P³Nano:
Expanding Commercial Potential of Cellulose Nanomaterials

Robert J Moon
Director/Technical Lead of P3Nano

https://research.fs.usda.gov/fpl/projects/p3nano

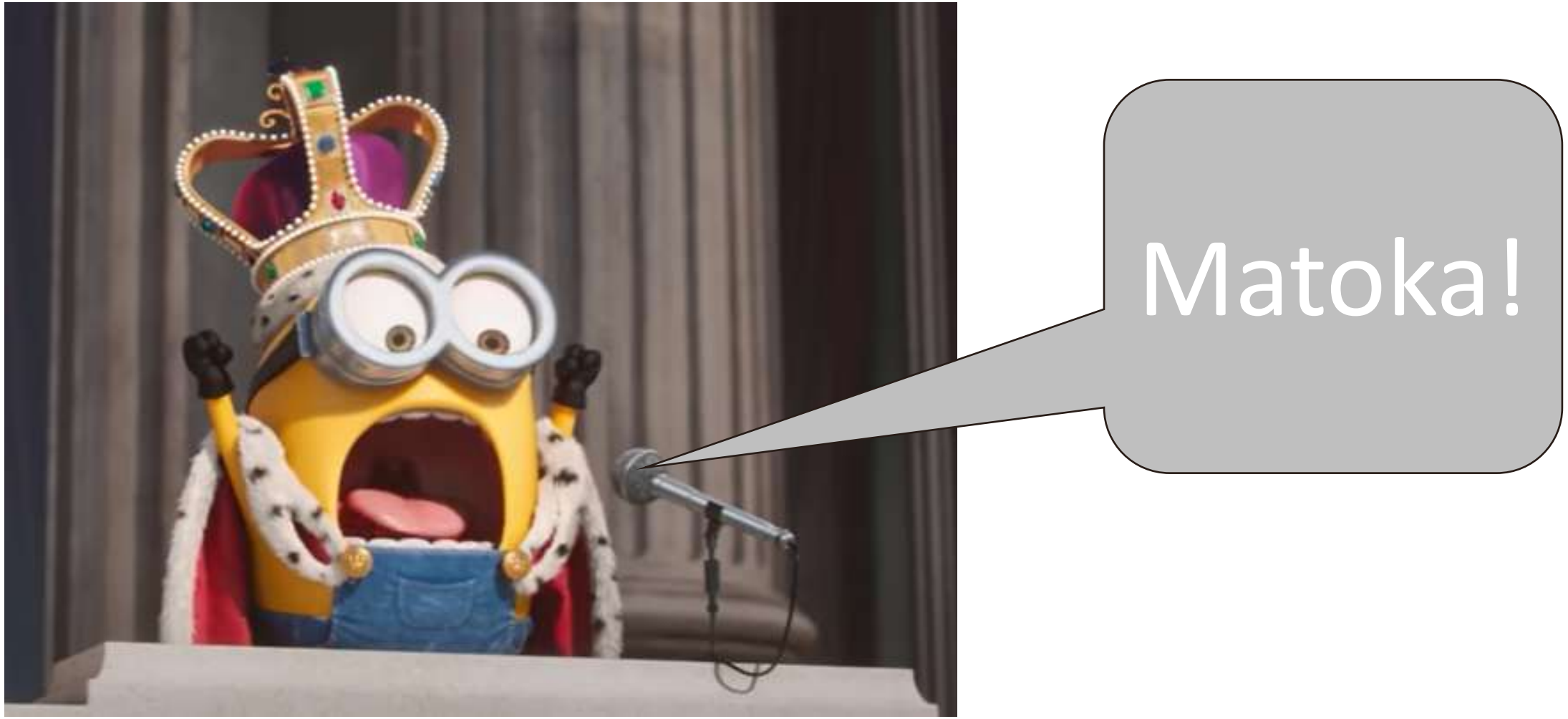
8 Sept 2026

P3Nano Funded Projects

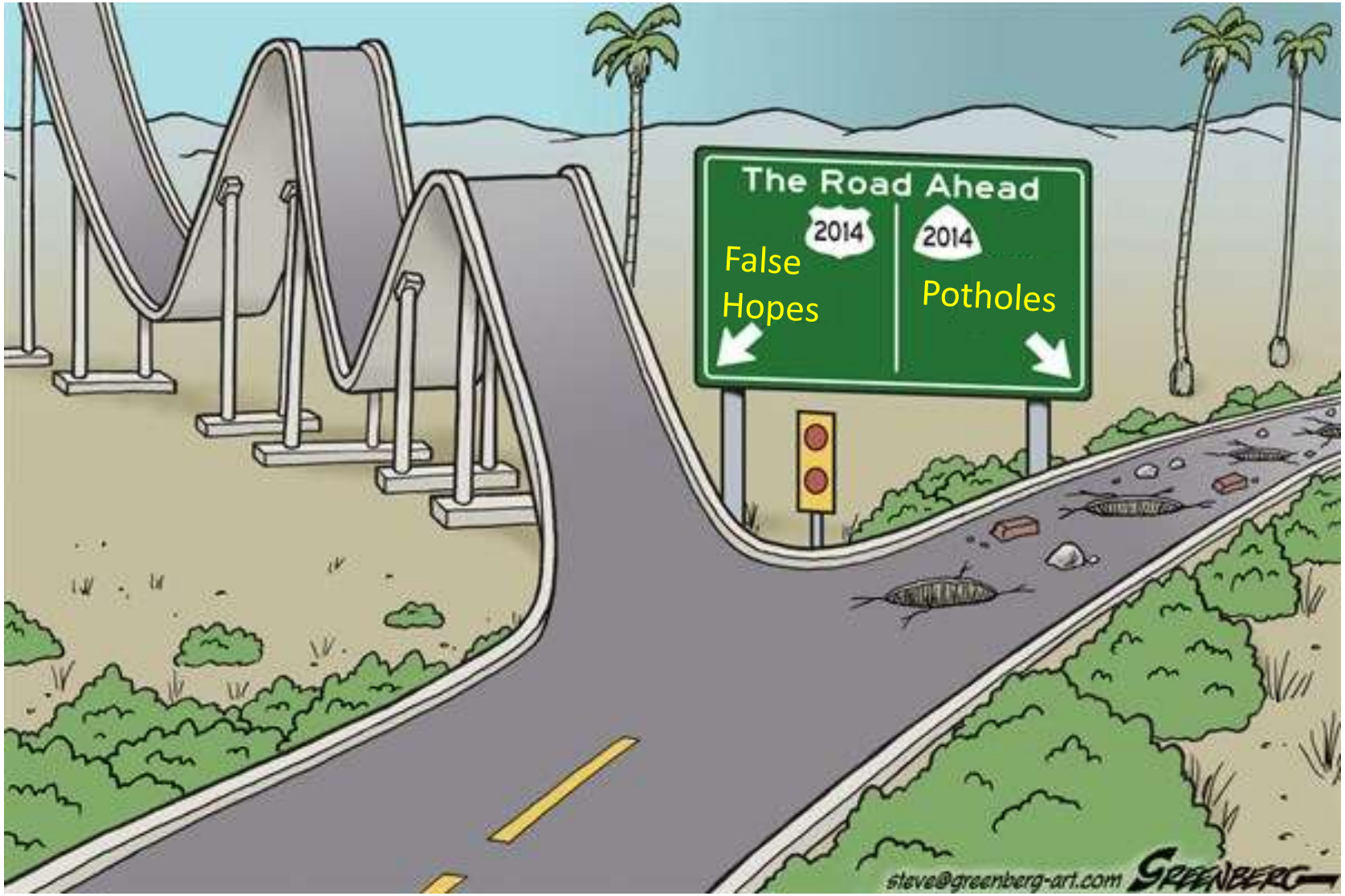
1. **Hybrid Molded Fiber (HMF): From Concept to Industrial Trials (7-Oct)**
   - Mehdi Tajvidi, University of Maine
2. **The AFSAC Alliance Efforts to Establish the Safety of MFC For Food- Related Applications**
   - Jo Anne Shatkin, Vireo Advisors, LLC
3. **MFC: High Solids Production and Barrier Coating of Fruits**
   - J.Y. Zhu, USDA Forest Service, Forest Products Laboratory
4. **Cellulosic Biobarriers for Sustainable Consumer Products**
   - Jeff Youngblood, Purdue University

Great Examples of how P^3Nano is Expanding the Commercial Potential of Cellulose Nanomaterials

Thank you for attention. Lunch Time !!



The long road to CN Commercialization



The Challenge for CN Commercialization



Fundamental Science



(Cool Stuff)

Valley of Death:

1. Address a worthy need
2. Applied Engineering
3. Costs/Benefit
4. Risk Reduction
5. Robust & Reproducible



&



Commercial Product



(Useful Stuff)

Many Barriers to CN Commercialization

- CN Production issues: high cost, low availability, no grades
- CN Consistency issues: depended on CN type & producer
- Application issues: not a drop in technology
- Scaling-up issues: benefits do not scale-up
- Regulatory issues: nano = bad
- Characterization issues: standards are needed
- TEA/LCA issues: underdeveloped
- Etc…….

P3Nano Focus



Fundamental Science



(Cool Stuff)

P3Nano

Commercial Product



(Useful Stuff)

P3Nano

- Approach
- Portfolio
- Highlights
- 2027 RFP



P3Nano: What is it?

2013

P3Nano

Public-Private Partnership

- USDA-Forest Service
- US Endowment
- Academic & Industry Institutions

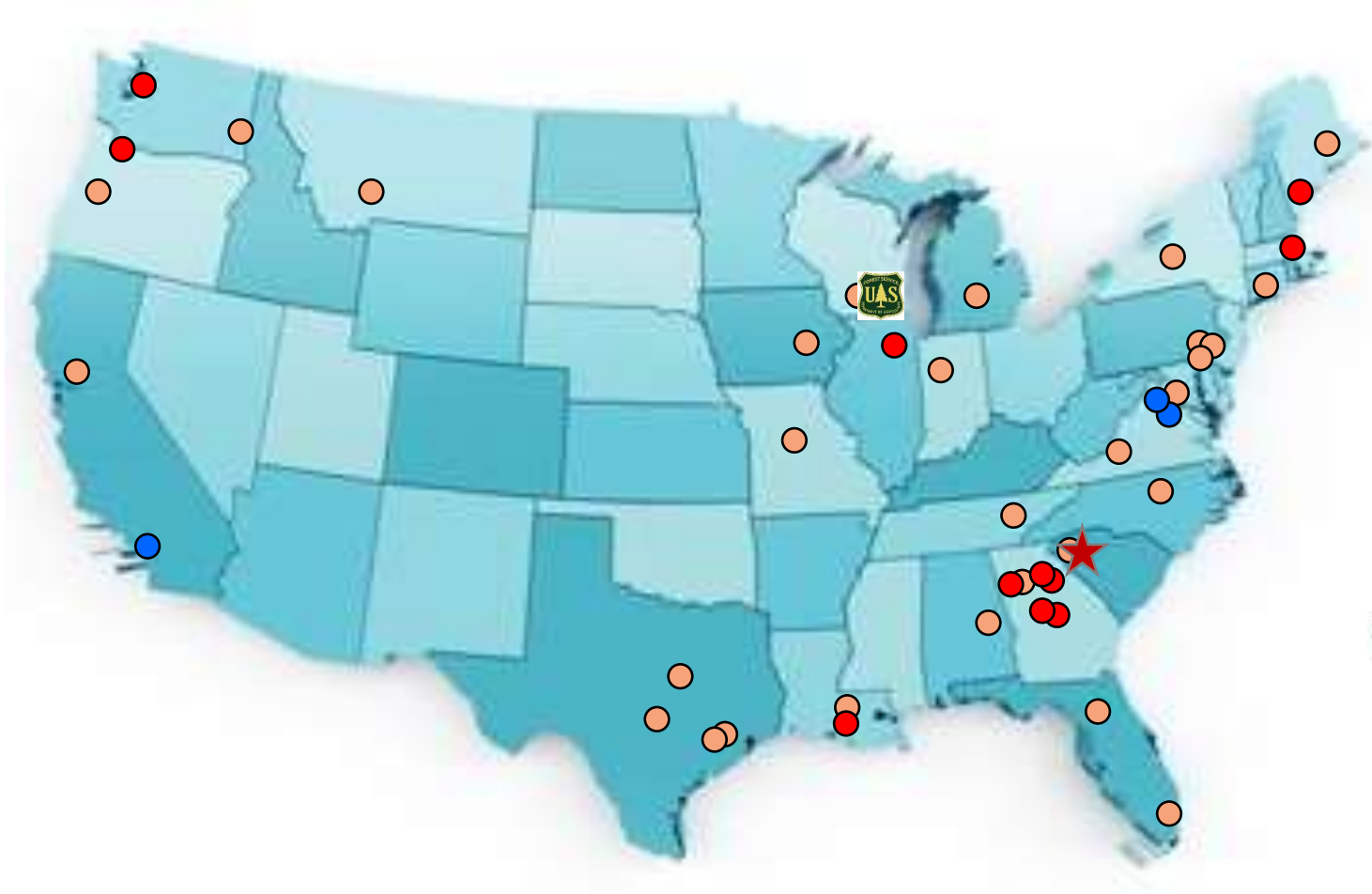
Wood-Based Nanomaterials

- Large volume applications

Remove Barriers to Commercialization

- Technology Research & Development

P3Nano: Collaboration is Key



Government

NIST

Caltrans

U.S. Endowment for Forestry and Communities

Industry

Vireo Advisors, LLC

HOLE PLUGGERS, LLC

FiberLean Technologies

CARTER ENGINEERING

GranBio

SURFATECH

sappi

Borregaard

amcor

BioFilaments

KNIFE RIVER

ADITYA BIRLA

BIRLA CARBON

Academia

THE UNIVERSITY OF MAINE

PURDUE UNIVERSITY

Oregon State University

MICHIGAN STATE UNIVERSITY

WISCONSIN

CLEMSON UNIVERSITY

MONTANA STATE UNIVERSITY

AUBURN UNIVERSITY

UF UNIVERSITY of FLORIDA

AMERICAN UNIVERSITY

THE UNIVERSITY OF IOWA

WASHINGTON STATE UNIVERSITY

UNIVERSITY OF HOUSTON

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Yale

Georgia Tech

RICE

SUNY

UNIVERSITY of DELAWARE

LSU

Virginia Tech

UNIVERSITY OF TEXAS ARLINGTON

Penn

TEMPLE UNIVERSITY

Duke UNIVERSITY

FIU FLORIDA INTERNATIONAL UNIVERSITY

Mizzou University of Missouri

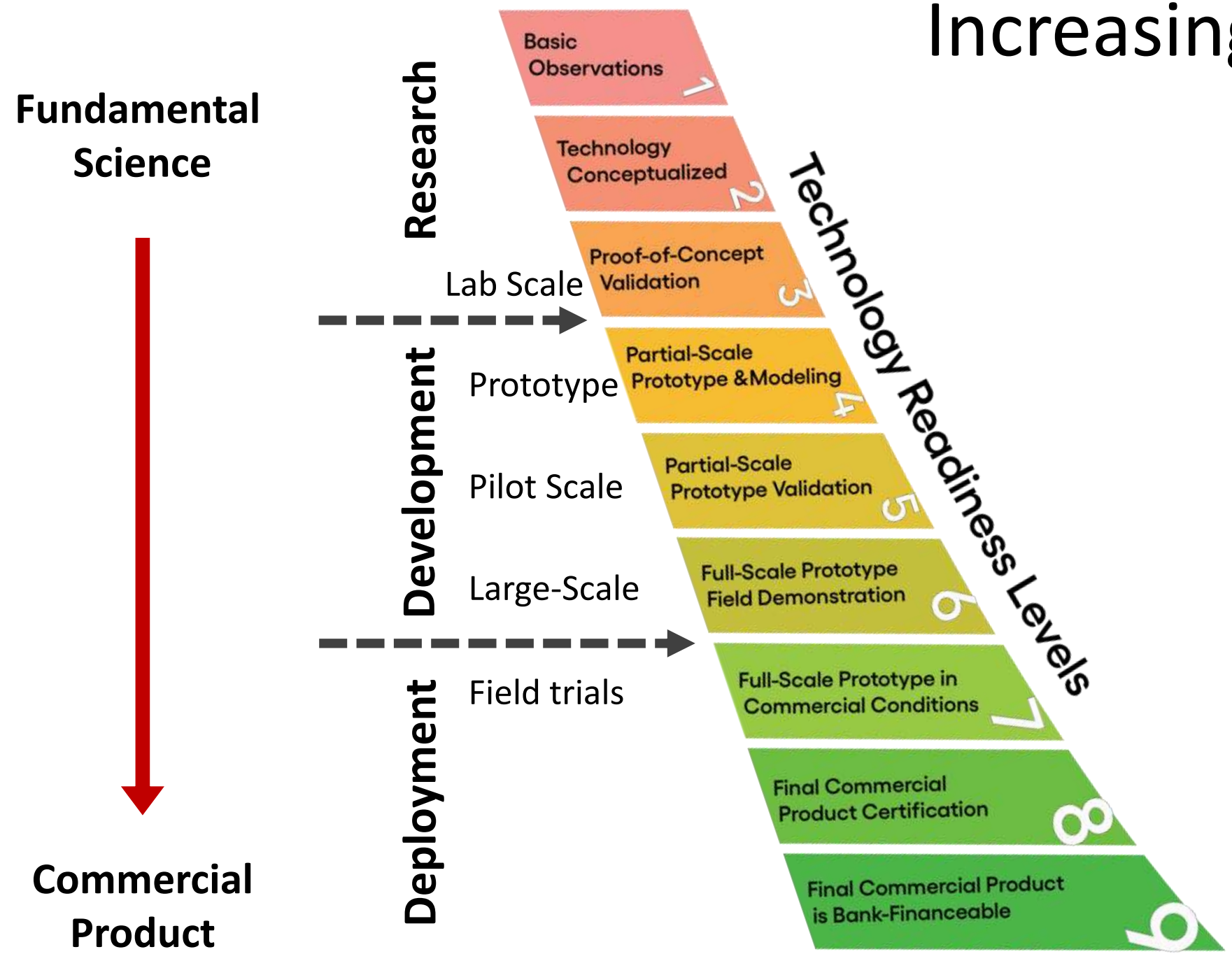
P3Nano: The Approach

P3Nano

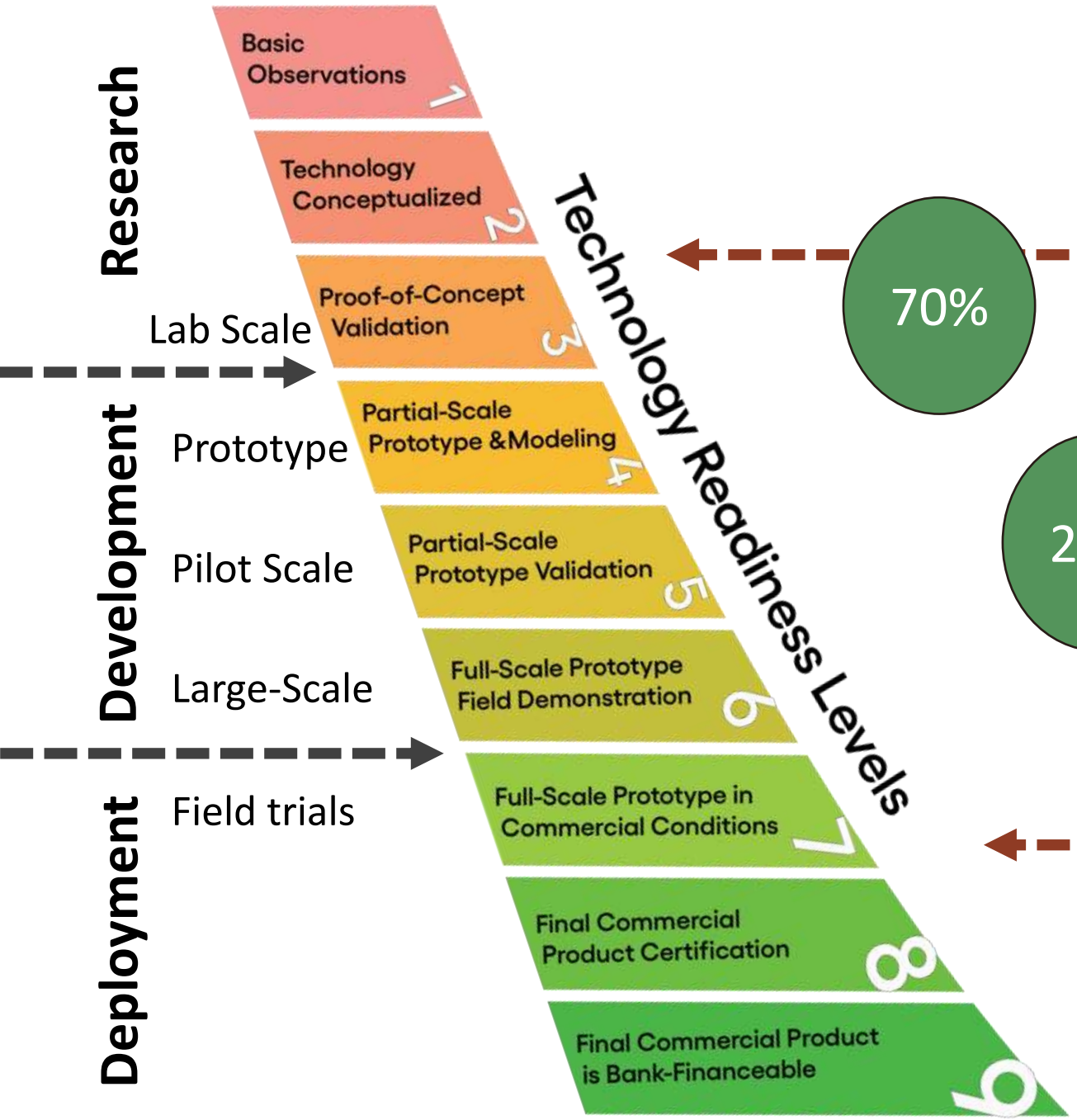
Technology Research & Development:

1. New application
2. Proof of concepts
3. Applied science & engineering
4. Prototype development
5. Pilot scale capabilities
6. Field trials
7. Risk Reduction
   - EHS (Environment, Health, Safety)
   - TEA (Techno Economical Analysis)
   - LCA (Life Cycle Analysis)

Increasing TR Levels



Increasing TR Levels



TRL 2/3

70%

25%

5%

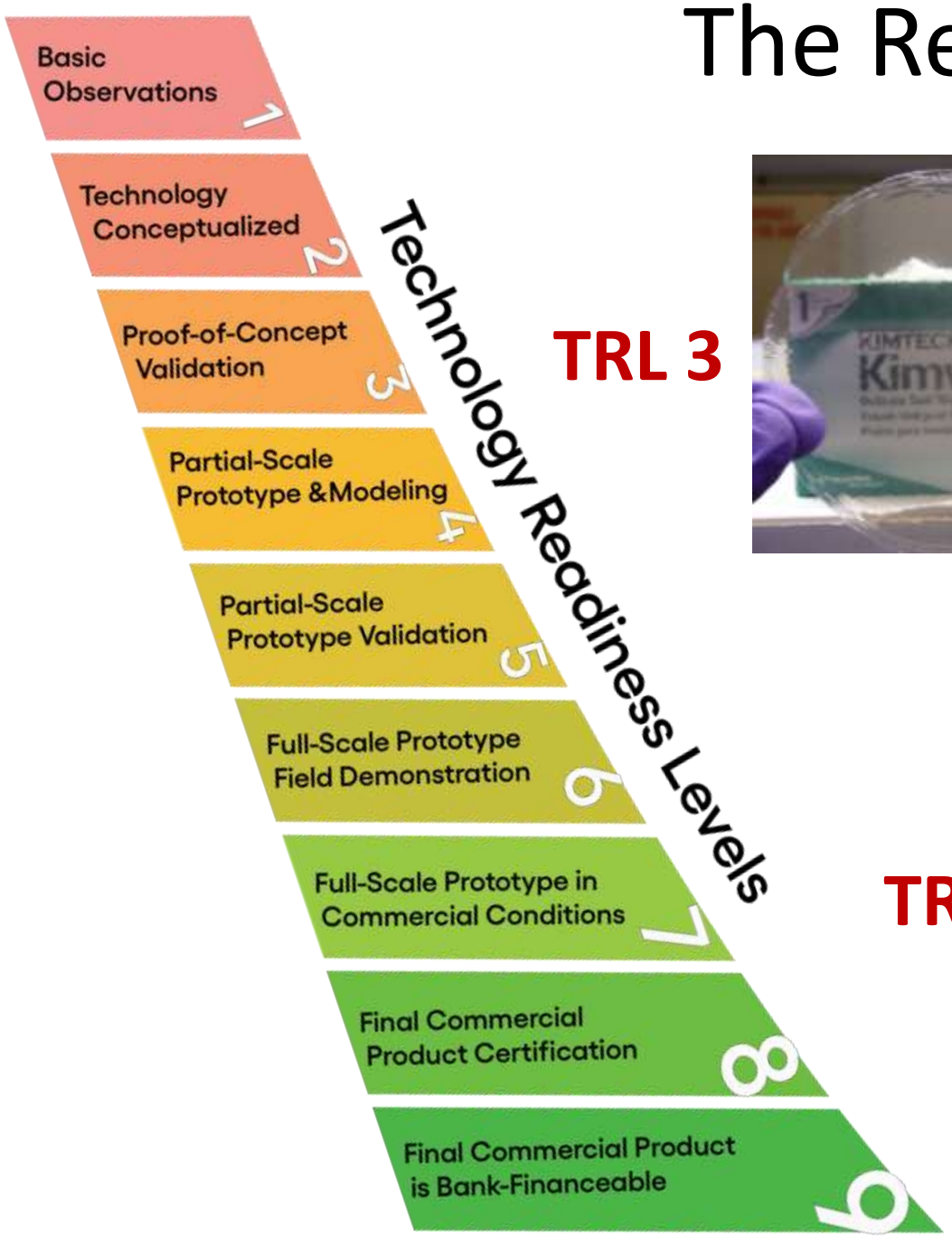
TRL ~7

- More Academic
- Smaller Volume

P^3Nano

- More Industrial
- Larger Volume

The Reality of Increasing TRLs



TRL 3



TRL 4/5



TRL 7



Funding Categories

Exploratory Projects: **$100K**

- TRLs 2 to 3
- Technology investigation & validation
- Explore new phenomena & mechanisms

Development Projects: up to **$500K**

- TRLs 4 to 7
- Need extensive relevant preliminary work (TRL=3)
- Applied engineering of technology
- Scaling up: prototypes, Larger volumes, industrial systems, field trials

Annual Grantee Meeting → Sharing Expertise

2024



Having Fun !!!



2026

P3Nano

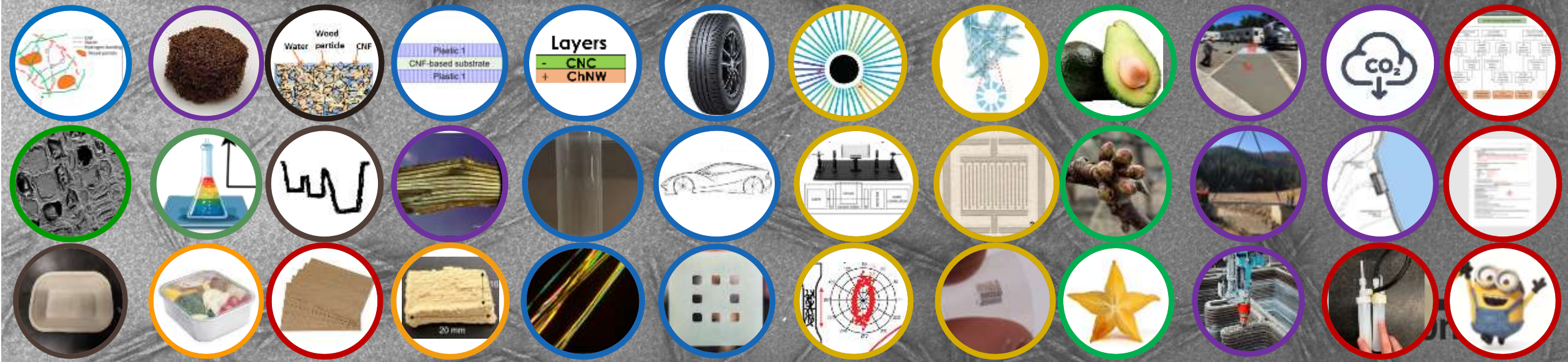
- Approach
- **Portfolio**
- Highlights
- 2027 RFP



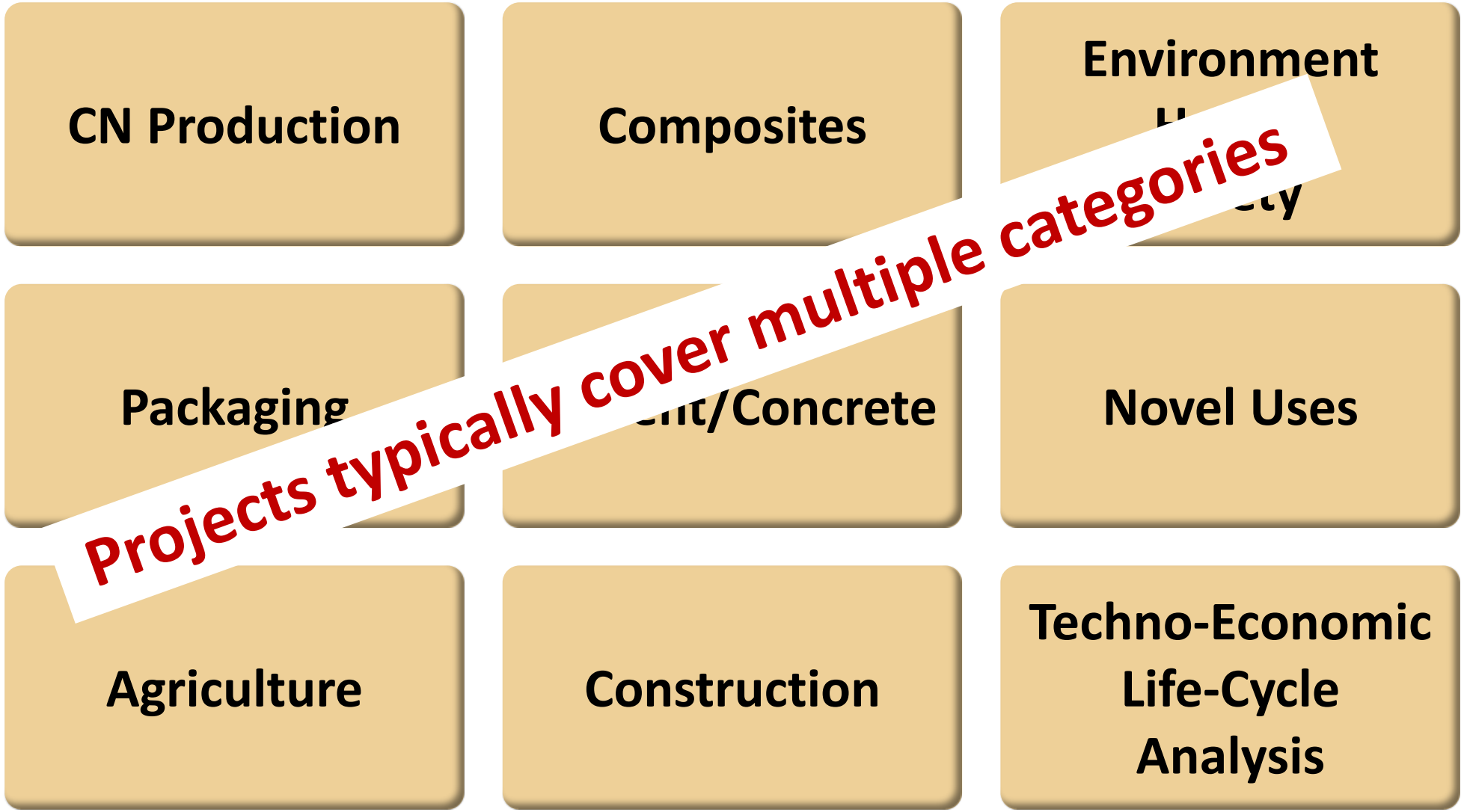
Project Portfolio

Funding:	~$27M
Projects:	**70+**
Collaborations:	**50+**
• Academia:	25
• Industry:	21
• Other	4

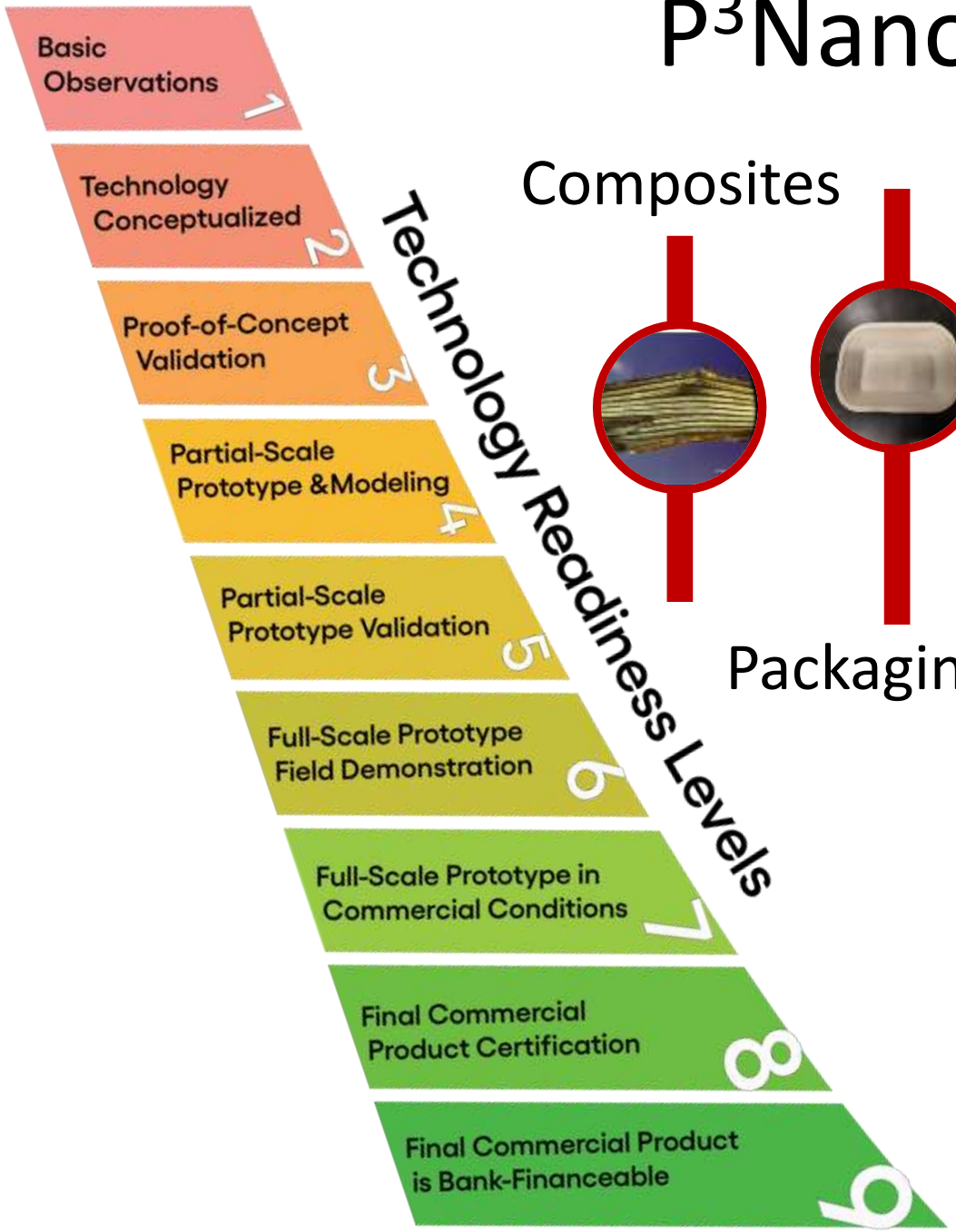


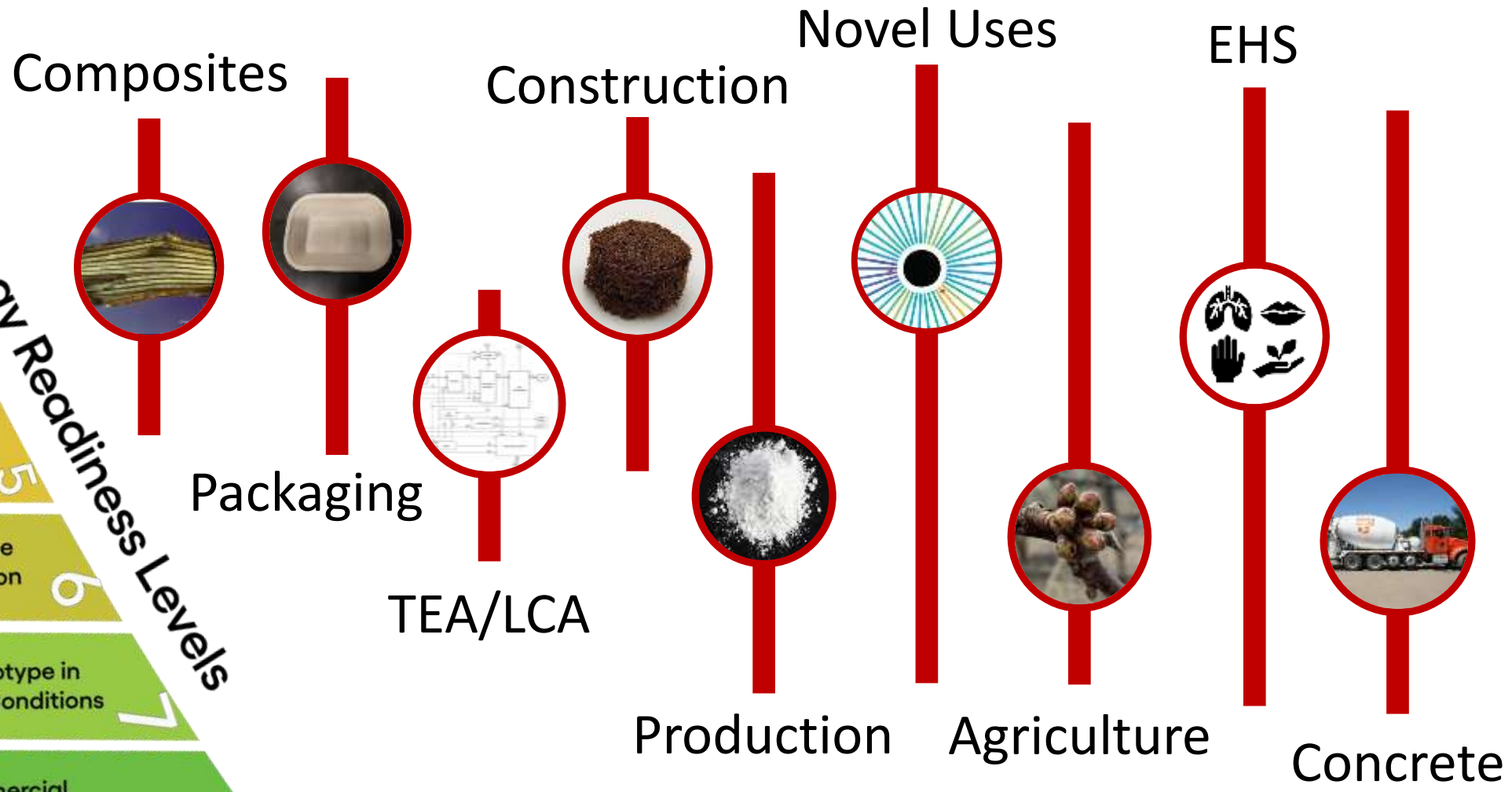


P3Nano: Research Categories

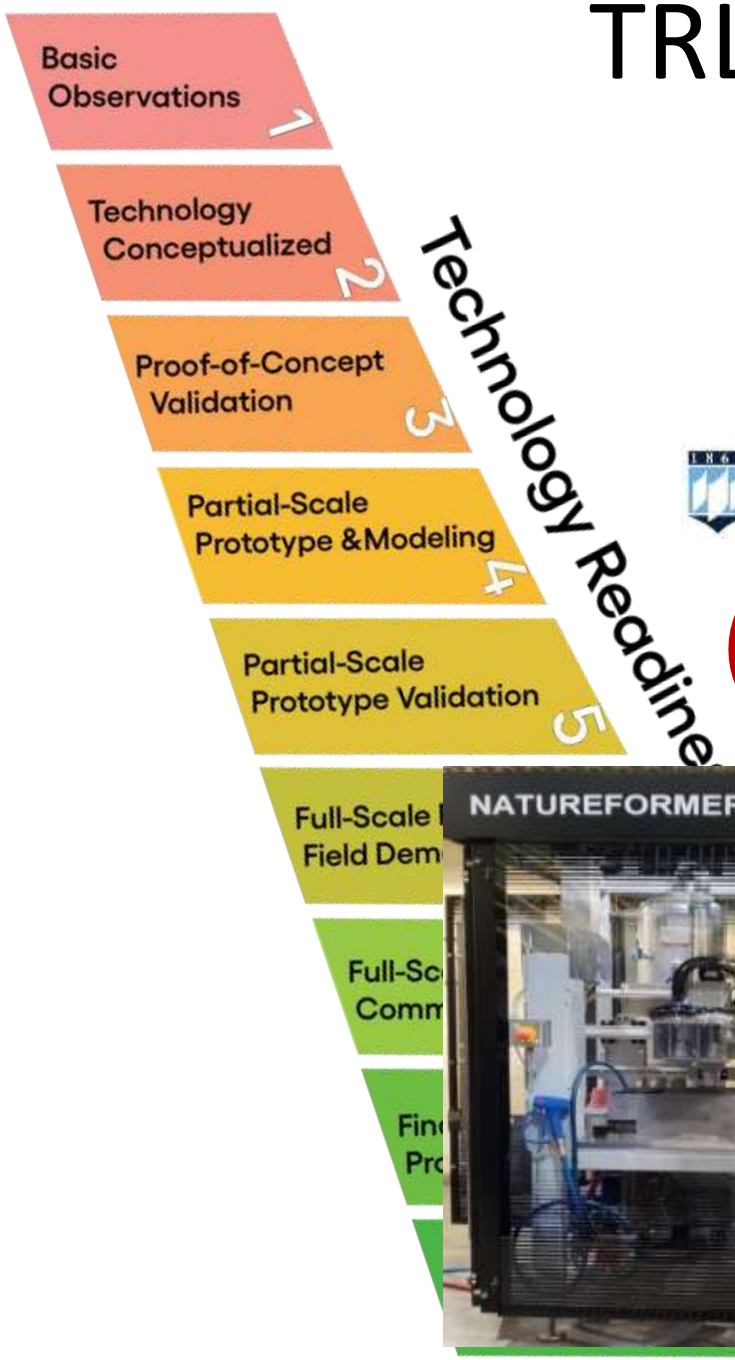


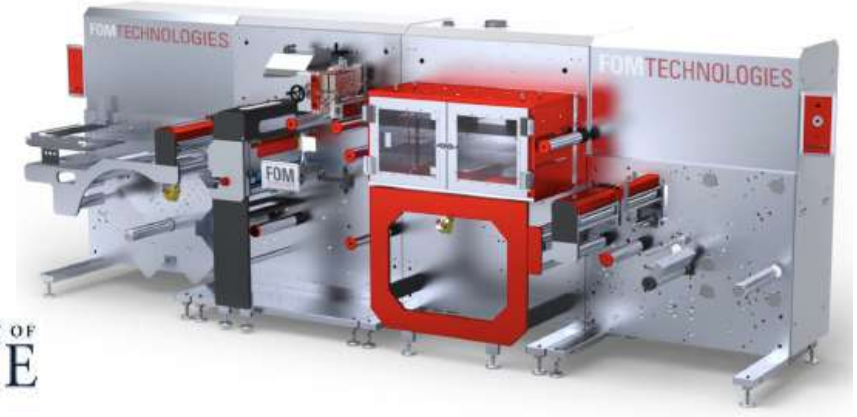
P³Nano Project TRL Overview





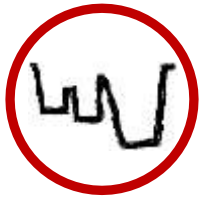
TRL 5 – Prototyping at scale

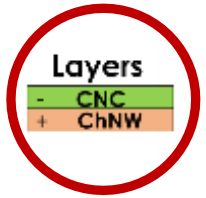






THE UNIVERSITY OF MAINE





Georgia Tech





Georgia Tech





MICHIGAN STATE UNIVERSITY

TRL 7 - Field Trials

Basic Observations









ness Levels

Full-Scale Prototype Field Demonstration 6

Full-Scale Prototype in Commercial Conditions 7

Final Commercial Product Certification 8

Final Commercial Product is Bank-Financeable 9



Full Scale Installations

Novel Uses

Technology Readiness Levels

1. Basic Observations
2. Technology Conceptualized
3. Proof-of-Concept Validation
4. Partial-Scale Prototype &Modeling
5. Partial-Scale Prototype Validation
6. Full-Scale Prototype Field Demonstration
7. Full-Scale Prototype in Commercial Conditions
8. Final Commercial Product Certification
9. Final Commercial Product is Bank-Financeable

Electronics



Pesticides



Sunscreen



Fruit Coating



Batteries



Passive Cooling



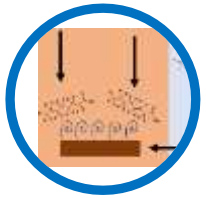
Fire Suppression



Soft Robotics



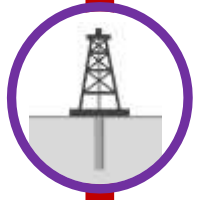
PFAS Filters



Frost Protection



Drilling Fluids



Active Projects

P³Nano

Funding:	~$7M
Active Projects:	**29**
• 2018-2023	21
• + 2026	8
Collaborations:	**24**
• Academia:	21
• Industry:	3
• Other:	0



Active Projects in 2026

Development (~$500K for 3 years)

1. Drilling Fluids	LSU
2. CNF-tableware	UMaine
3. Lidded trays	**Purdue**
4. CNC-barrier packaging:	GaTech
5. CNC size measurement-nZADS	GaTech
6. CNC-PU Foams at industrial scale	Uni Delaware
7. CN-paper substrates for electronics	UPenn
8. Scale up CNC-Protein fruit Coatings	Uni Houston
9. LCNFs for PFAS Removal	Uni Missouri
10. CNF – multi-layered barrier films	MSU
11. CNF-tropical fruit coatings	**UF & WSU**
12. EHS- CNF GRASS	**Vireo Advisors**

Active Projects in 2026

Exploratory (~$100K for 1 year)

1.	CNC enhanced veneer	MSU
2.	CNF for Fire-Fighting	UMaine
3.	CNF Enhanced Concrete	UMaine
4.	CNF for Passive Cooling	UMaine
5.	CNF for Soft Robotics	Duke
6.	CNF-based prills for Pesticides	Auburn Uni
7.	Functionalized CNs & Lignin for barrier	GaTech
8.	LCNF for recycled packaging	SUNY
9.	TEA for 4 CN application case studies	UW-Mad

New Projects Starting in 2026

Development (up to $500K for 3 years)

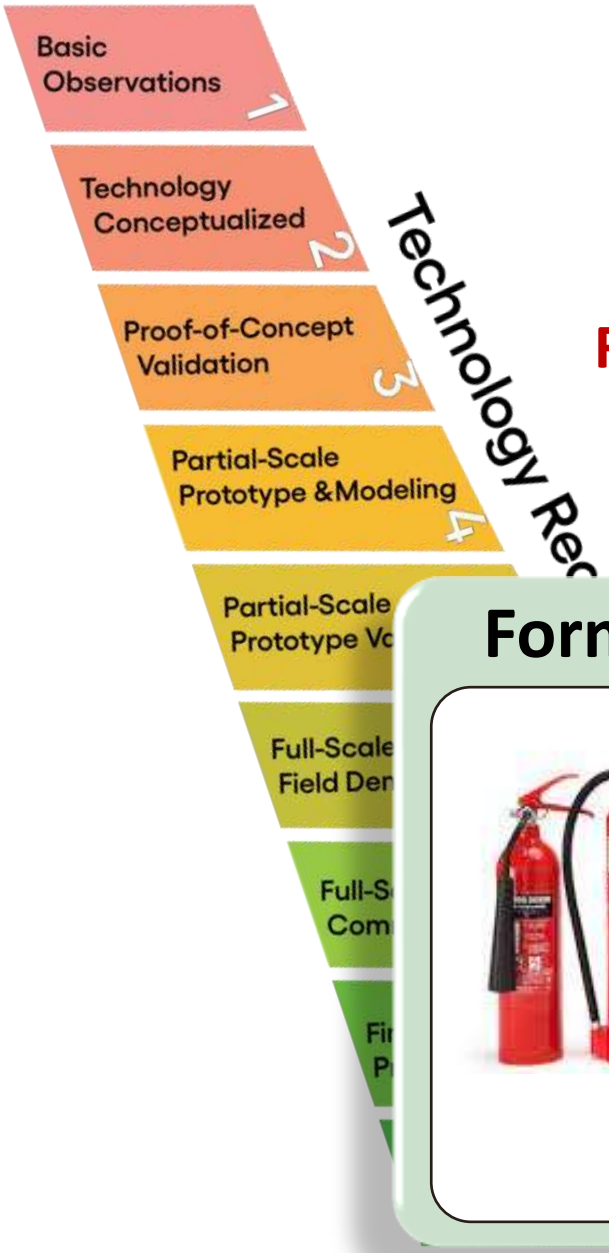
13. Scale-up CNF-based pesticides	Clemson
14. C-CNF for Grid Energy Storage	Yale
15. Scale-up CNF-enabled Molded Fiber	**UMaine**
16. CNF Safety Assessments for Regulation	Vireo Advisors

Exploratory (~$100K for 1 year)

10. Drying to Improve Dispersion	American Uni
11. Polymer-CNF for TPE reinforcement	**UMaine**
12. CNF-Encapsulated Polyphenolics for MP	SUNY-ESF
13. CNF-Foliar Nano-fungicides	UTK

29 Total Projects

CNF for Fire-Fighting Application



Fire-Fighting

- Noval Use

Exploratory Project:

- James Anderson (UMaine)
- Collen Walker (UMaine)
- Ron Sabo (FPL)

Formulation design, scale-up, delivery & demonstration



Class A, B, C

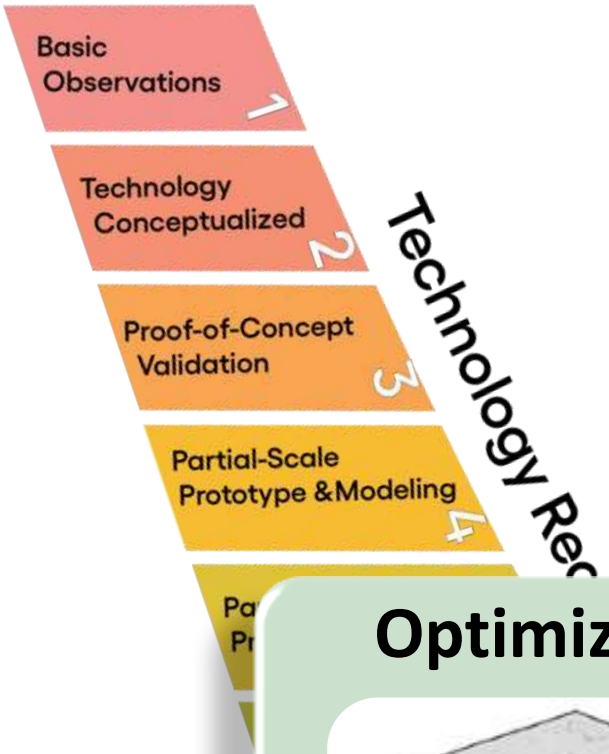


Municipal firefighting

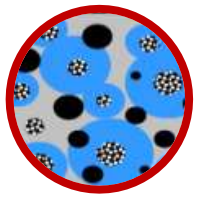
- 1% CNF
- Water-based system
- Extinguishes Faster
- Prevents Reignition

BioGel

Enhancing Internal Curing of Concrete from CNF



Internal Curing



- Concrete

Exploratory Project:

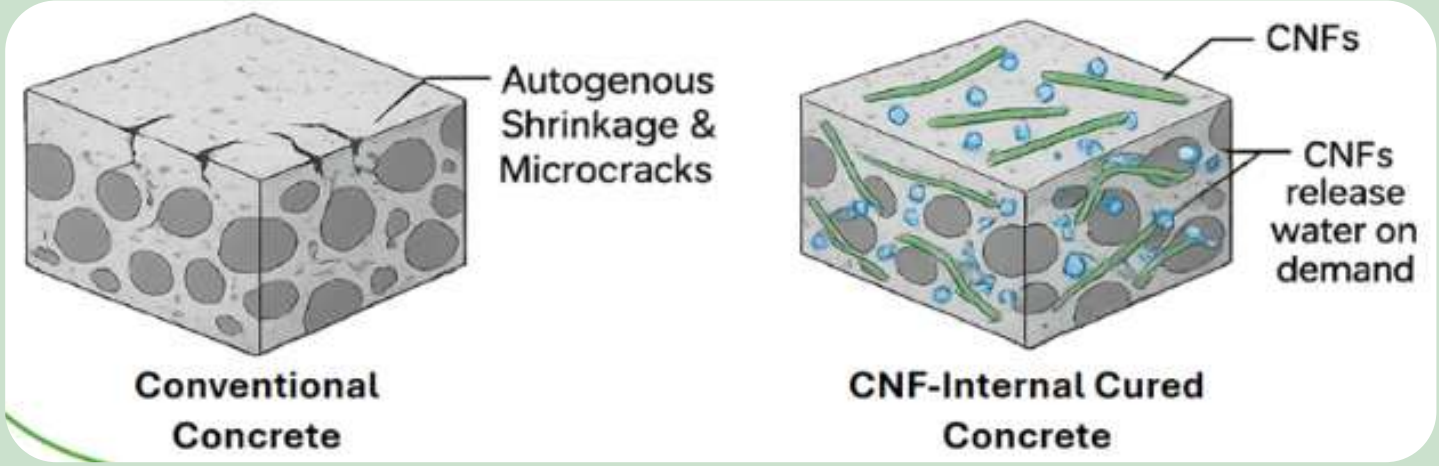
- Linfei Li (FIU)
- Eric Landis (UMaine)
- Collen Walker (UMaine)
- Jason Weiss (OSU)
- Robert Moon (FPL)

FIU FLORIDA INTERNATIONAL UNIVERSITY

THE UNIVERSITY OF MAINE

FOREST SERVICE UAS DEPARTMENT OF AGRICULTURE

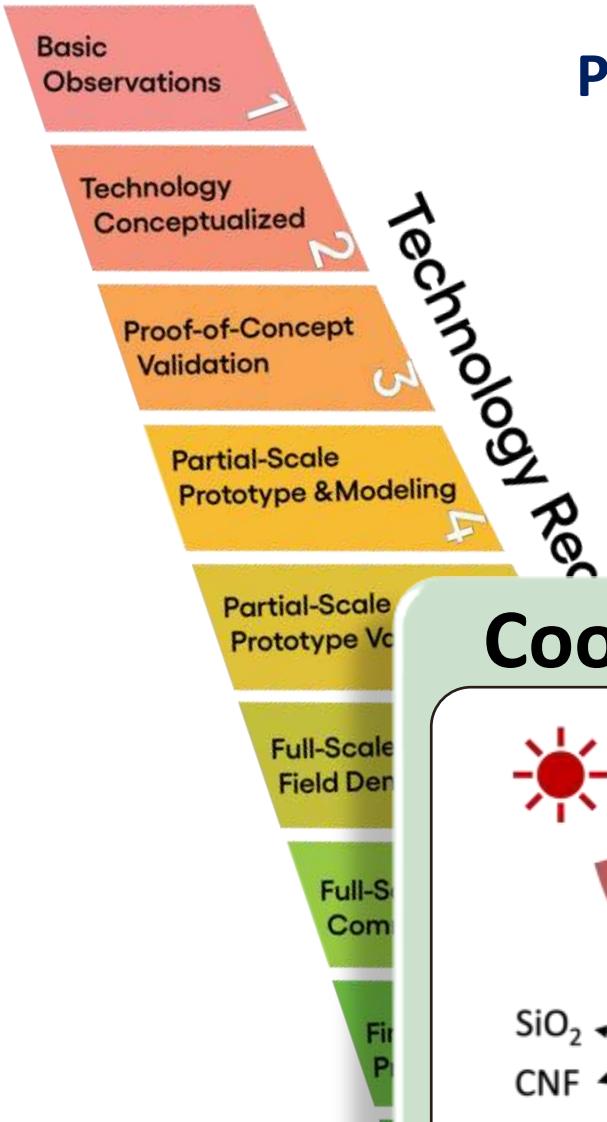
Optimizing Internal Curing



- CNF additions Increase
  - Desorption
  - Dispersion
  - Hydration Kinetics

- Minimize Shrinkage
- Improved Durability
- Increase Strength

CNF for Passive Cooling Food Packaging



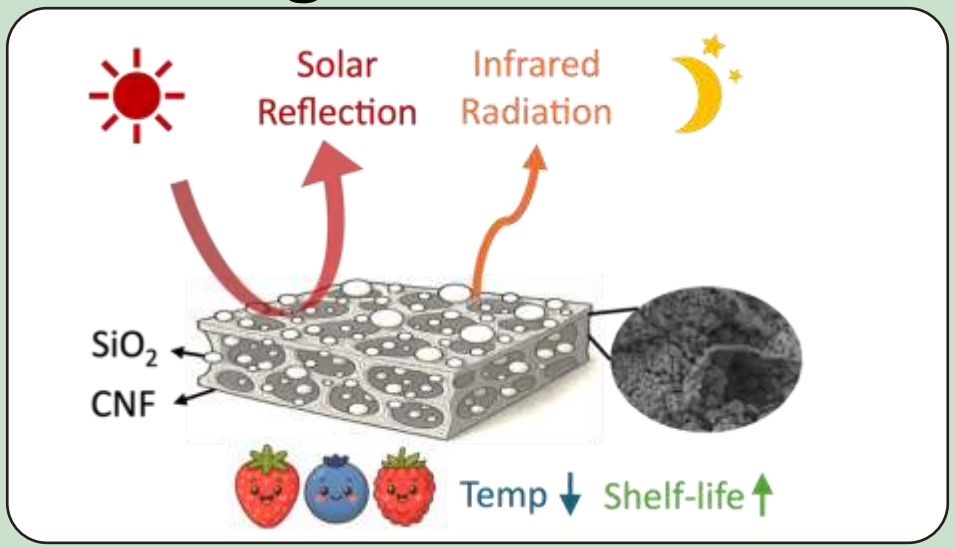
Passive Cooling

- Packaging
- Noval Use

Exploratory Project:

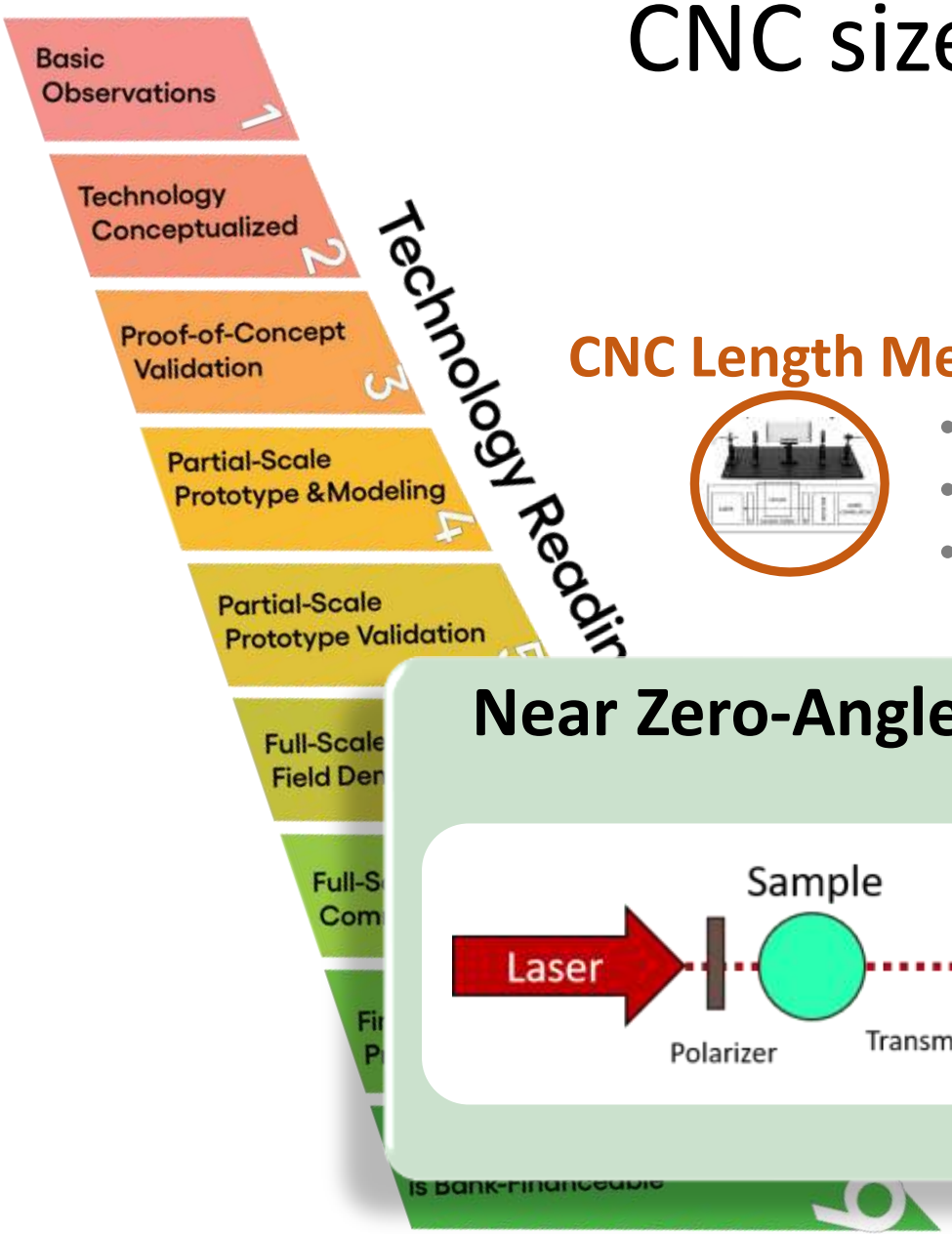
- Qing Jin (UMaine)
- Ling Li (UMaine)
- Collen Walker (UMaine)
- Yiming Feng (VT)
- Jinwu Wang (FPL)
- Jun Yang (PepsiCo)

Cooling without Electricity



- CNF as structural platform
- Controlled porous structure
- Increase Cooling by
  - Reflect Solar Radiation
  - Emit thermal radiation

Development of a rapid and robust instrument for CNC size distribution measurement



CNC Length Measurement

- Validation
- Production
- TEA/LCA

Development Project:

- Victor Breedveld (GaTech)
- Robert Moon (FPL)
- Carl Houtman (FPL)
- Nayomi Plaza (FPL)

Near Zero-Angle Depolarized Scattering (nZADS) Prototype



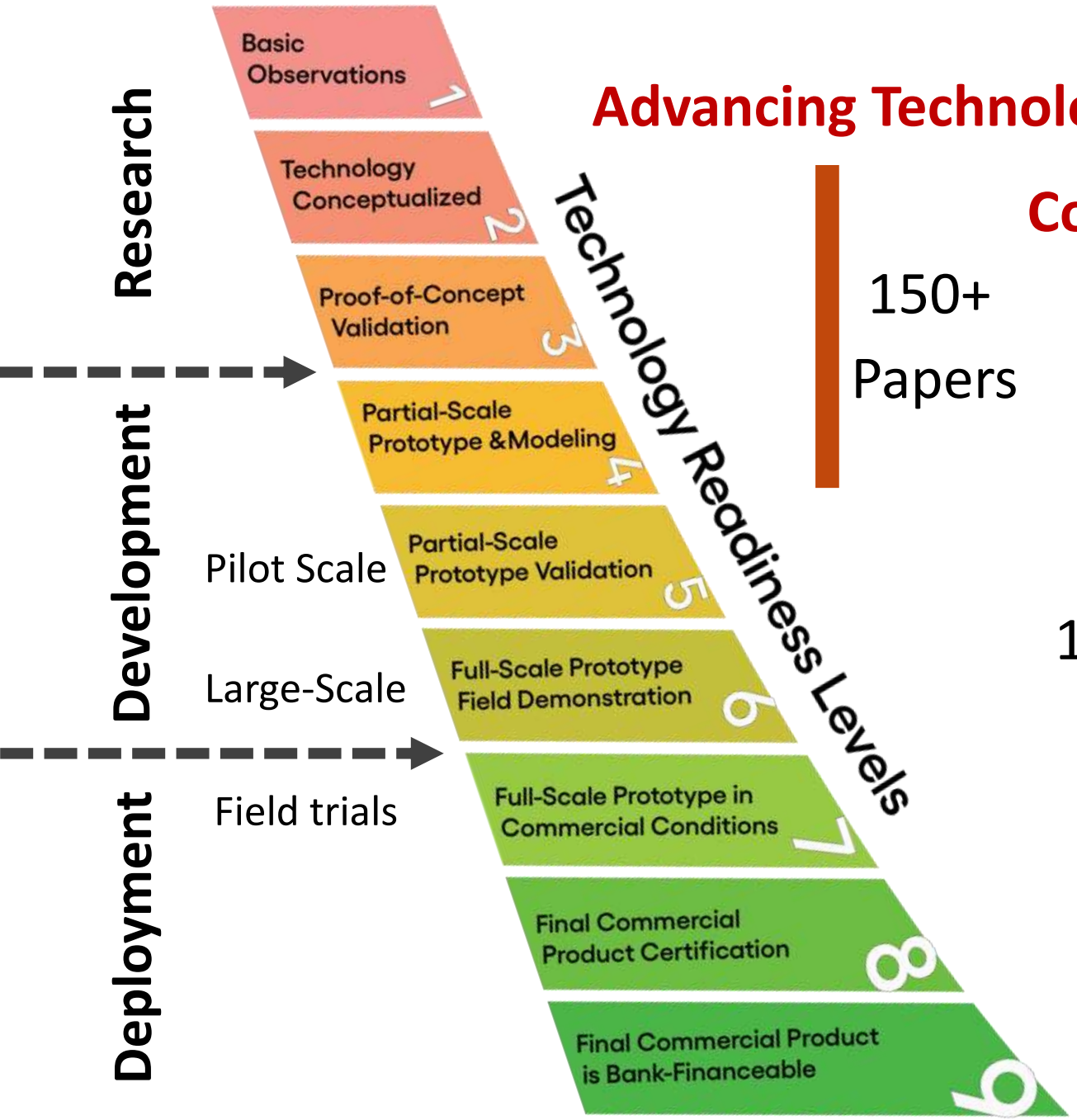
- vs DLS, MALS
  - Cheaper, faster, smaller
  - L=14”, W= 8”, H=6”
- Robust, simple to run
- Prototype I - soon
- < $20,000 Price Goal…

P3Nano

- Approach
- Portfolio
- **Highlights**
- 2027 RFP



P³Nano Output



Advancing Technology

150+ Papers

Commercial Utility

7 Patents
17 Applications

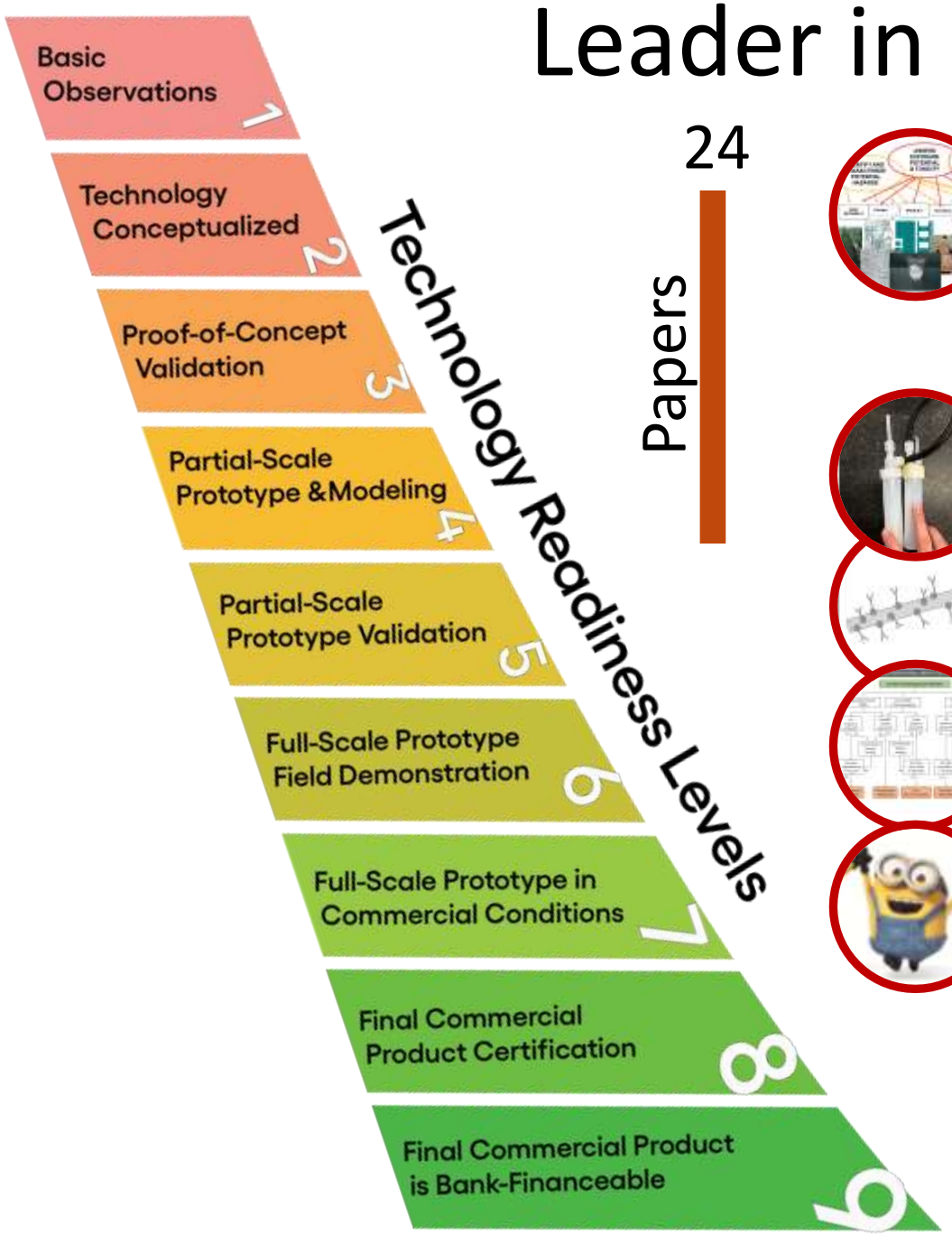
Technology Scale-up

12 Pilot Scale

Deployment

6 Field Trial

Leader in EHS



LCRA Road Map

Air Sampling
CN detection

Tagging CNs

Generally Regarded as Safe (GRAS)

CN Handling Guide

Development Projects:
- Jo Anne Shatkin
- James Ede

Vireo Advisors, LLC
Raising the Bar on Sustainability in Innovation

Toxicity testing





Safer-by-design toolbox
-functionalized CNs
- online data base



CN Materials Safety Data Sheet Templates

Application Highlights

Drilling Fluids



Rheology

Frost Protection



Coating

Particle Boards



Binder

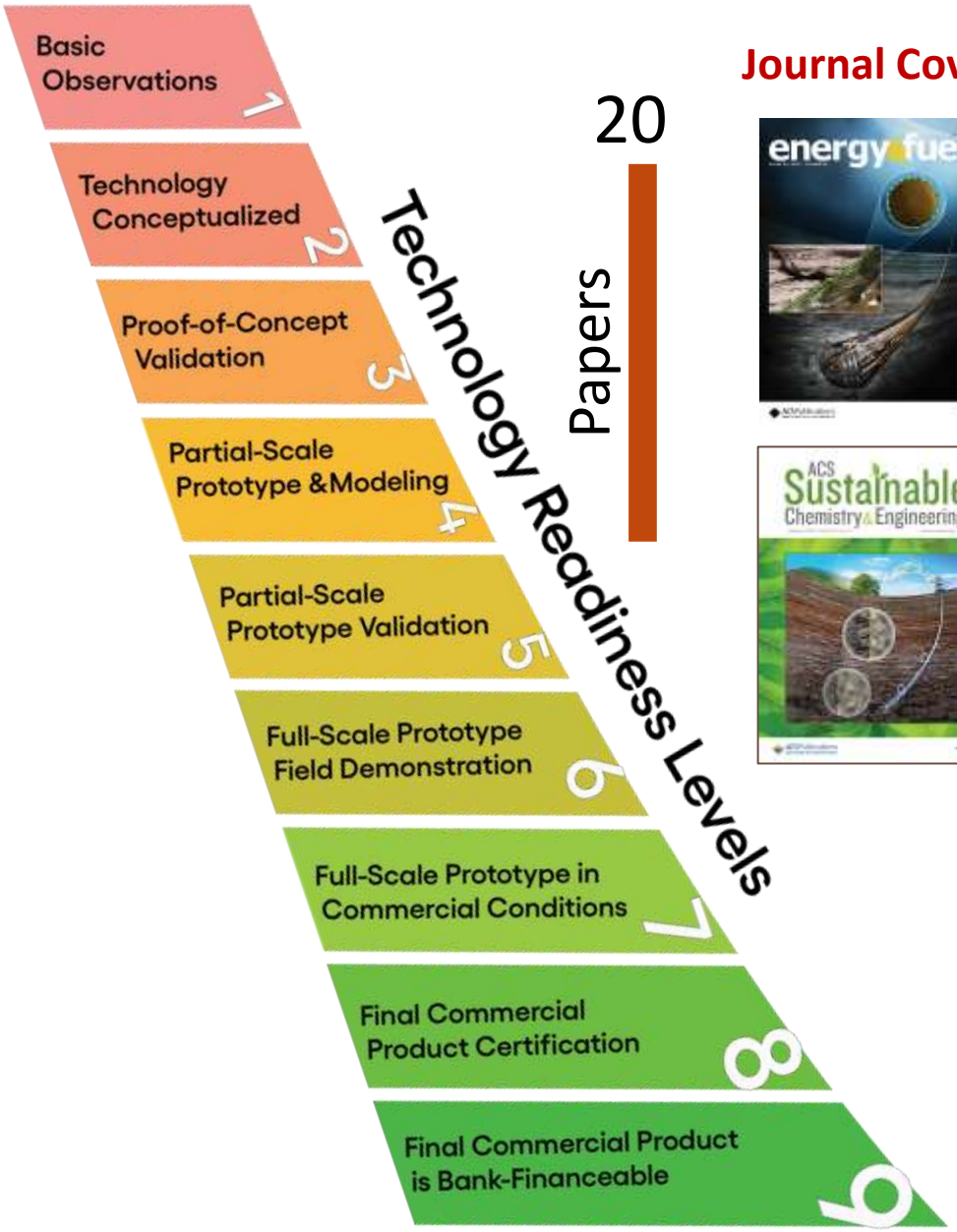
Concrete



It just works..

200nm

CN Additives for Drilling Fluids



20 Papers

Journal Cover

1/1 Patent Applications

1 Production



2 Field Trials

- **Alaska**
- **Oklahoma**

Development Projects (2):

- Qinglin Wu (LSU)
- Tom & JoAnn Parker (Hole Pluggers, LLC)
- Robert Moon (FPL)

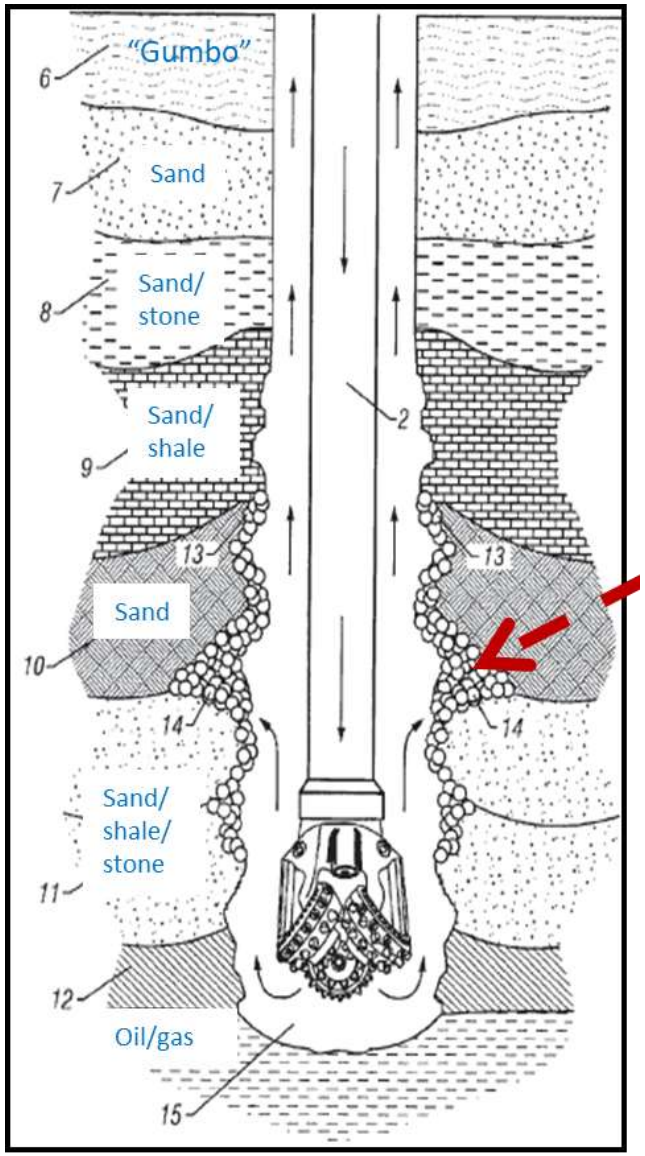
HOLE PLUGGERS, LLC LSU



Lignin CNF-Drilling Fluids

CN-Mechanism:

- Rheology –Shear Thinning
- Stabilizer
- Thermal/salt tolerant agent
- Minimize fluid loss



Limited by LCNF Production:

- Need local production on site
- 20-40 tons/yr

Frost Protection



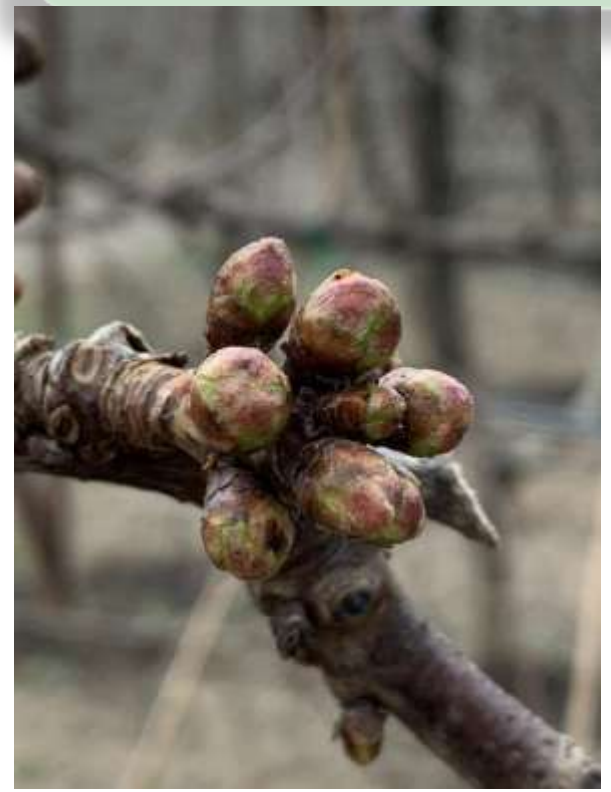
Development Project:

- Qi Wang, Sappi
- Xiao Zhang, Matt Whiting - WSU
- Jinwu Wang, Nicole Stark - FPL

Plant-Based Dispersions (PBDs)

Mechanism:

- Create insulating layer
- Modify ice crystal formation
- Flower Buds Survival:
  - More tolerant to colder peak temp
  - Less loss at given temp



P3Nano Achievements:

- Developed “M1”
  - Drop-in replacement of “H”
  - Scaled up production of “M1”
- **Reduced Cost by 75%**
- Large scale Field trials in 2022, 2023, 2024
- up to 5°C more cold tolerant

Good **Bad**



2023 Field Trials:

- 120 Standard Totes
- 17 Farms
- 400 acres

- Washington State
- Cherry, Apple, Grape

CN Enhanced Cement/Concrete



Development Projects:

- Prof. Jason Wiess, OSU
- Prof. Jeff Youngblood, Purdue University
- Dr. Carl Houtman, FPL
- Micheal Goergen, US Endowment

Oregon State University
PURDUE UNIVERSITY
UNIVERSITY OF TEXAS ARLINGTON
WISCONSIN UNIVERSITY OF WISCONSIN–MADISON
THE UNIVERSITY OF MAINE
TEMPLE UNIVERSITY
U.S. Endowment for Forestry and Communities
FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

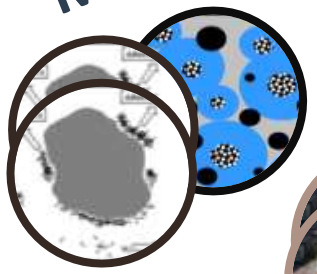
200nm

Cement/Concrete

Technology Readiness Levels

1 Basic Observations
2 Technology Conceptualized
3 Proof-of-Concept Validation
4 Partial-Scale Prototype &Modeling
5 Partial-Scale Prototype Validation
6 Full-Scale Prototype Field Demonstration
7 Full-Scale Prototype in Commercial Conditions
8 Final Commercial Product Certification
9 Final Commercial Product is Bank-Financeable

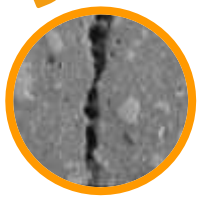
Mechanisms



Mixture Design



Durability



CO_2 Reduction



3D Printing



Full Scale Installations



Field Trials

Field Trials

- Full scale truck
- Sidewalk @FPL & @OSU
- Parking lot @ US endowment
- Bridge deck @ Yreka
- Dam Spillway @ Wildwood Farm















NBRC – Demonstration Grant

Northern Boarder Regional Commission (NBRC):

- "Nanocellulose-Enhanced Concrete Demonstration Projects"
- ~$2 Million over 3yrs
- Locally sourced pulp for CNC production. @FPL
- Locally sourced concrete, Local contractors, Local gov.

The Team

- VT Dept Forest Parks & Rec
- UNH Cooperative Extension
- UMaine - Shane O'Neill
- SUNY-ESF
- USFS-FPL -

7+ Demonstrations

- 1 Full scale truck
- ~400ft^2 area
- Slabs – ie.. Sidewalks
- VT(2), NH(2), NY (2), ME (1+)



P3Nano

- Approach
- Portfolio
- Highlights
- **2027 RFP**



— P³Nano —
FPL Internal RFP 2027

Anticipated 2027 Funding:	**$1.75 million**
Submission Deadline:	**9-Nov 2026** *
Review Deadline:	**14-Dec 2026**
***Official* - Announcement:**	**~ Jan 2027**
USFS Contracting:	**TBD -2027**

Project Category

Exploratory Projects: **FS-cash to cooperator** **$50-100K**

- ~1-2 year project
- TRLs 2 to 3
- Fundamental science, engineering, validation
- Explore new phenomena, mechanisms, solutions
- Or solve a specific barrier to commercialization

Development Projects: **FS-cash to cooperator** **$200-500K**

- ~2-3 year project
- TRLs 4 to 7 (ie, TRL 3 must already be met)
- Scaling up: Larger volumes, industrial systems
- Focused on addressing technical barriers to commercialization
- Need extensive relevant preliminary work (e.g. demonstrate TRL 3)
- Need Industrial collaborator(s)
- **No "If – Then" Proposals**. e.g. If x works, then we scale up

Goals of the RFP

Focus: Wood-Based Cellulose Nanomaterials

Build Collaborations:

- FPL scientists & US Cooperator (University and/or Industry)

Technology Development & Utilization:

- Build credible application & preliminary work
- Increase Technical Readiness Level (TRL)
- Industrial collaborator(s)

Strengthen FPL Emphases Areas:

- Construction materials, Packaging, Wood to value, Sustainability
- Enabled by Cellulose Nanomaterials

2027 Priority Categories:

- High CN volume applications
- CN R&D that supports pulp & paper industries

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How to get involved

Connect with FPL Scientist

- Must have FPL scientist with creditable role in project
- All contact and submission completed by FPL Scientist
- FPL website: https://research.fs.usda.gov/fpl/people

Contact:.

- Robet.j.moon@usda.gov
- Send copy of RFP
- Help with linking you to potential FPL Scientist(s)

— Questions—


Creating a
Sustainable Future
Through Forest
Products Research
and Development


Matoka!