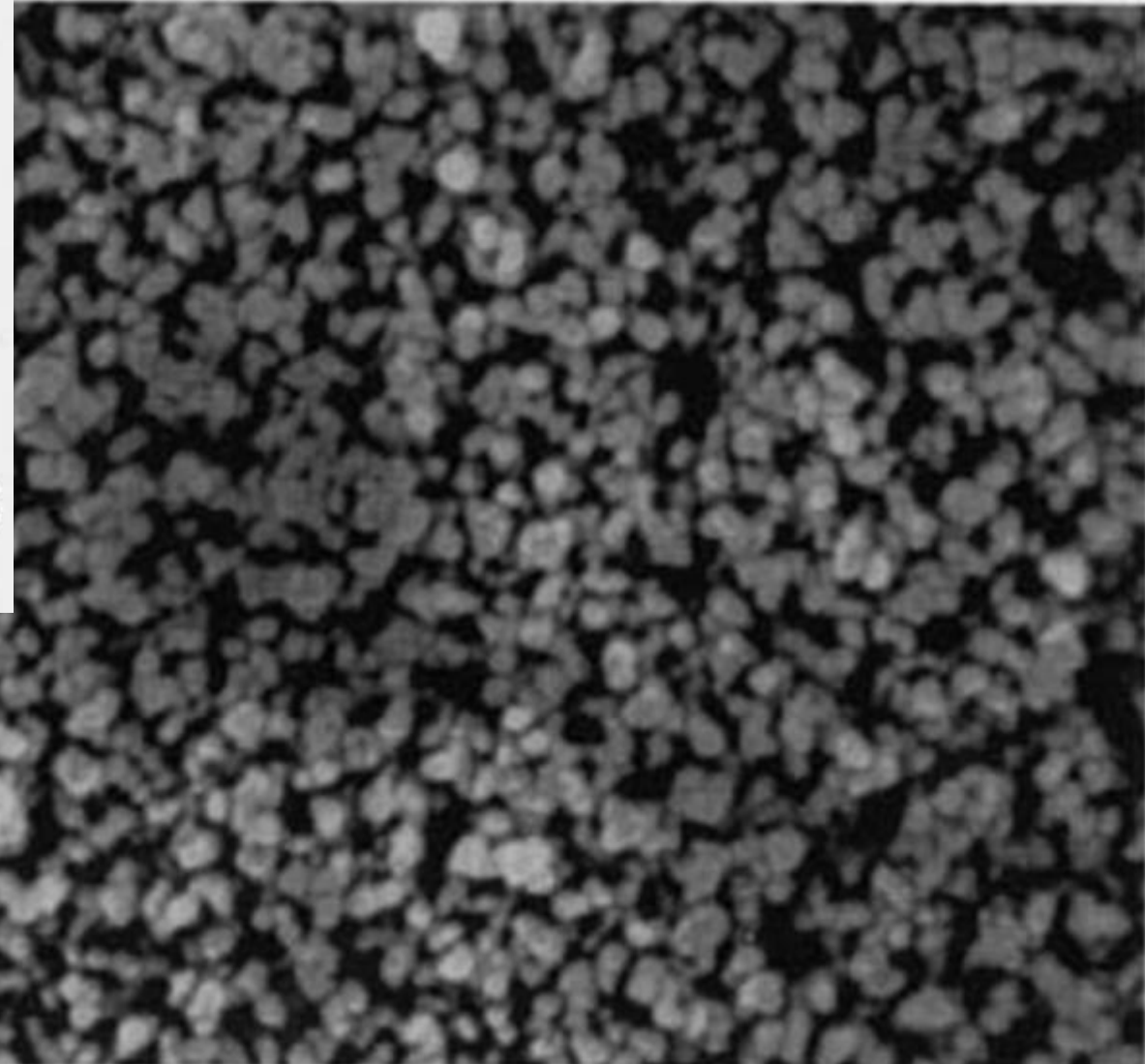
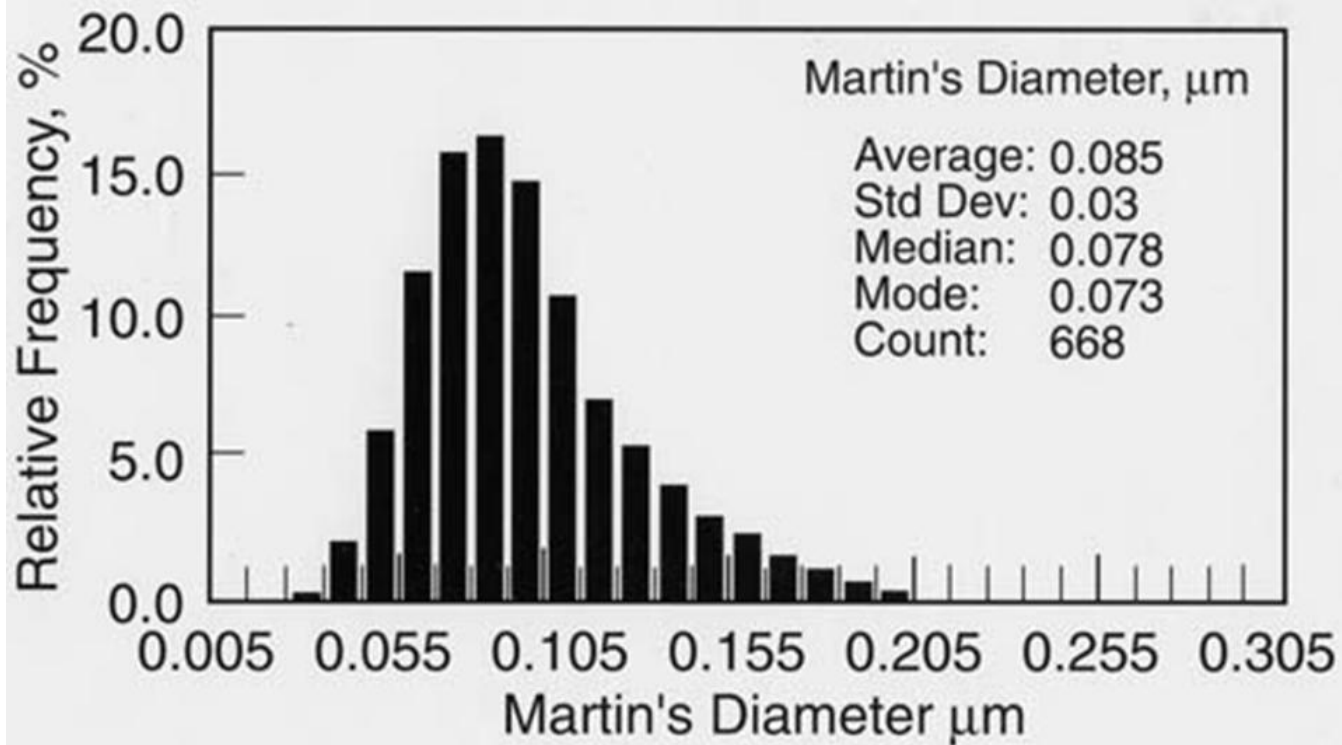


Helicopter Seats

RCCR SiC produced from C/SiO₂



This is a great product



Weimer, A.W, AIChE Journal,
39 (3), 493 (1993)

Great Technology, but Business-People Dominate

“The SiC market is only worth \$25 M/yr. We’re The Dow Chemical Company and we make \$18B/yr. Go find a product that will make at least \$500M/yr. Come back then.”

Industry – Commercial Tungsten Carbide Powders



MATERIALS RESEARCH SOCIETY®
Advancing materials. Improving the quality of life.

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~ 1992

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2025 **MRS®**

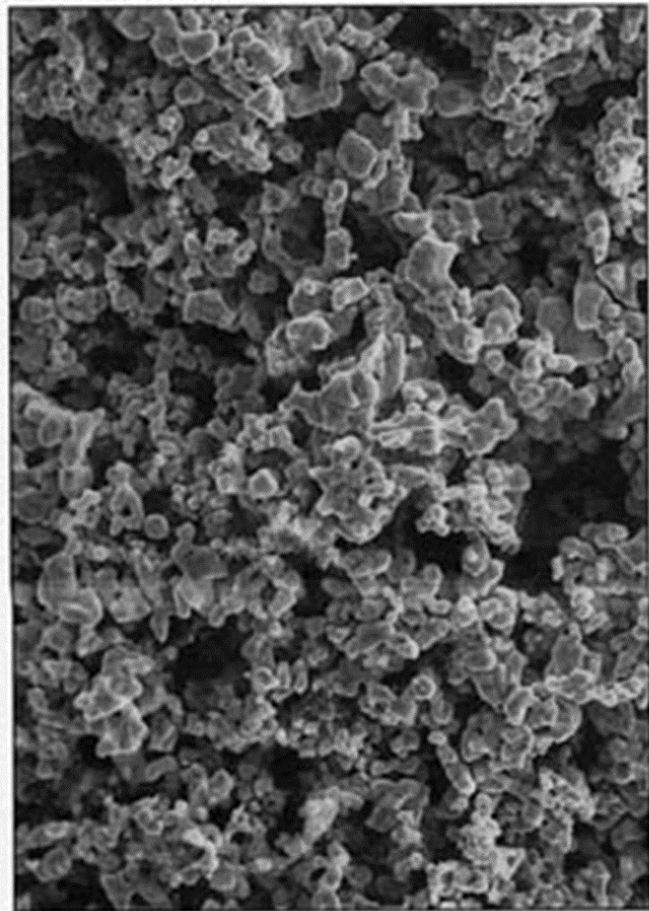
FALL MEETING & EXHIBIT

November 30–December 5, 2025 | Boston, Massachusetts

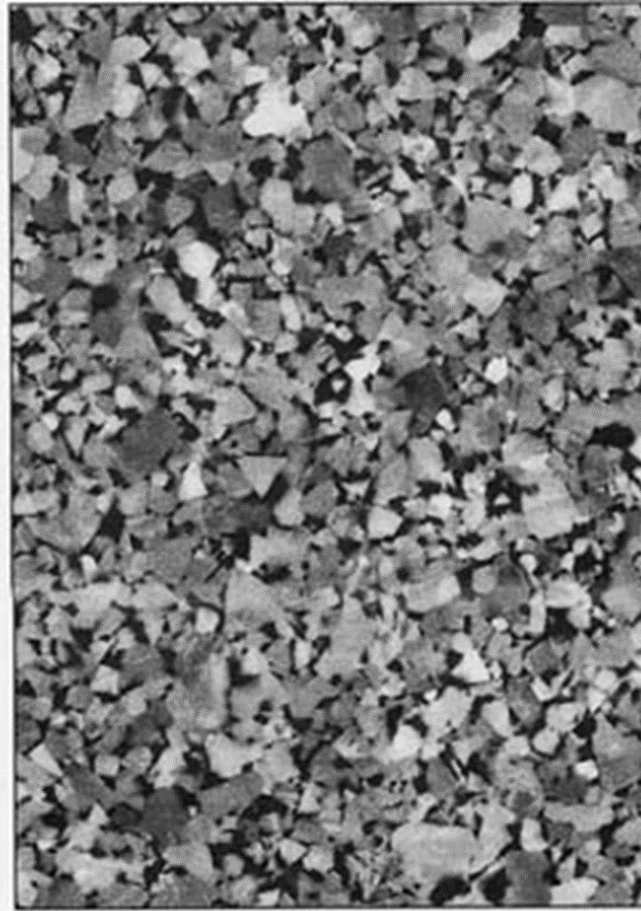
Product WC Powder sent to Sandvik (“over the fence”)



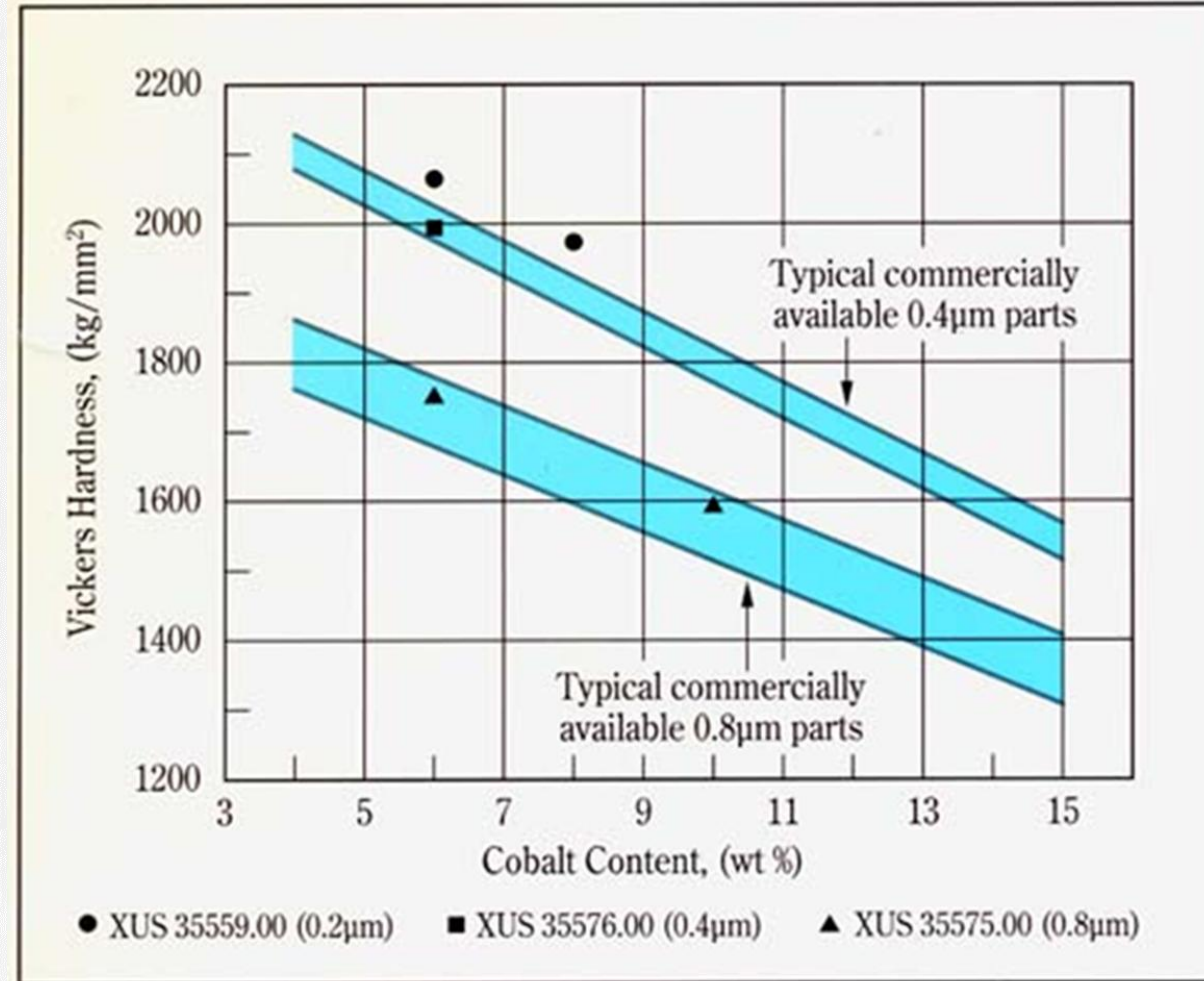
Industry – Commercial Tungsten Carbide Powders



Powder @ 10,000 X |——| 1μm



Part @ 10,000 X |——| 1μm



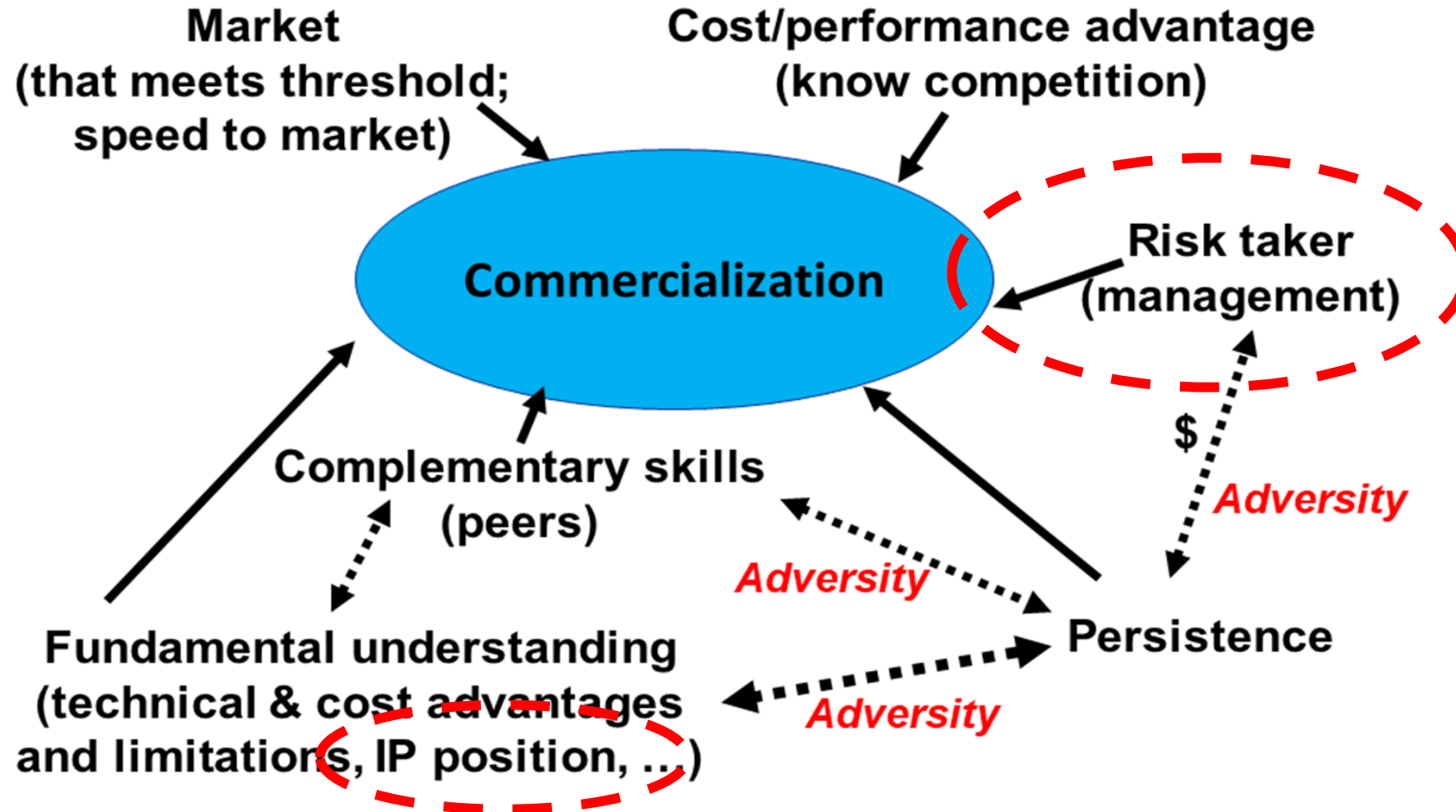
WC Powder
(~ 0.2 μm grains)

WC Fabricated Part
(submicron grains)

WC Powder Grain Size vs. Hardness
& Cobalt Content (WC/Co hardmetals)

Weimer, A.W et al., Mid-Michigan Inorganic Science Group 1st Quarter Tutorial Presentation (Midland, MI) 1994.

Persistence to Commercialize



Composition of Matter

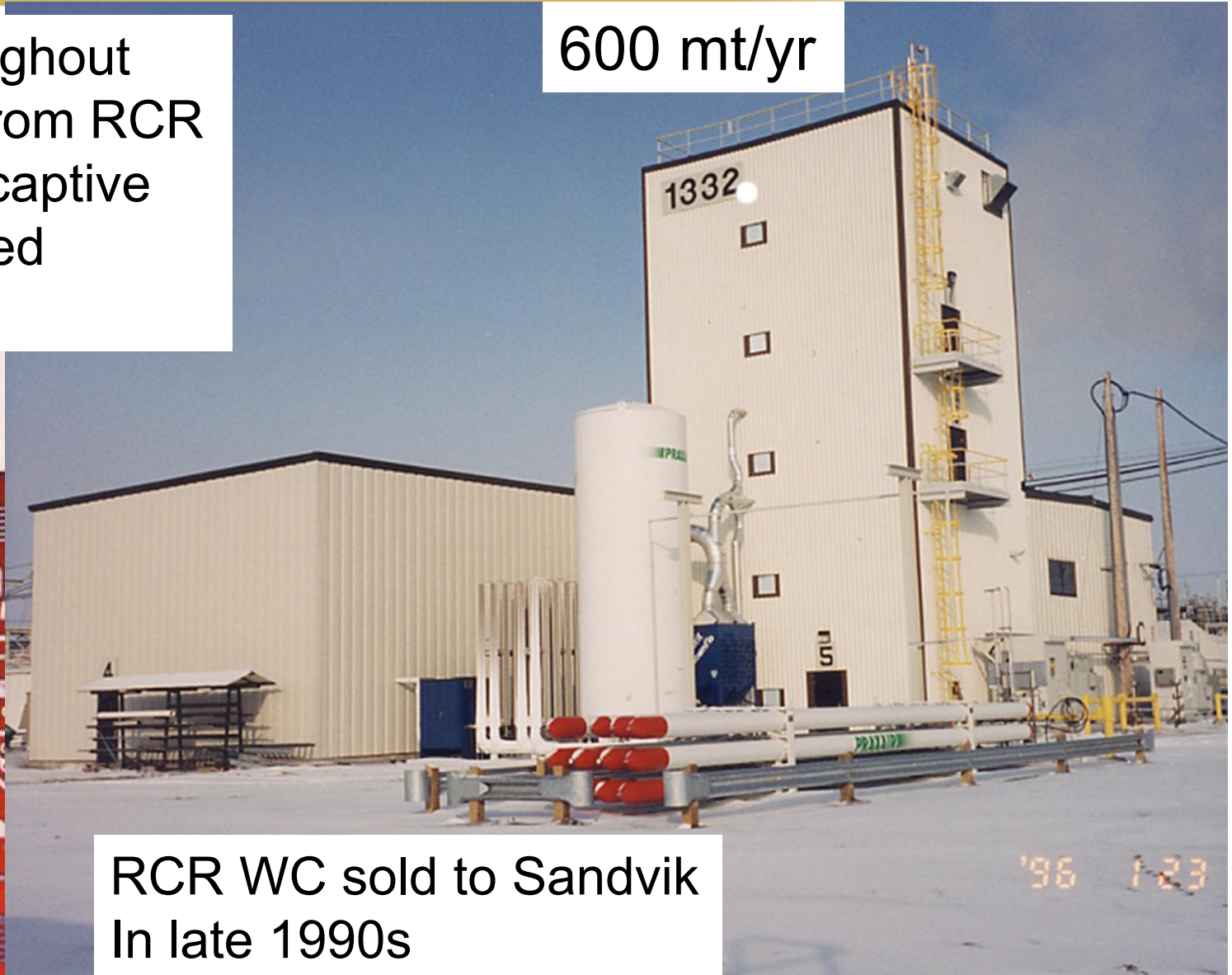
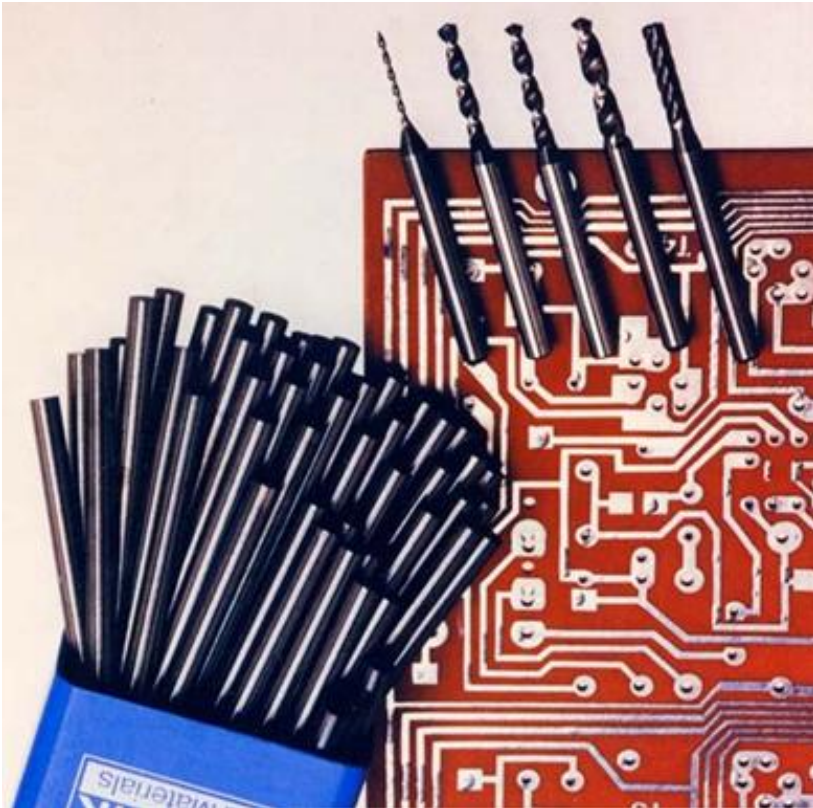
Claim 22. “A particulate metallic carbide having a mean as synthesized particle diameter that is between 0.01 micrometer and 0.3 micrometer and a metallic component that is selected from the group consisting of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo and W.” (U.S. Patent 5,380,688; 1995; Dow Chemical Company)



Finally, maybe \$500M (?), but not Dow

(Majority of microdrills used throughout the world were/are(?) produced from RCR tungsten carbide (WC) powder); captive market – powder not sold, but used internally to make cutting tools

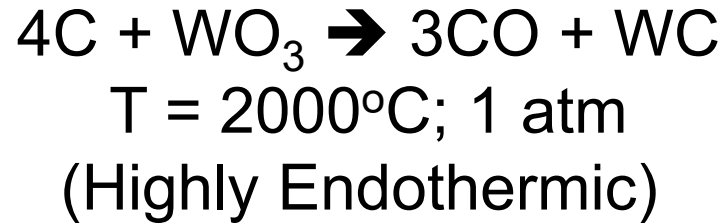
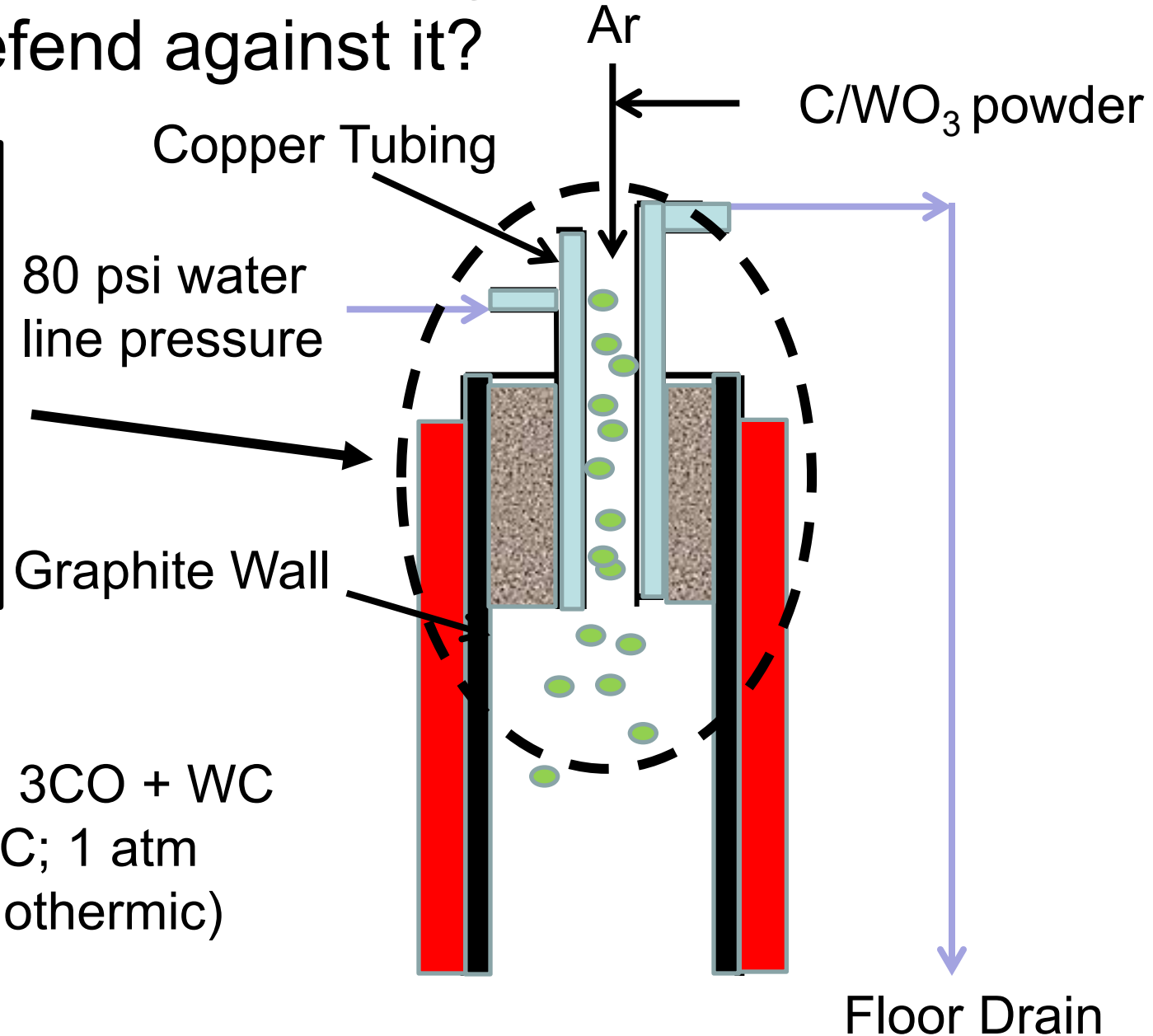
600 mt/yr



RCR WC sold to Sandvik
In late 1990s

Worst Case Scenario might be what, and how do you defend against it?

Opportunity – apply high-level CFD modeling to design the rapid heating feed section of the reactor



Final Thoughts



- ***It is best to be first and lead instead of following***, but early funding is difficult due to skeptics. Think about what the next big challenge is, and then come up with ideas to solve the problem. ***“Out of the box”*** is best. ***Have patience, maintain calm, persevere against adversity!***
- When someone tells you it is impossible to achieve what you are trying to achieve, ***consider it a major opportunity***. But, be sure that you understand the ***fundamentals***, the competitive alternatives, and the cost/performance issues before you jump in.
- ***If you’re young, take the risk*** – you don’t want to regret not doing something; you’ll have time to recover if needed.
- **Communication skills are critical.** Know who you are dealing with, respect them, and maintain your cool!
- ***Stay involved in your professional societies – learn, network!***
- **Always take the high-road**

Navigating the foggy fork in the road

You aren't reaching high enough if the future is known, the path is clear, and outcomes are certain. But navigating ambiguity drives most of us nuts.



<https://www.offset.com/search/fork+in+the+road>



Thank you for listening!

Any questions?



University of Colorado
Boulder