International Fine Particles Research Institute

Decoding Particle Science and Technology into Practical Manufacturing

Presented By: Willie Hendrickson, IFPRI President and CEO & Founder of AVEKA

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Presentation Outline

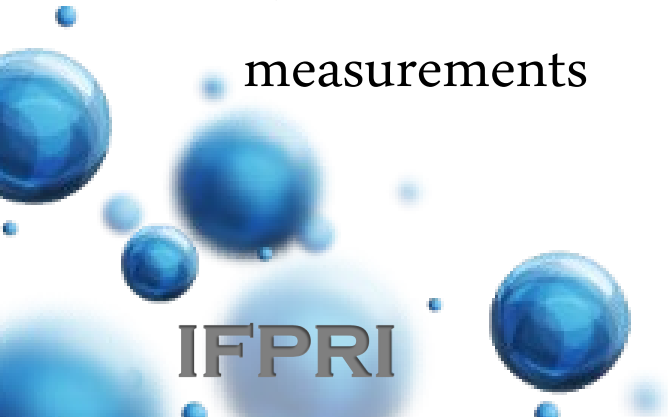
- Chemistry vs. Particle Science and Technology
- Why do we care about Particle Science and Technology
- Historical Perspective
- Technology Readiness Levels and Particle Science and Technology
- Genesis of IFPRI
- Structure of IFPRI
- Technical Program at IFPRI
- Conclusion

Chemical Measurement Methods Development: Weight, Temperature, and Pressure

- Weight
  - 3100 BC Scales - Egypt
- Temperature
  - 1593 Thermoscope – Galileo Galilei
  - 1709 Alcohol Thermometer – Daniel Fahrenheit
  - 1821 Thermocouple – Thomas Seebeck
- Pressure
  - 1643 Barometer – Evangelista Torricelli

An Example of Particle Science and Technology Development: Particle Size Measurement

- 4000 BC sieves used in Egypt
- 1670's Antonie Van Leeuwenhoek invented the microscope
- 1850's G.G. Stokes applied settling phenomena to particle size measurement
- 1950's Wallace Coulter pioneered the electrozone method for particle size measurement
- 1970's Fraunhoffer laser diffraction method commercialized for particle size measurements



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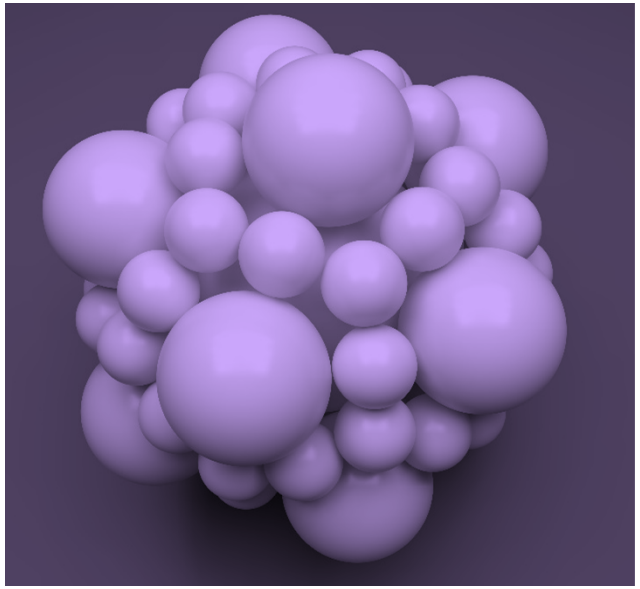
Why is Particle Science Important?

- Ubiquitous throughout all industrial manufacturing
- Small changes in particle related processes and properties can have huge effects on productivity and profitability
- ~40% of value added to chemical industry is linked to particle technology



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Historical Overview and Context of Particle Technology – Mid 20th Century

- Invention of pelletizing process for taconite ore 1940-1960
- Prior to 1970's individual schools in US, Europe and Japan (Pfeffer, Austin, Rumpf, Iinoya, Scarlett)
- 1970's Franhoffer laser diffraction methods for particle size determination commercialized
- 1974 Stan Sadin at NASA conceived of the Technology Readiness Levels (TRL)
- 1979 IFPRI founded to promote industrial particle technology strategy
- Estimating Start-up Times in Solids Processing Plants E. Merrow Chen Eng 24 89-92, 1988

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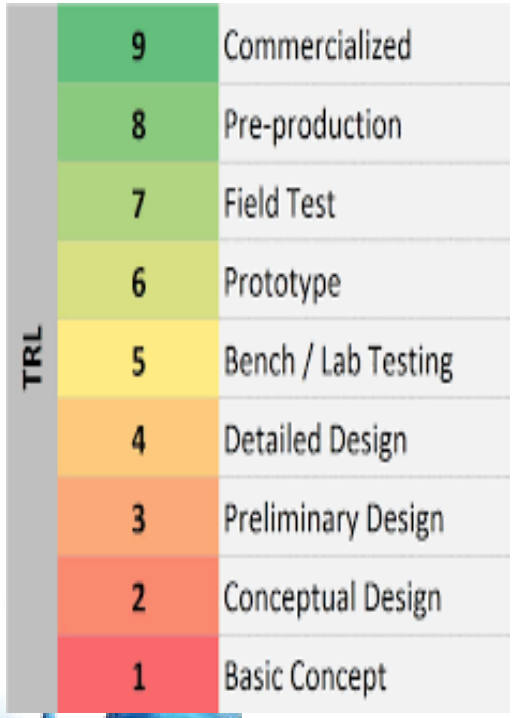
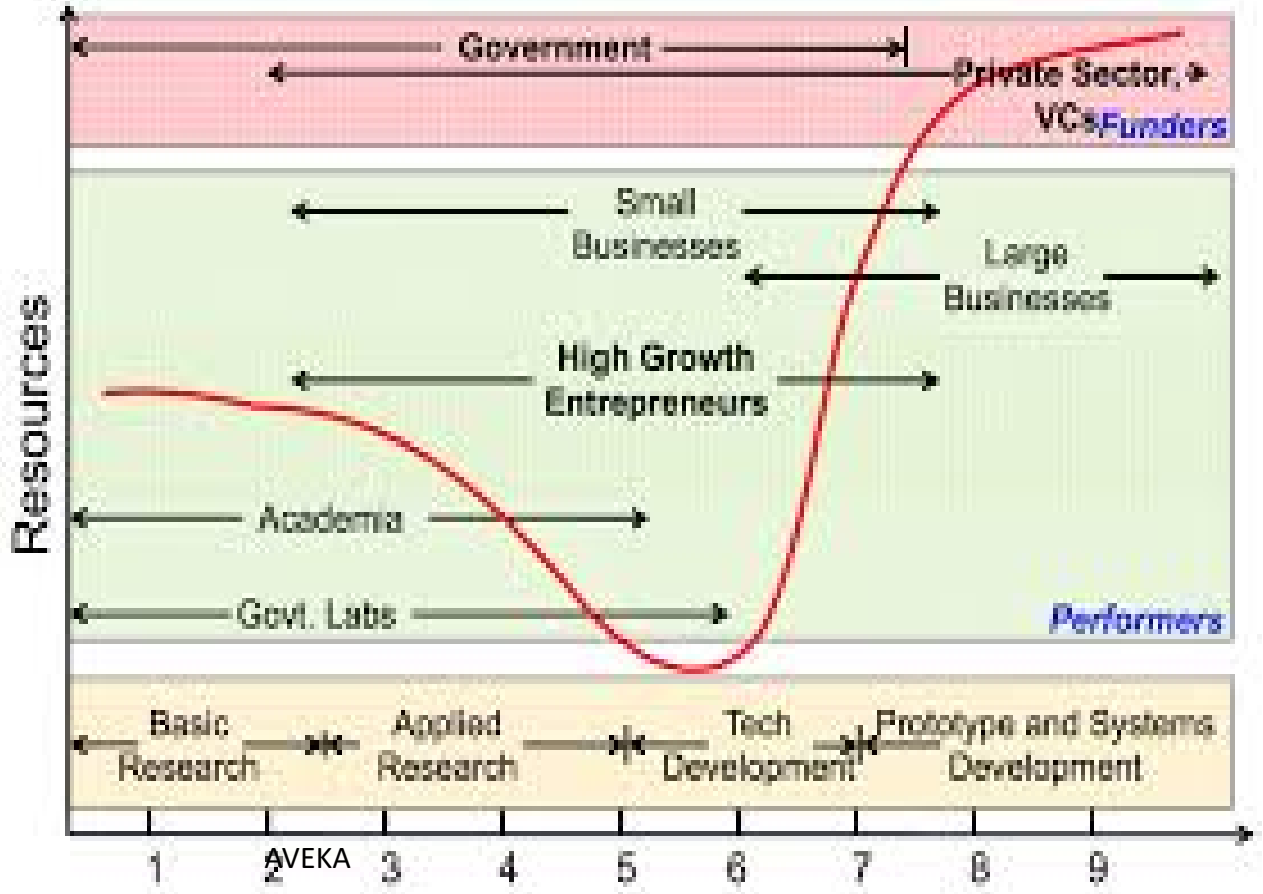
Technology Readiness Levels and the Valley of Death

Concept to grams to kilograms to metric tonnes





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Industrial and Academia Approaches to Commercialization

Similarities

- Inventors - Up to the Valley of Death
- Developers - Drivers through the Valley of Death
- Funding Sources - Food and Fuel through the Valley of Death

Differences

- Academia
  - ✓ Equations
  - ✓ Novel concepts based on fundamental research
  - ✓ Characterization equipment
- Industry
  - ✓ Process optimization numbers
  - ✓ Standard processes based on applied research
  - ✓ Automatic, large scale, multi unit ops equipment

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Why is Commercialization so difficult?

- Preparation is all done with small scale processing – one becomes immune to:
  1) Inefficiencies
  2) Not understanding alternative processes
  3) Bad choices of equipment
  4) Poor to no mass balances
  5) Not enough money

- Acceptance of a new product or process needs to fit within current understandings of:
  1) Process standards
  2) Equipment modifications
  3) Trained operators
  4) Safety considerations
  5) Internal vs. external IP

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Original Observations and Mission of IFPRI

- Lack of fundamental particle science understanding
- Lack of forum for intercompany discussion
- Poor connectivity between universities and industry

- Provide venue for particle technology discussion
- Develop pre-competitive strategic plan for particle science
- R&D focus on industry concerns

IFPRI History

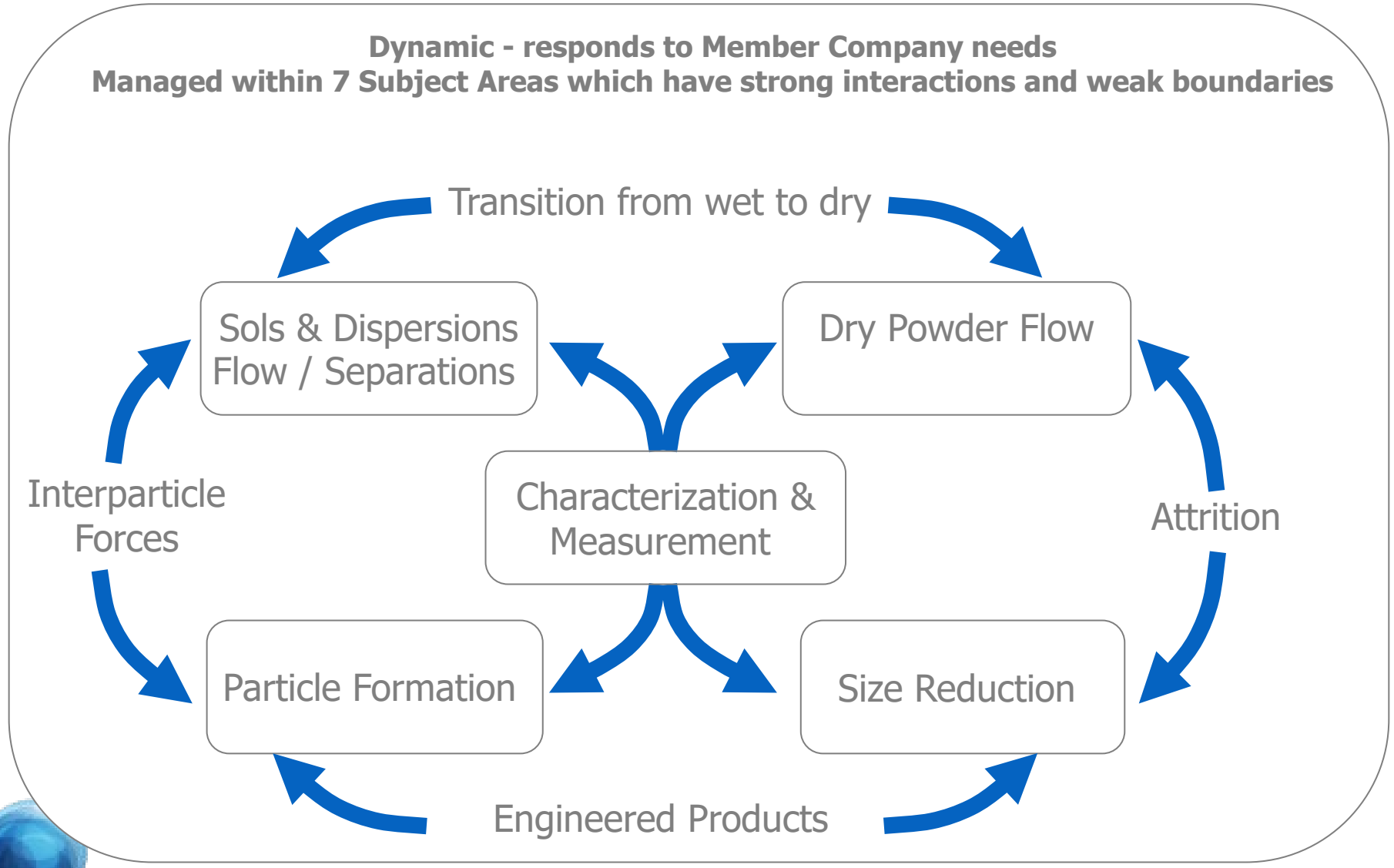
Started in 1979 by 5 professors

- Pfeffer
- Leschonski
- Iinoya
- Scarlett
- Tiller

12 International Companies

- DuPont
- Unilever
- Standard Oil Of Indiana
- Bethlehem Steel
- Exxon
- British Nuclear Fuels
- Alcoa
- US Steel
- Eastman Kodak
- P&G
- 3M
- ICI

IFPRI Technical Program



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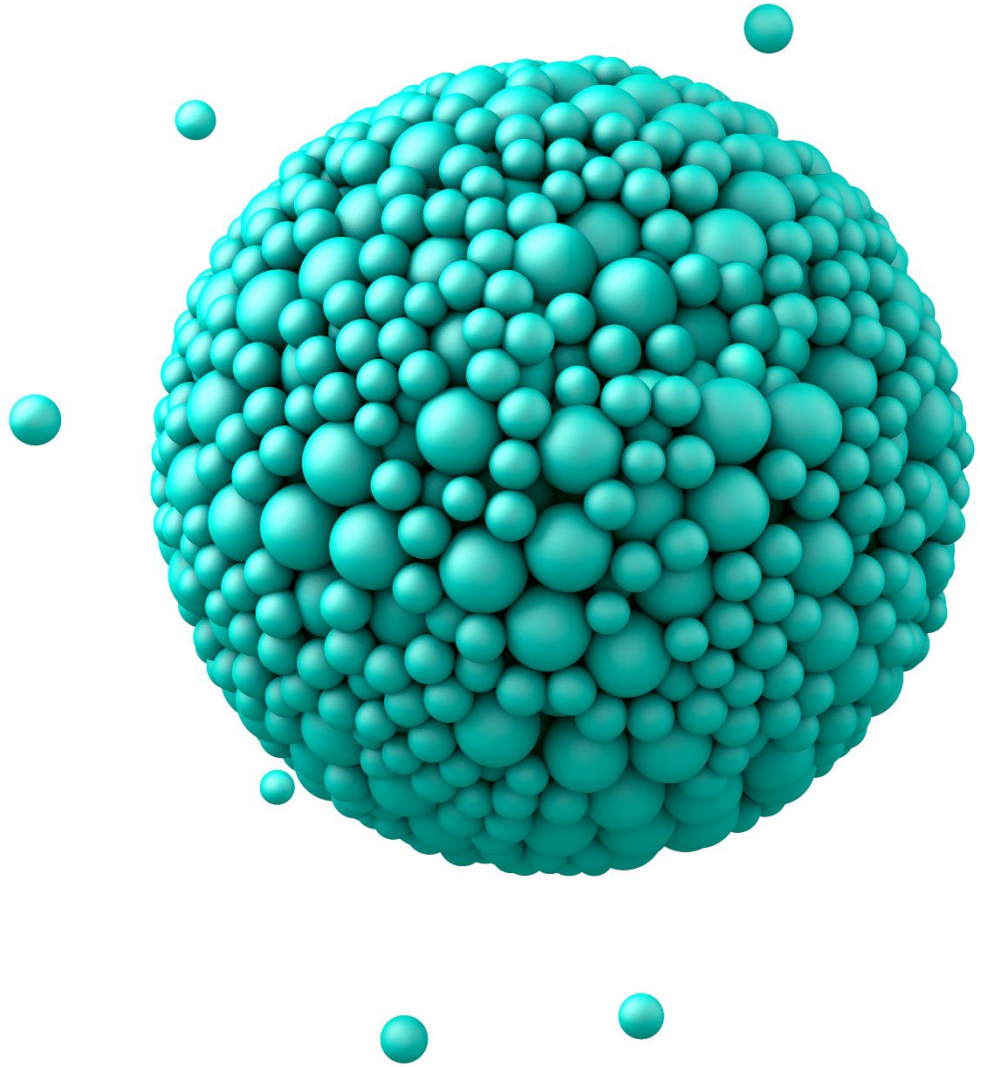
IFPRI Deliverables

- Interpersonal Forum
  - Annual General Meeting
  - Winter Business Meeting
  - Monthly Update Conference Calls
- Defined Industrial Strategy
  - Technical Research Program
  - Technical Reviews
  - Focused Workshops
  - Roundtable Best Practices
- Written Reports
  - 18-21 Annual Research Reports
  - 2-3 Annual Reviews
  - Library of over 700 Reports and Review
- Education Program



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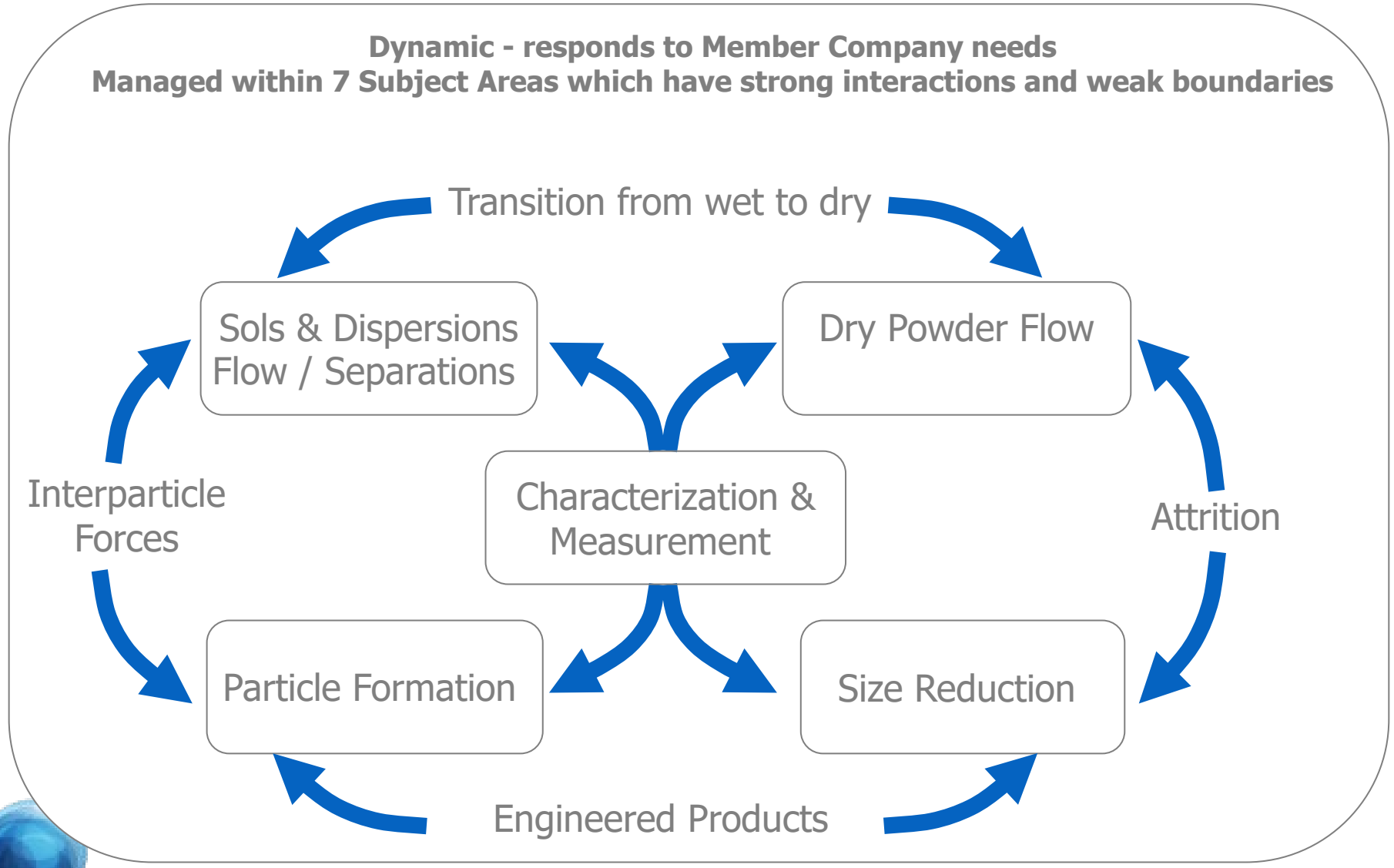
Annual General Meeting (AGM)

- Reports from Academic Grantees
  - Short Presentations
  - Small Group Poster Sessions
  - Industrial Feedback to Academics
- Reviews and Invited Presentations
- Small Group Discussions on New Areas for Research
- Discussion, Brief Writing, and Voting on New Programs for Funding
- Local Student Poster Session
- Informal Discussions, Meals, Happy Hours and Sporting Events

IFPRI Technical Program



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IFPRI 2021-2022 Programs (Part I)

Type	Technical Area	Project Description	Research Associate	Institute
Full Proposals	Characterization			
	Formation	Drying Kinetics and Morphology	M. Jaskulski	Lodz U.
		Molecular Self Assembly	U. Weisner	U. Cornell
		Crystal Shape Control	M. Doherty	UCSB
		Characterization of Spray Nozzles at Industrial Conditions	N. Ashgriz	U. Toronto
		Process and Product Models for Wet Granulation	R. Smith	U. Sheffield
	Wet Systems	A Multi-Scale Study of Powder Reconstitution Phenomena	C. Gaiani	U. Lorraine
		Slurry and Paste Rheology	E. Koos	KU Leuven
		Simplified Industrial Formulations – Design Challenges	J. Vermant	ETH Zurich
	Size Reduction	Systems Engineering Approach to Dry Milling with Grinding Aids	A. Kwade	TU Braunschweig
	Dry Systems	Selection of Flow Aids	R. Dave	NJIT
		Dry Powder Rheology	K. Daniels	NCSU
		Air-Induced Defect Formation During Compaction	K. Kamrin	MIT
		Powder Adhesion to Metal Surfaces During Compaction	C. Sinka	U. Leicester
		Modelling of Powder Flow Through Screw Feeders	P. Nott	IIS Bangalore
	Systems Engineering	Model-Based Control of Crystallization	Z. Nagy	Purdue U.

IFPRI 2021-2022 Programs (Part II)

Type	Technical Area	Project Description	Research Associate	Institute
Reviews	Formation	Horizons in Granular Modeling – Beyond DEM	F. Radjai	U. Montpellier
	Dry Systems	Dynamic Powder Flow	N. Gray	U. Manchester
Round Robin	Dry Systems	Round Robin Exercise on Calibration of DEM Simulations	J. Seville	U. Birmingham
Collabor-ation	Wet Systems	Simplified Industrial Formulations - Collaboration (in conjunction with J. Vermant)	L. Hsiao	NCSU
	Dry Systems	Non-Local Rheology of Dry Flows: From Experiments to Practical Model - Collaboration (in conjunction with P. Nott)	K. Daniels	NCSU
Work shop	Characterization	Particle Characterization of Complex Systems	Date TBD	Location TBD

IFPRI 2021-2022 Programs (Part III)

Type	Technical Area	Project Description	Research Associate	Institute
Project Briefs for 2022 AGM Voting	Wet Systems	Computational Modeling of Suspensions	R. Zia	Stanford U.
	Formation	Numerical Modeling of Spray Droplet Formation, Dispersion and Drying	O. Desjardins	Cornell U.
			M. W. Woo	U. Aukland
		Spray Drying of Pastes to Improve Sustainability	V. Gaukel	KIT
	Dry Systems	Aeration and Dearation of Geldart Group C Powders During Flow	O. Pouliquen	Marseille U.
	Grinding	Effect of Drying on Particle-Particle Bonds	H. Emady	ASU
			A. Sauret	UCSB
Other	Education and Advocacy	Economic Justification for Particle Technology – Update and Expand the 1985 Merrow Report	E. Merrow	IPA

IFPRI Membership

Full Membership

- AbbVie
- Albemarle
- Alkermes
- AVEKA
- Chemours
- Corbion
- Corning
- Corteva
- DFE Pharma
- DSM
- Ecolab
- FMC
- Haldor Topsoe
- Hoffman La Roche
- Imerys
- Johnson Matthey
- Keurig Green Mountain
- Lincoln Electric
- Merck
- Nestle
- Novozymes
- Pfizer
- Procter & Gamble
- Sandia National Laboratories
- Sherwin-Williams
- Syngeta
- Unilever
- Vertex Pharmaceutical

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IFPRI Membership

Associate Members

- Bepex
- Elcon Precision
- Freeman Technology
- Granutools
- Horiba
- JM Canty
- Paul O. Abbe
- PSE
- Schenck Process
- Silanano Technologies

38 Total Members

- Pharma
- Chemical
- Food
- Consumer
- Government Labs
- Ceramics
- Agriculture
- Equipment
- Modeling

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Workshops as a Model for Strategic Development

2 Day Format

- 2-3 Core questions posed for discussion
- 4-8 Presentations on state of industrial and academic field in defined area

30-60 Attendees

- Worldwide distribution
- Approximately equal industrial and academic

Workshops as a Model for Strategic Development

The two days are spent in breakout discussions followed by development of:

- Action Items
- Recommended Programs
- Written Internal IFPRI Report

Workshops as a Model for Strategic Development

IFPRI has Sponsored 10 Workshops in the Past 15 Years Including:

• Powder Flow	NSF Sponsored Collaboration
• Grinding	IFPRI Project on Nanotechnology
• Gel Formation	Led to Second Workshop
• Colloidal Gels	IFPRI Project on Structure and Characterization on Colloidal Gels
• Particle Formation	IFPRI Project on 3D Printing of Uniform Particles
• Crystallization	IFPRI Project on Control of Crystal Morphology
• Powder Flow	IFPRI Project on Powder Mixing
• Education in Particle Technology	Education Sub-Committee to Present at Next AGM
• Dense Phase Rheology	IFPRI Project on Slurry and Paste Rheology
• Cohesion	Workshop held in January 2020

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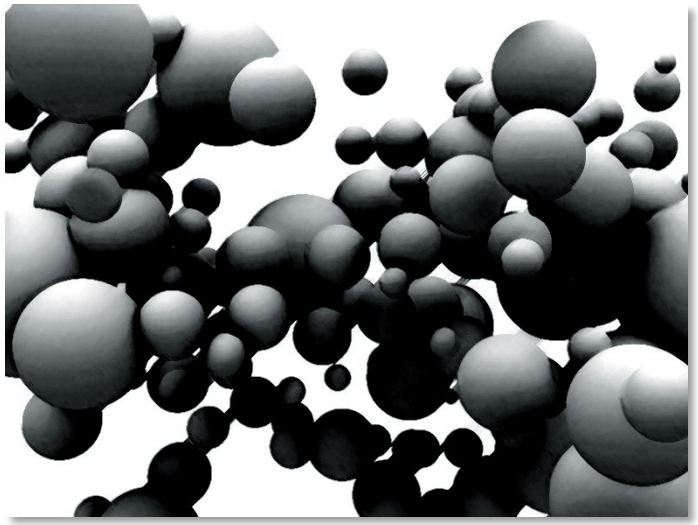
Roundtable Discussions for Strategic Development

2-5 Hour Format

- Teleconference or Informal Meeting
- Industrial Best Practices Discussed

5-80 Attendees

- All Industrial Participants
- Non-member Participants Welcomed



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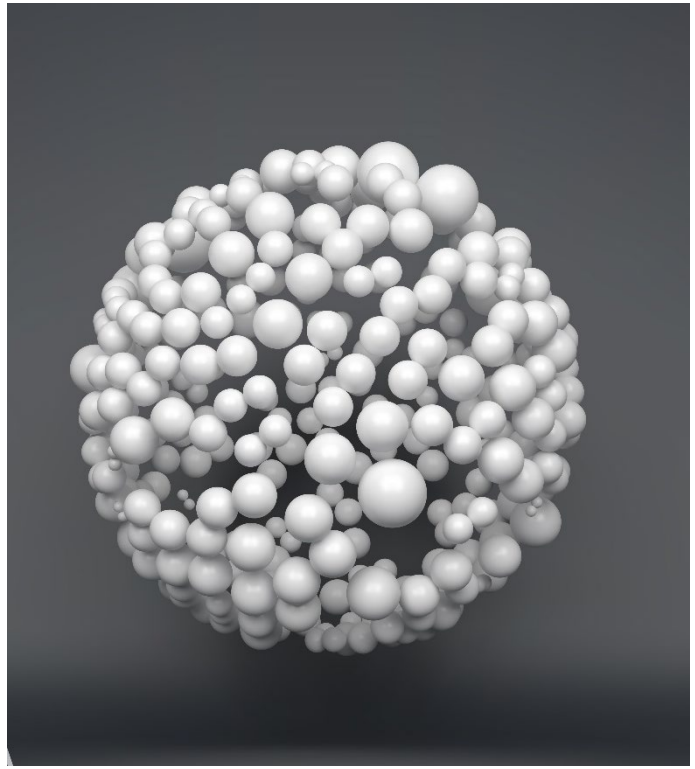
Roundtable Discussions for Strategic Development

- New Format for IFPRI
- Started in 2015
  - Powder Flow Measurements
  - DEM
  - DEM
  - Characterization
  - Education (October 7, 2021)
- Called by members to investigate specific topics

Shear Testing Round Table Discussion

IFPRI Member Roundtable January 2015

- Intent of flowability measurements
- What devices or methods were employed?
- Number of samples measured
- Who conducts the tests?
- What problems are encountered?
- Unmet needs
- Is this a topic for further IFPRI sponsored R&D?



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Education Roundtable Discussion

- October 21, 2021
- 50 attendees to the first 2 hour session
  - Defined areas that need more training and education
  - Defined need for operator and engineer level courses
- Small Subgroup Formed
  - Further refinement and development of example short video library
  - Looking to continue the discussion at the upcoming AGM

Other Programs at IFPRI

- Round Robin Evaluation of DEM Modeling
  - University of Birmingham and IFPRI Industrial Members
- Promotional Outreach for Particle Science and Technology
  - Merrow Report
- Collaboration with other groups and conferences
  - Gordon Conference on Granular Flow – Easton, MA — June 26- July 1
  - World Congress on Particle Technology – Madrid, Spain — Sept 18-22
  - Classification and Communition – Toulose, France — June 27-29
  - AIChE Particle Technology Forum

General Conclusion

- IFPRI academic associates are world-class authorities providing a unique global network and forum in Particle Technology to help IFPRI Members develop a strategic plan in particle technology
- Full profit of IFPRI membership is based on an active participation among members and contractors in meetings, workshops and roundtable discussions
- IFPRI provides tools to help bridge the Valley of Death gap to facilitate commercialization
- Next Annual General Meeting will be held in Brussels, Belgium June 12-16, 2022