A Needs-Based Assessment of Nanotechnology Environmental Health & Safety

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National Institute of Standards and Technology

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Environmental, Health & Safety Issues in Nanomaterials Workshop, June 9-10, 2008

Outline

- **USMS initial results**
- **Nanotechnology-EHS focus**

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Nanomaterials and the USMS Assessment: Observations

High demand for new advanced measurement instrumentation for **accurate, high resolution characterization of physical, chemical and biological properties of materials at nanometer dimensions**

Absence of regulations is having a serious impact on innovation

Timely delivery of materials measurement solutions is increasingly challenging

Principal measurement barrier to innovation is the absence of measurement instruments, techniques and methods capable of **accurately characterizing the behavior of complex materials systems and structures**

Key factor driving the need for innovation is anticipation of the production/marketplace needs for the evaluation of **Materials Performance, Manufacturability, and Reliability**

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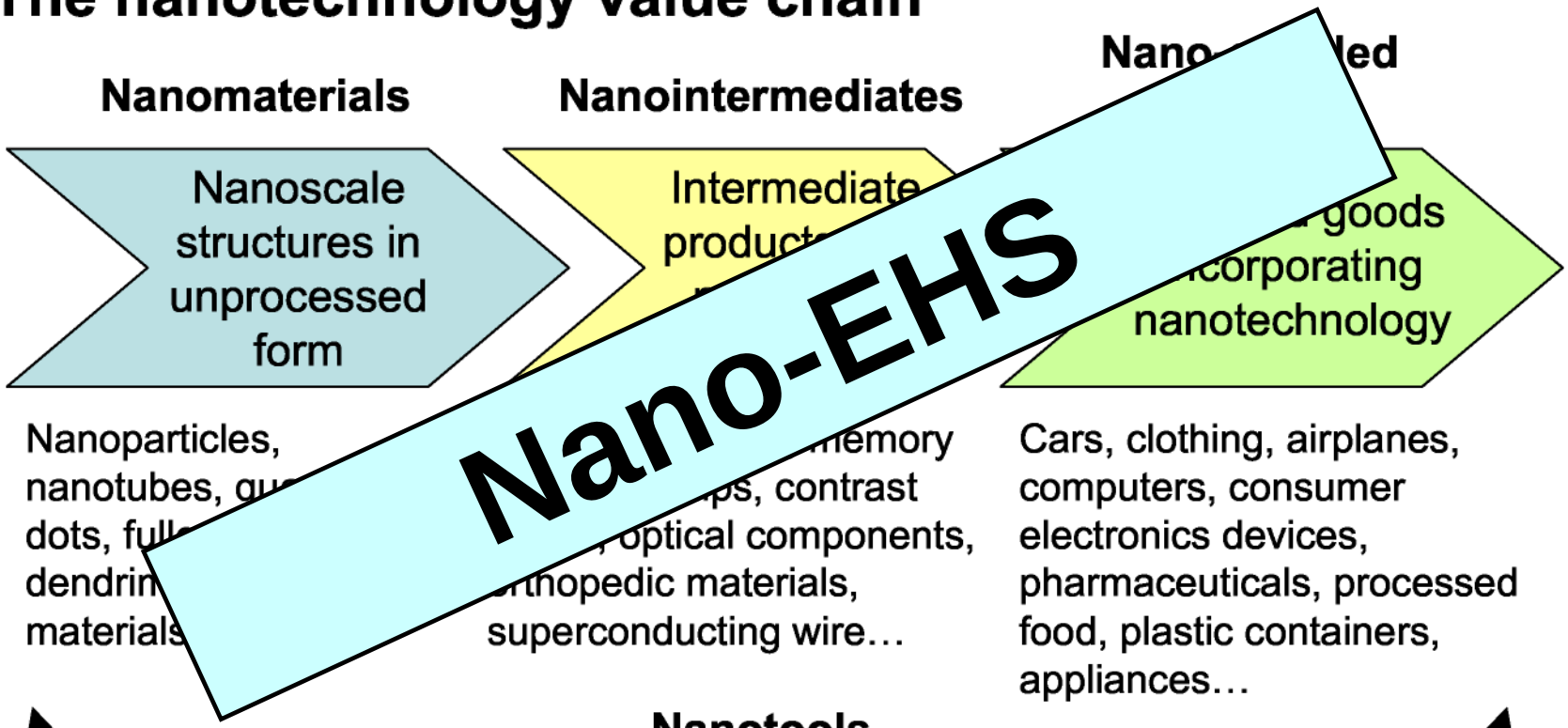
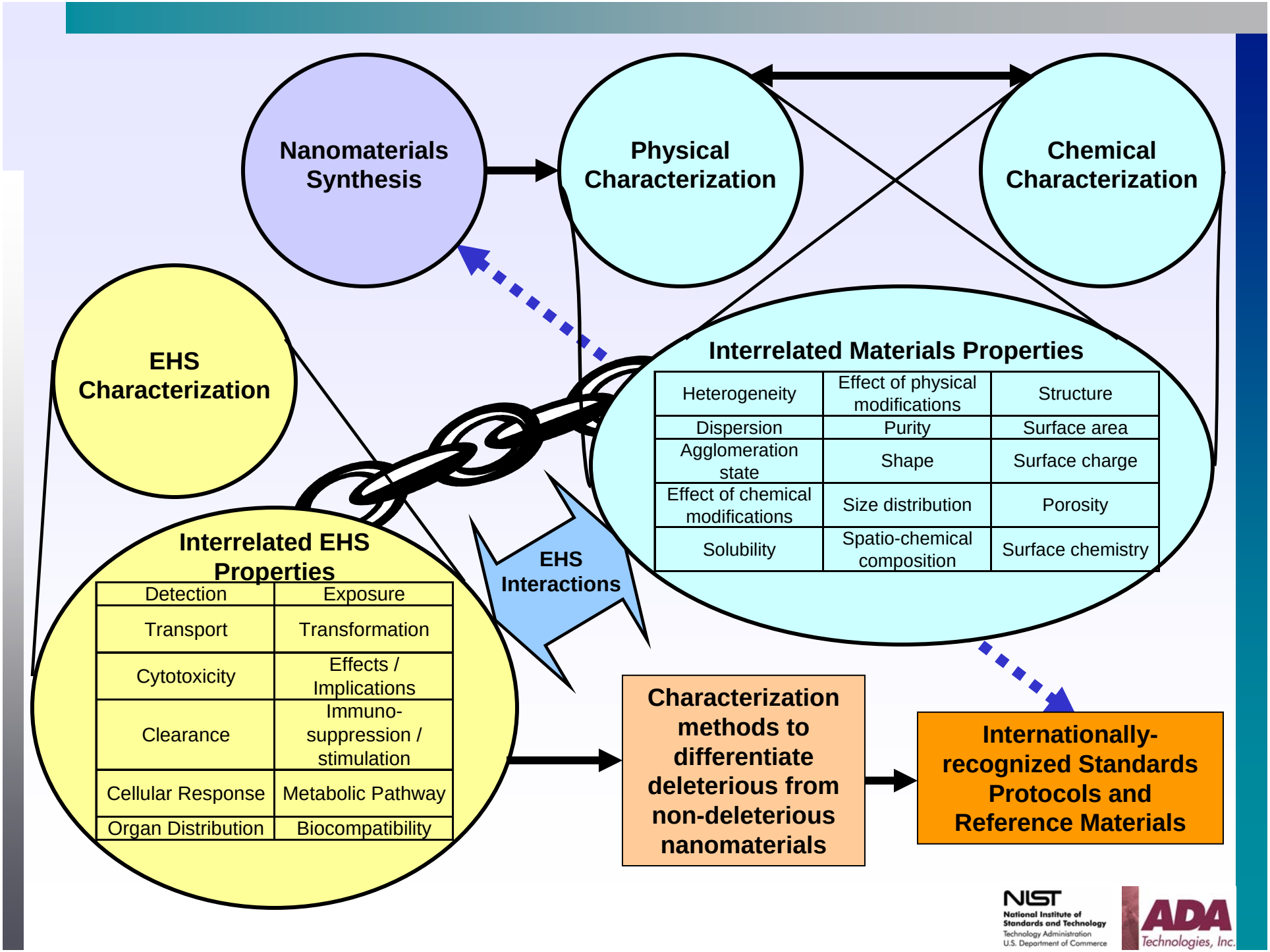
The nanotechnology value chain



Nanotools

Capital equipment and software used to visualize, manipulate, and model matter at the nanoscale

Atomic force microscopes, nanoimprint lithography equipment, nanomanipulators…


Nanomaterials Synthesis
Physical Characterization
Chemical Characterization
EHS Characterization
Interrelated Materials Properties
Heterogeneity
Effect of physical modifications
Structure
Dispersion
Purity
Surface area
Agglomeration state
Shape
Surface charge
Effect of chemical modifications
Size distribution
Porosity
Solubility
Spatio-chemical composition
Surface chemistry
EHS Interactions
Interrelated EHS Properties
Detection
Exposure
Transport
Transformation
Cytotoxicity
Effects / Implications
Clearance
Immuno-suppression / stimulation
Cellular Response
Metabolic Pathway
Organ Distribution
Biocompatibility
Characterization methods to differentiate deleterious from non-deleterious nanomaterials
Internationally-recognized Standards Protocols and Reference Materials
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What are the Components of an Authenticated MN (How)?

- MN Template
  - Technological innovation at stake
  - Economic significance of the innovation
  - Technical barrier to the innovation
  - Stage of innovation at which technical barrier appears
  - Measurement-problem part of the technical barrier
  - Potential solutions to the measurement problem
  - Potential providers of these solutions
- Tags / Indicators
  - MN Characteristics that may be used to compare MNs
- Authentication
  - Evidence that MN represents a significant portion of Measurement Solution Users

31 Measurement Needs (MNs) submitted by Scientists & Engineers – *examples include:*

- **Nano-scale drug delivery**
- **Toxicology of nanoparticles in biological systems**
- **Real time measurements for pharmaceuticals and biologics manufacturing**
- **Advanced drug delivery systems, including implantable devices that automatically administer drugs and sense drug levels**
- **Sensors for airborne chemicals or other toxins**
- **Nanocrystal biophotonic sensors**
- **Nanomagnetic MRI contrast agents**
- **Inhalation insulin delivery/diabetes management**
- **Small particle monitoring for advanced semiconductor manufacturing**
- **Health care/nanotechnology – cancer diagnosis and treatment**
- **Quality control in cytometry for improved clinical diagnostics**
- **C60 carbon nanomaterials for nanobiotechnology**

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104 Roadmap Measurement Needs (RMNs) identifed from roadmaps, workshop reports, and white papers – *sources include:*

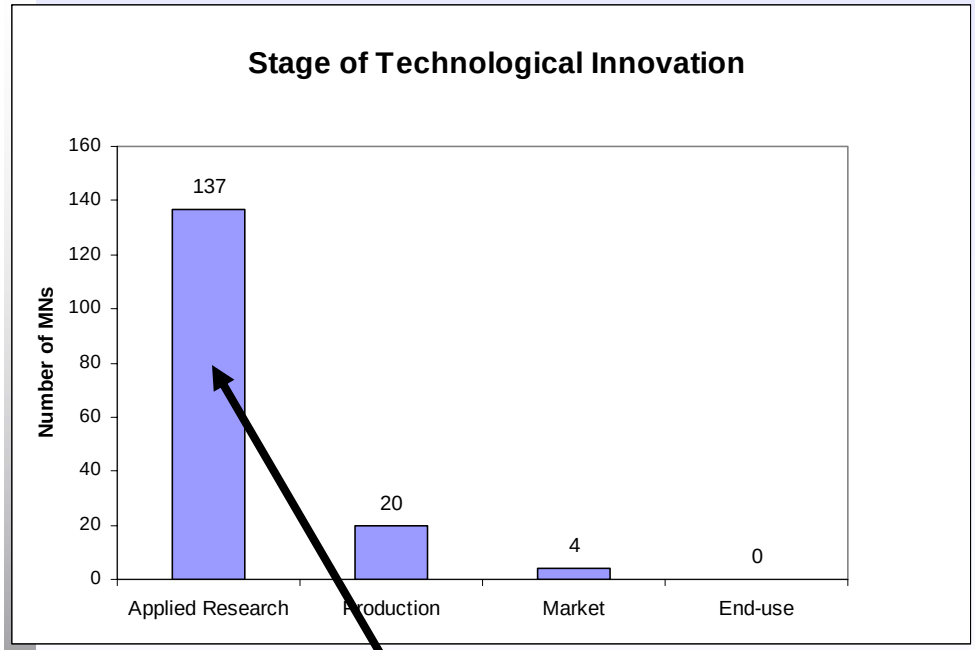
Roadmap, White Paper or Workshop Report	Year	Source	# of RMNs
Strategy for Nanotechnology-Related Environmental, Health, and Safety Research	2008	http://www.nano.gov/	4
Toxicology steps up to nanotechnology safety	2008	http://www.rdmag.com/	7
Strategic Plan for NIOSH Nanotechnology Research and Guidance	2008	http://www.cdc.gov/niosh/topics/nanotech/strat_plan.html	3
Nanotechnology - A report of the US FDA Nanotechnology Task Force (FDA)	2007	http://www.fda.gov/nanotechnology/taskforce/report2007.html	3
Prioritization of EHS Research Needs for Engineered Nanoscale Materials - An interim document for public comment (NEHI Working Group)	2007	http://www.nano.gov/Prioritization_EHS_Research_Needs_Engineered_Nanoscale_Materials.pdf	21
Nanomaterials in the workplace - Policy and planning workshop on Occupational Safety		http://www.rand.org/pubs/conf_proceedings/2006/RAND	2
			6
			3
The National Nanotechnology Initiative - Strategic Plan	2007	http://www.nano.gov/html/about/strategicplan.html	2
Nanotechnology environmental health & safety standards	2007	http://www.iso.org/iso/iso-focus-index	4
EHS Research Needs for Engineered Nanoscale Materials	2006	http://www.nano.gov/NNI_EHS_research_needs.pdf	31
			1
			1
			2
Assessment Study on Sensors and Automation in the Industries of the Future	2004	n/pdfs/doe_report.pdf	1
International Technology Roadmap for Semiconductors	2004	http://www.itrs.net/Common/2004Update/2004Update.htm	1
Chemical Industry R&D Roadmap for Nanomaterials By Design	2003	http://www.chemicalvision2020.org/pdfs/nano_roadmap.pdf	1
Nanoscale Science and Engineering for Agriculture and Food Systems	2003	http://www.nseafs.cornell.edu/web.roadmap.pdf	1
Nanobiotechnology	2003	http://www.nano.gov/nni_nanobiotechnology_rpt.pdf	3
Nanotechnology	2003	http://www.technology.gov/reports/TechPolicy/Nanotech/030523.pdf	2
Nanotechnology and the Environment: Applications and Implications STAR Progress Review Workshop	2002	http://es.epa.gov/ncer/publications/workshop/nano_proceed.pdf	3
Nanotechnology Innovation for Chemical, Biological, Radiological, and Explosive Detection and Protection	2002	http://www.wtec.org/nanoreports/cbre/CBRE_Detection_11_1_02_hires.pdf	2
Vision 2020 Materials Technology Roadmap	2000	http://www.eere.energy.gov/industry/chemicals/pdfs/materials_tech_roadmap.pdf	1

EHS Research Needs for Engineered Nanoscale Materials (NNI)

Prioritization of EHS Research Needs for Engineered Nanoscale Materials (NEHI)

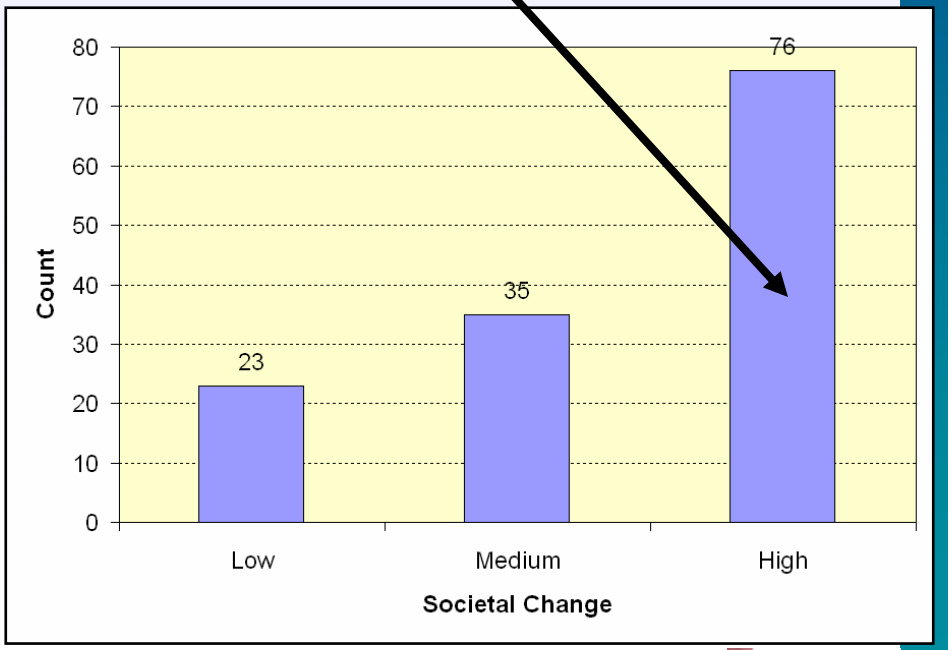
Preliminary Inferential Analysis of nano-EHS Measurement Needs (MNs) & Roadmap Measurement Needs (RMNs)

Data analyzed from 31 MNs and 104 RMNs



We've only just begun…

…but the effects on society could be significant.



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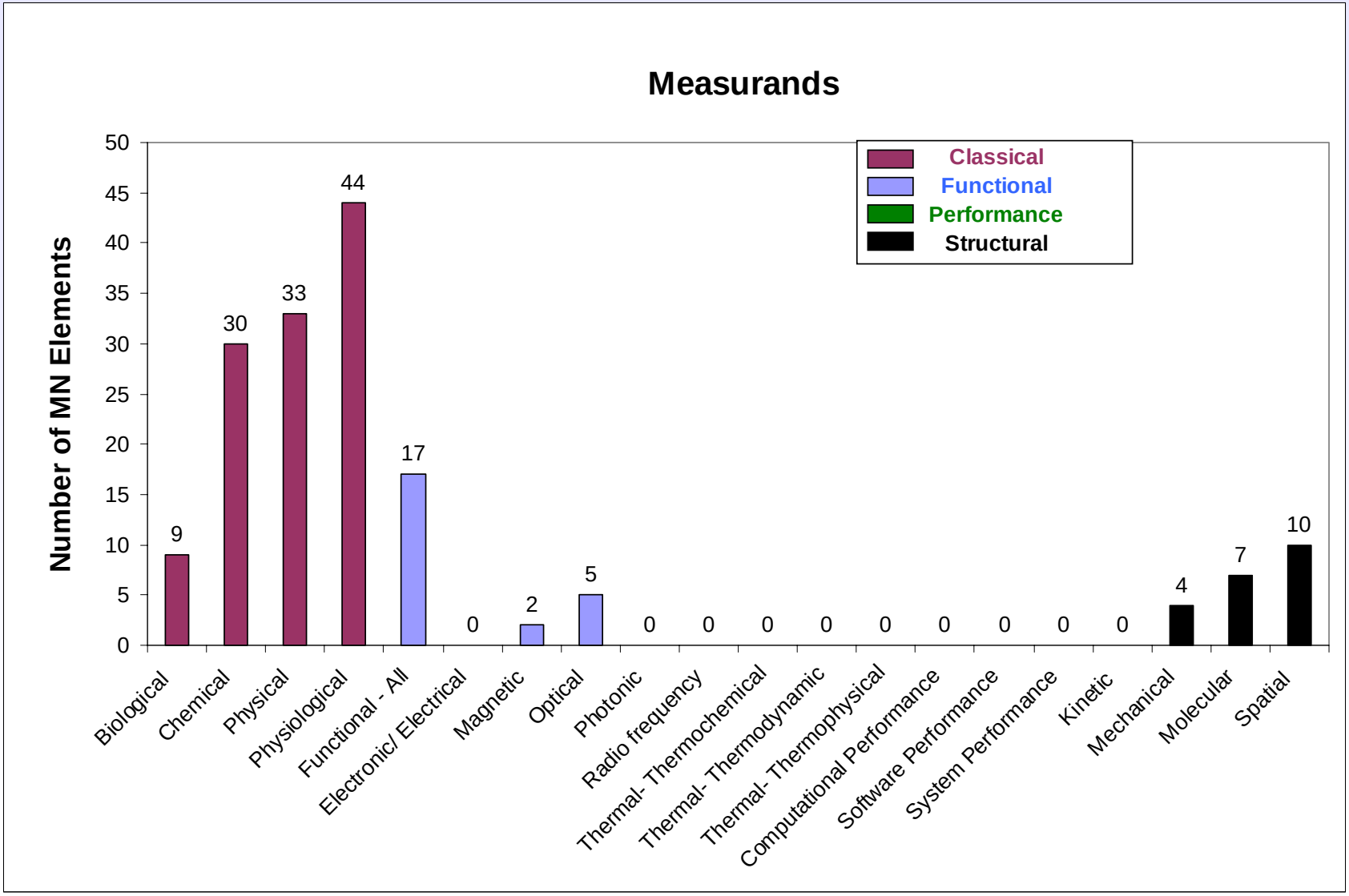
Preliminary Inferential Analysis of Nano EHS



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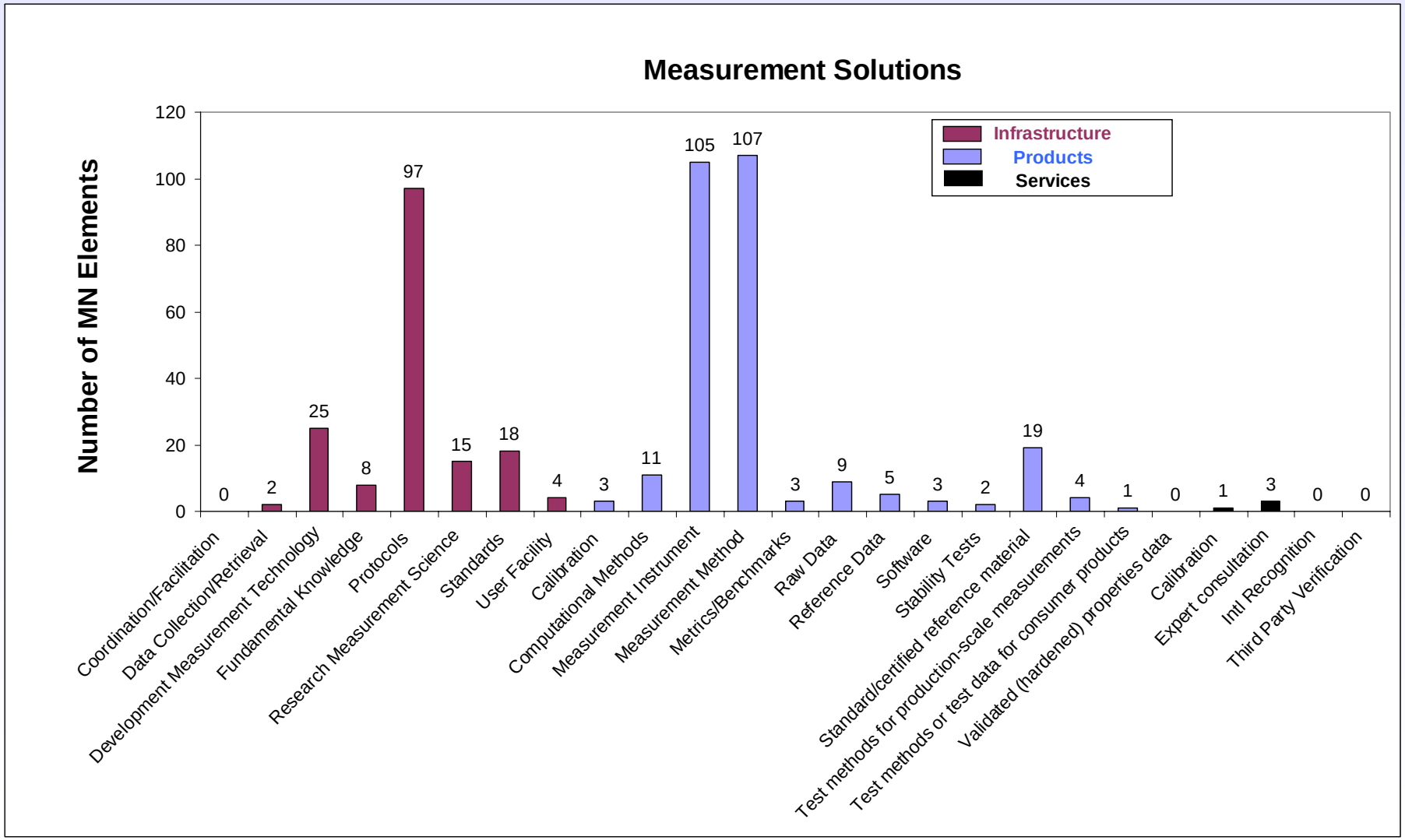

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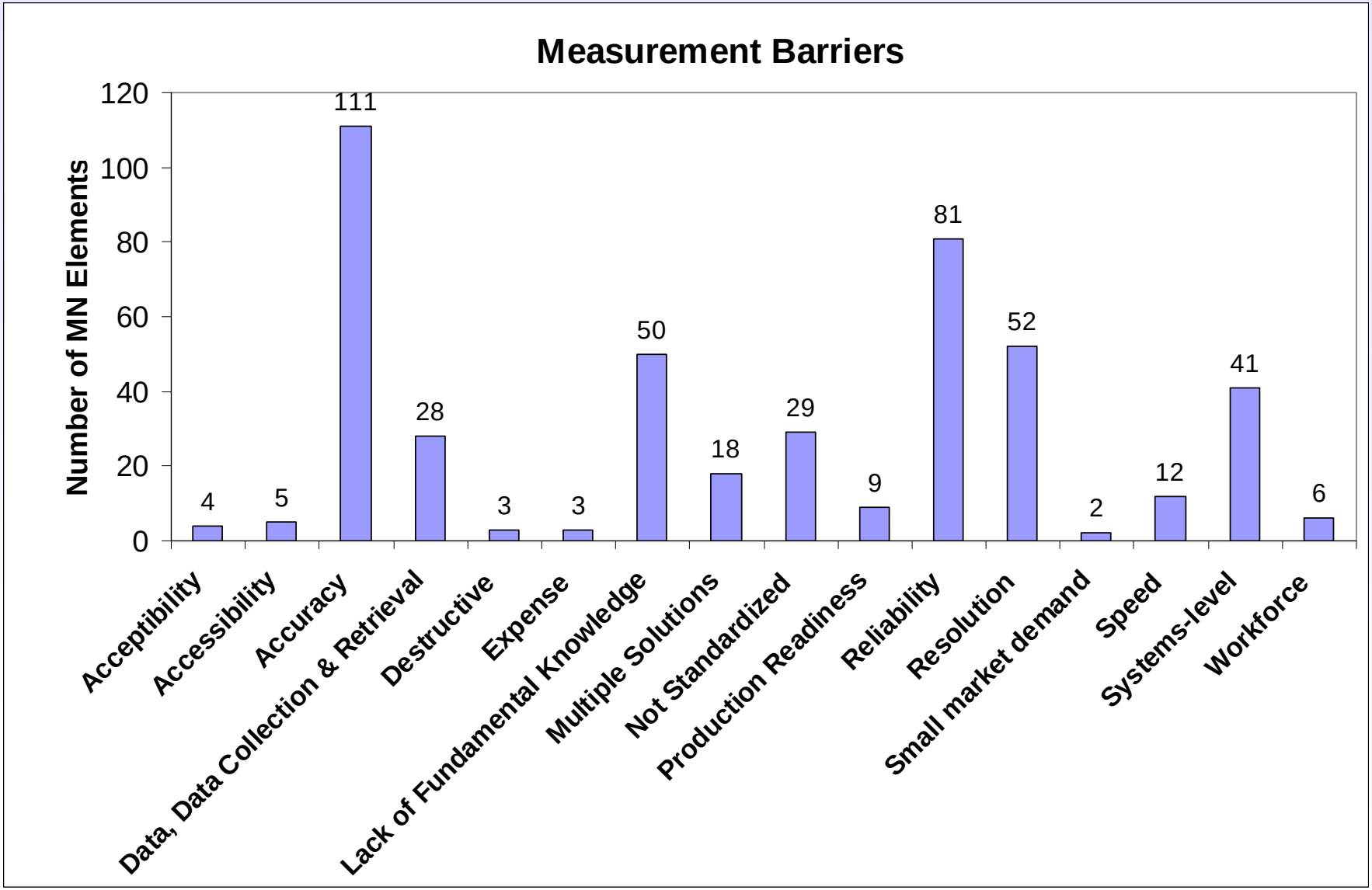

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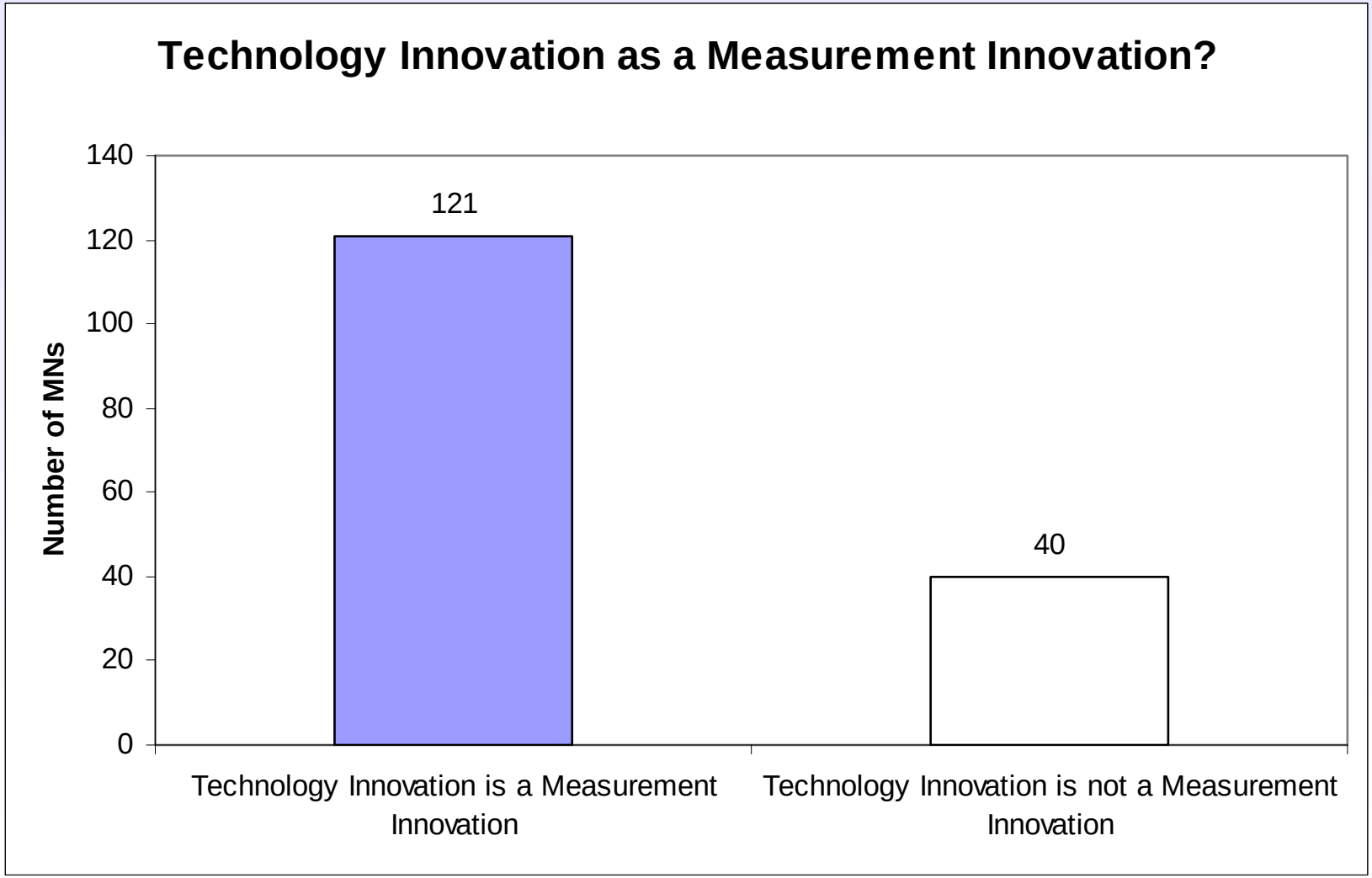

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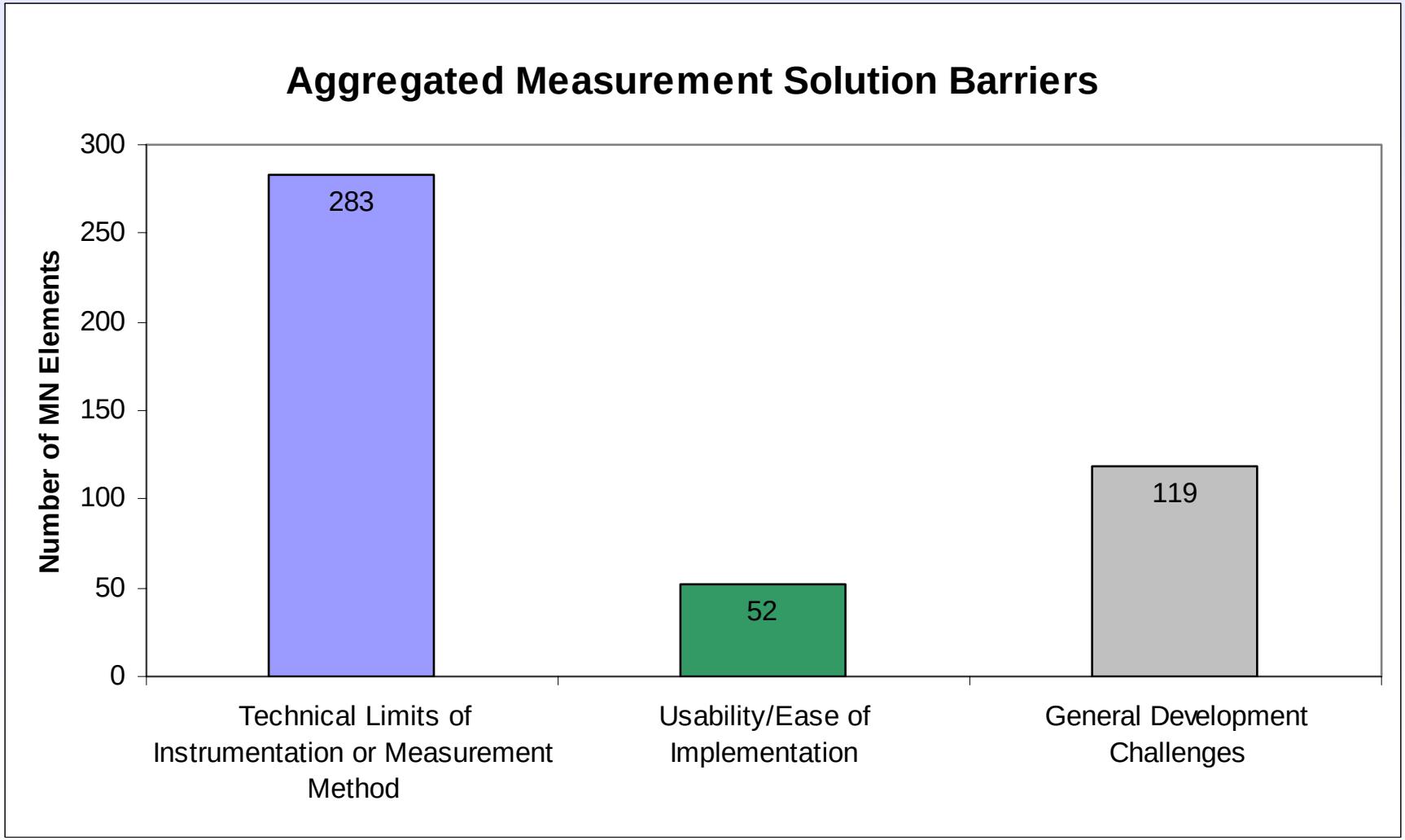

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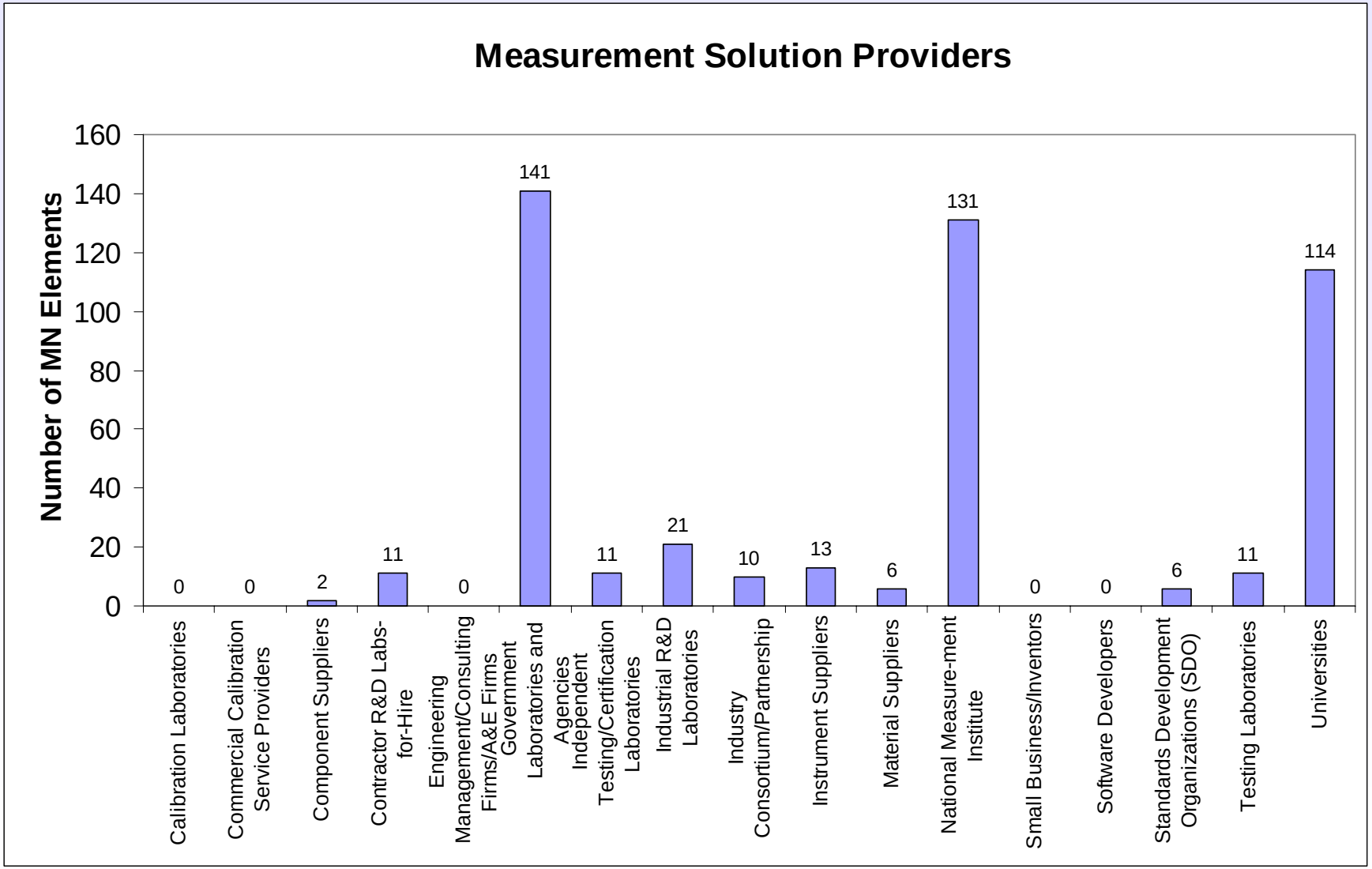

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Preliminary Inferential Analysis of Nano EHS

Stage of Technological Innovation	Measurement Solution Barriers															
	Acceptability/Compatibility	Accessibility	Accuracy	Data, Data Collection and/or Retrieval	Destructive	Expense	Lack of fundamental knowledge	Multiple Solutions Exist	Not Standardized	Production Readiness	Reliability	Resolution	Small Market Demand	Speed	System-Level Problem	Workforce
Applied Research	2	3	101	22	3	2	44	16	18	6	72	48	2	9	38	2
Production	2	2	8	4		1	6	2	7	3	5	4		3	3	4
Market			2	2					4		4					
End-use																

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Preliminary Inferential Analysis of Nano EHS

Stage of Technological Innovation	Measurement Solutions																								
	Infrastructure								Products													Services			
	Coordination/ facilitation	Data Collection/ Retrieval	Development for Measurement Technology	Fundamental Scientific Knowledge	Protocols	Research for Measurement Science	Standards	User Facility	Calibration Method	Computation Method	Measurement Instrument	Measurement Method	Metrics/ Benchmarks	Raw Properties Data	Reference Data	Software	Stability Tests	Standard/CRM	Test Methods - Production Scale	Test Methods - Consumer Products	Validated Data	Calibration Services	Expert Consultation	International Recognition	3rd Party Verification
Applied Research		2	21	8	87	15	10	4	3	7	95	97	3	9	4	3	2	9	1				3		
Production			4		8		4			2	10	10			1			8	2			1			
Market					2		4			2								2	1	1					
End-use																									

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Preliminary Inferential Analysis of Nano EHS

	Measurement Solution Barriers															
Aggregated Measurands	Acceptability/compatibility	Accessibility	Accuracy	Data, data collection and/or retrieval	Destructive	Expense	Lack of fundamental knowledge	Multiple solutions exist	Not standardized	Production readiness	Reliability	Resolution	Small market demand	Speed	System-level problem	Workforce
Classical	2	1	80	21	2	2	35	16	21	5	65	38	1	7	32	4
Functional	1	4	15	7	1		8	1	5	2	6	6		1	6	2
Performance																
Structural	1		16			1	7	1	3	2	10	8	1	4	3	

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Preliminary Inferential Analysis of Nano EHS

		Stage of Technological Innovation			
	Measurand	Applied Research	Production	Market	End-Use
Classical	Biological	7		2	
	Chemical	23	7		
	Physical	31		2	
	Physiological	36	8		
Functional	All	15	2		
	Electronic/Electrical				
	Magnetic	2			
	Optical	3	2		
	Photonic				
	Radio frequency				
	Thermal - Thermochemical				
	Thermal - Thermodynamic				
	Thermal - Thermophysical				
Performance	Computational Performance				
	Software Performance				
	System Performance				
Structural	Kinetic				
	Mechanical	3	1		
	Molecular	7			
	Spatial	10			

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		Measurement Solution Barriers															
	Measurand	Acceptability/compatibility	Accessibility	Accuracy	Data, data collection and/or retrieval	Destructive	Expense	Lack of fundamental knowledge	Multiple solutions exist	Not standardized	Production readiness	Reliability	Resolution	Small market demand	Speed	System-level problem	Workforce
Classical	Biological			7				2	2	3		9	2		2		
	Chemical		1	22	7			8	4	3	1	18	17		3	3	1
	Physical	2		26	11	2	1	7		9	1	17	10			6	
	Physiological			25	3		1	18	10	6	3	21	9	1	2	23	3
Functional	All	1	4	8	7	1		4	1	5	2	6	3		1	6	2
	Electronic/Electrical																
	Magnetic			2				2					2				
	Optical			5				2					1				
	Photonic																
	Radio frequency																
	Thermal - Thermochemical																
	Thermal - Thermodynamic																
	Thermal - Thermophysical																
Performance	Computational Performance																
	Software Performance																
	System Performance																
Structural	Kinetic																
	Mechanical	1		3						1		2	2		2	1	
	Molecular			5				3	1		2	3			1		
	Spatial			8			1	4		2		5	6	1	1	2	

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Preliminary Inferential Analysis of Nano EHS

Aggregated Measurement Solutions	Measurement Solution Barriers															
	Acceptability/Compatibility	Accessibility	Accuracy	Data, Data Collection and/or Retrieval	Destructive	Expense	Lack of fundamental knowledge	Multiple Solutions Exist	Not Standardized	Production Readiness	Reliability	Resolution	Small Market Demand	Speed	System-Level Problem	Workforce
Infrastructure	4	5	125	35	3	4	57	18	27	5	86	63	2	10	35	4
Products	5	7	189	40	5	4	82	36	45	17	149	87	4	23	75	10
Services	1			3			2		1						4	1

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CONCLUSIONS

- Measurement Needs and Roadmap Measurement Needs are being assessed within the Nano-EHS sector
- Preliminary indications are that Nano-EHS is *early-stage* in its development of measurement solutions
- Nano-EHS measurement needs will *push the envelope* of metrology equipment in the near future
- A concerted effort across multiple disciplines is needed to solve many of the Nano-EHS measurement needs
- It is critical to engage experts in this activity for their opinions on techniques, priorities and strategic directions

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PURPOSE OF WORKSHOP

- **Engage experts in the field in the development of Measurement Needs to make an accurate assessment of the state-of-the-art Nano-EHS USMS**

- **Initiate a dialogue about the best means for obtaining measurement *solutions* to addressing measurement needs**

- **Create a new opportunity for networking among experts in the Nano-EHS research and business sector**

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