Biologically Inspired Design for Industry: An Evolving Practice

Marsha Forthofer, Kimberly-Clark Corporation

Dr. Michael Helms, Georgia Institute of Technology

Image source: Stu Porter

Introductions

Marsha Forthofer

- Senior Scientist – Materials at Kimberly-Clark Corporation (K-C)
- B.S. in Chemical Engineering
- M.S. in Biomimicry
- Certified Biomimicry Professional from Biomimicry 3.8

Dr. Michael Helms

- Research Scientist, Georgia Institute of Technology (GT)
- Ph.D. in Cognitive Science
- Founder, PatternFox Consulting

Kimberly-Clark Georgia Institute of Technology patternfox Evolutionary Designs, Revolutionary Ideas.

Survey Question

Biologically Inspired Design (aka Biomimicry, Biomimetics, Bionics, etc.): the understanding and applying of *deep design principles found in biology.*

I believe the primary goal of biologically inspired design is to:

1. Generate more sustainable designs, or
2. Increase radical design innovation, or
3. Change the relationship between humans and nature, or
4. Generate interest and investment for biological research

K-C is leading the world in "Essentials for a Better Life"

Formed in **1872**

43,000 employees worldwide

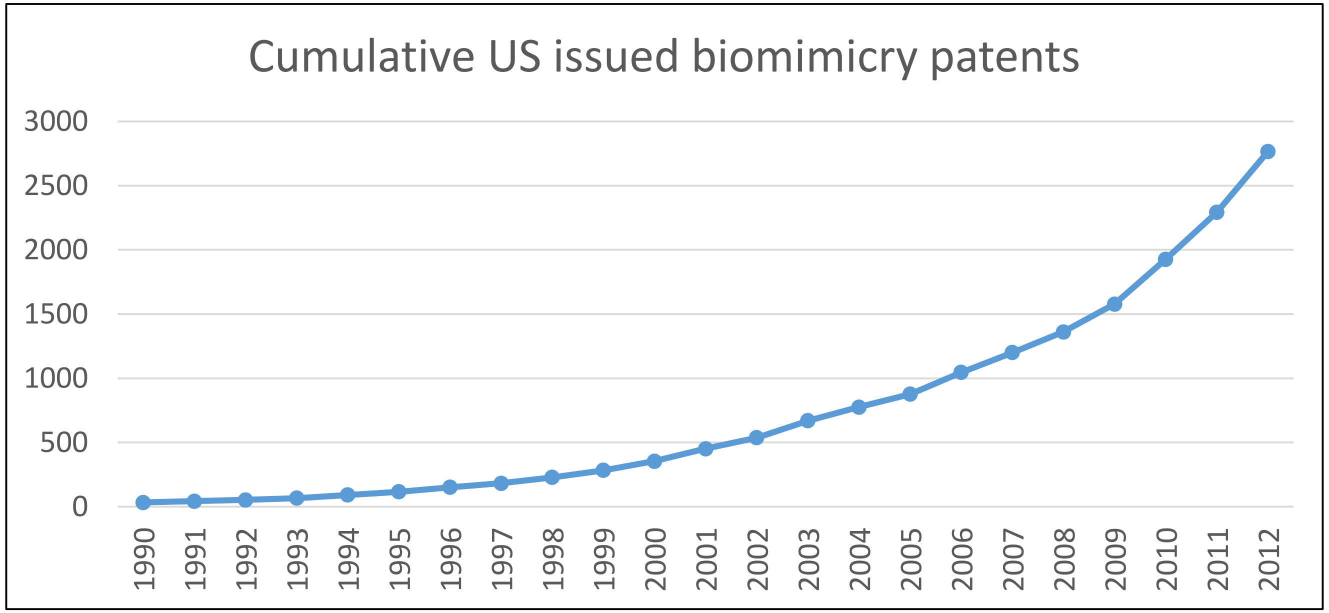
$18.6 Billion in Net Sales in 2015

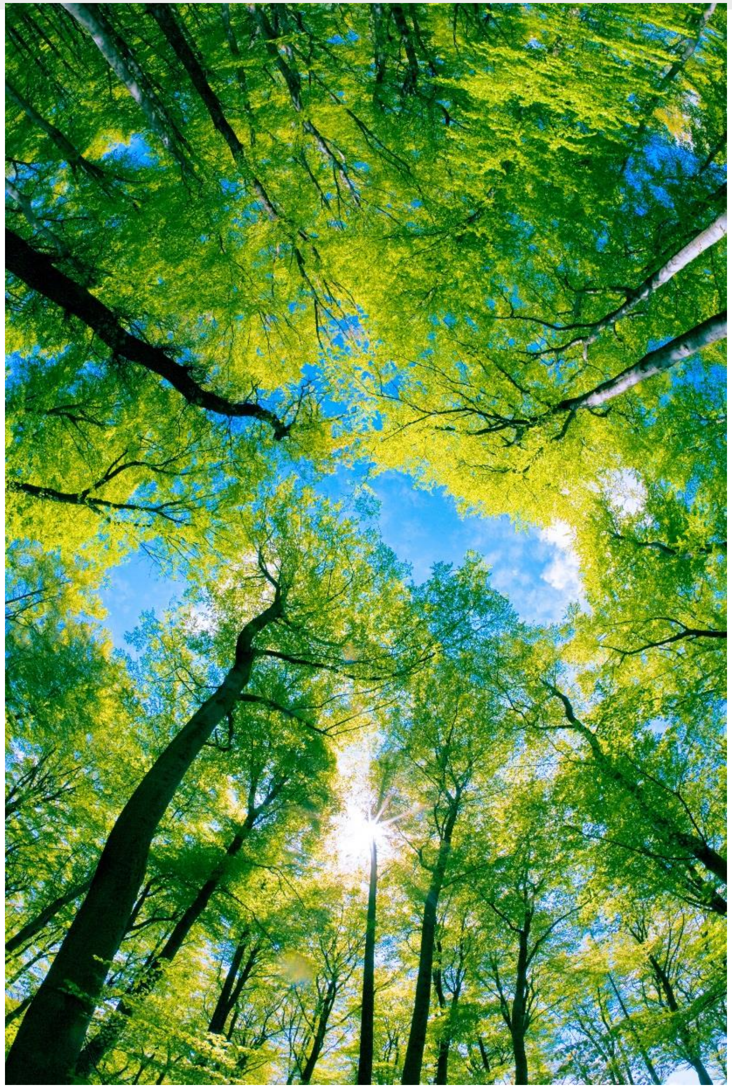
#1 or #2 share position in 80 countries

Nearly **one-quarter** of the world's population use our products daily

K-C learns from nature to develop new material innovations

The mission of K-C's Nature-inspired Materials platform is to develop new materials to enable K-C business plans and sustainability goals by discovering and translating nature's strategies.





Source: Shutterstock

We explored a “single-solution” approach

Known System

Source: Ben Goodwyn

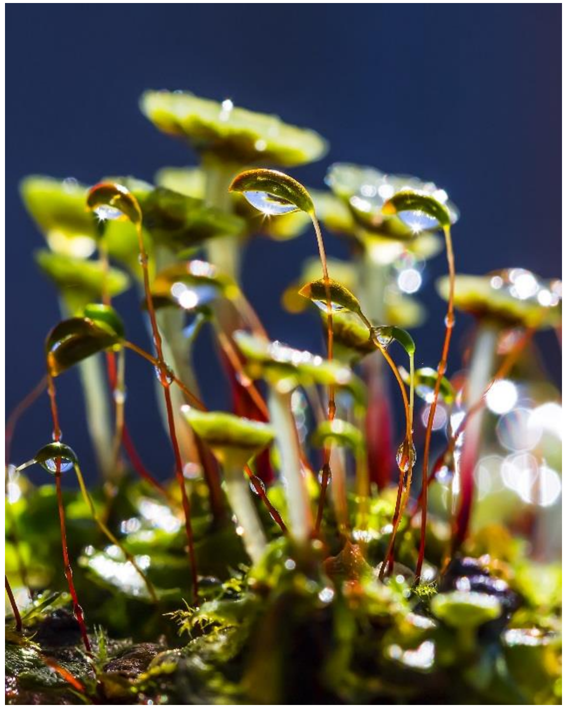
Relevant Problem:

Moving liquid unidirectionally

We explored a “problem-based” inspirational approach

Known Problem:

High humidity in the products leads to discomfort and skin health issues



Relevant Systems

Sources: Shutterstock

From our work, we identified key challenges and interests

- Key challenge: How do we translate a set of partially understood biological solutions to a product prototype?

- Other interests:
  - Gain exposure to other BID-related tools
  - Improve facilitation of the BID process
  - Understand key biological mechanisms

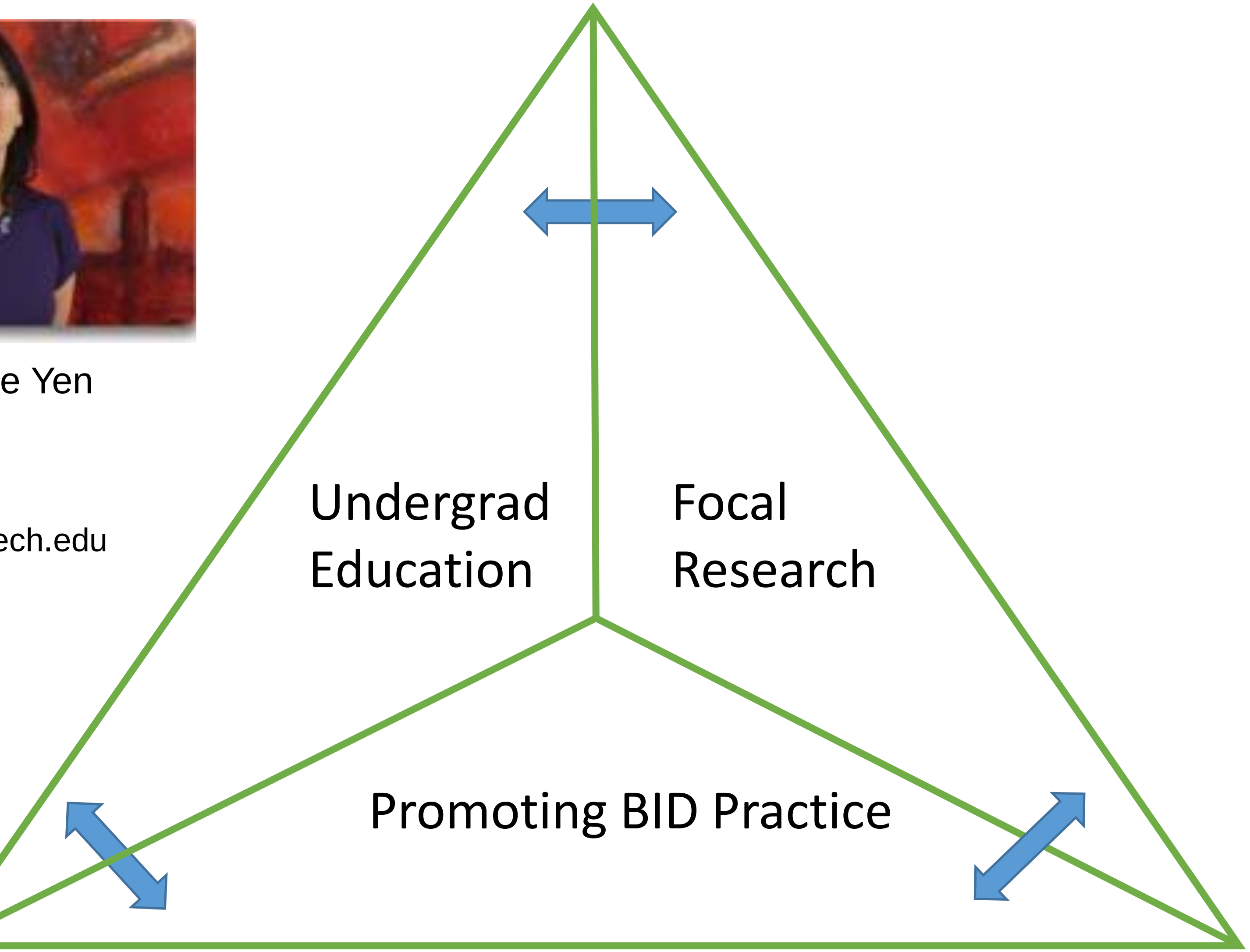
- We engaged with Georgia Tech's Center for Biologically Inspired Design in 2014 to address the key challenge and other interests.

center for biologically inspired design

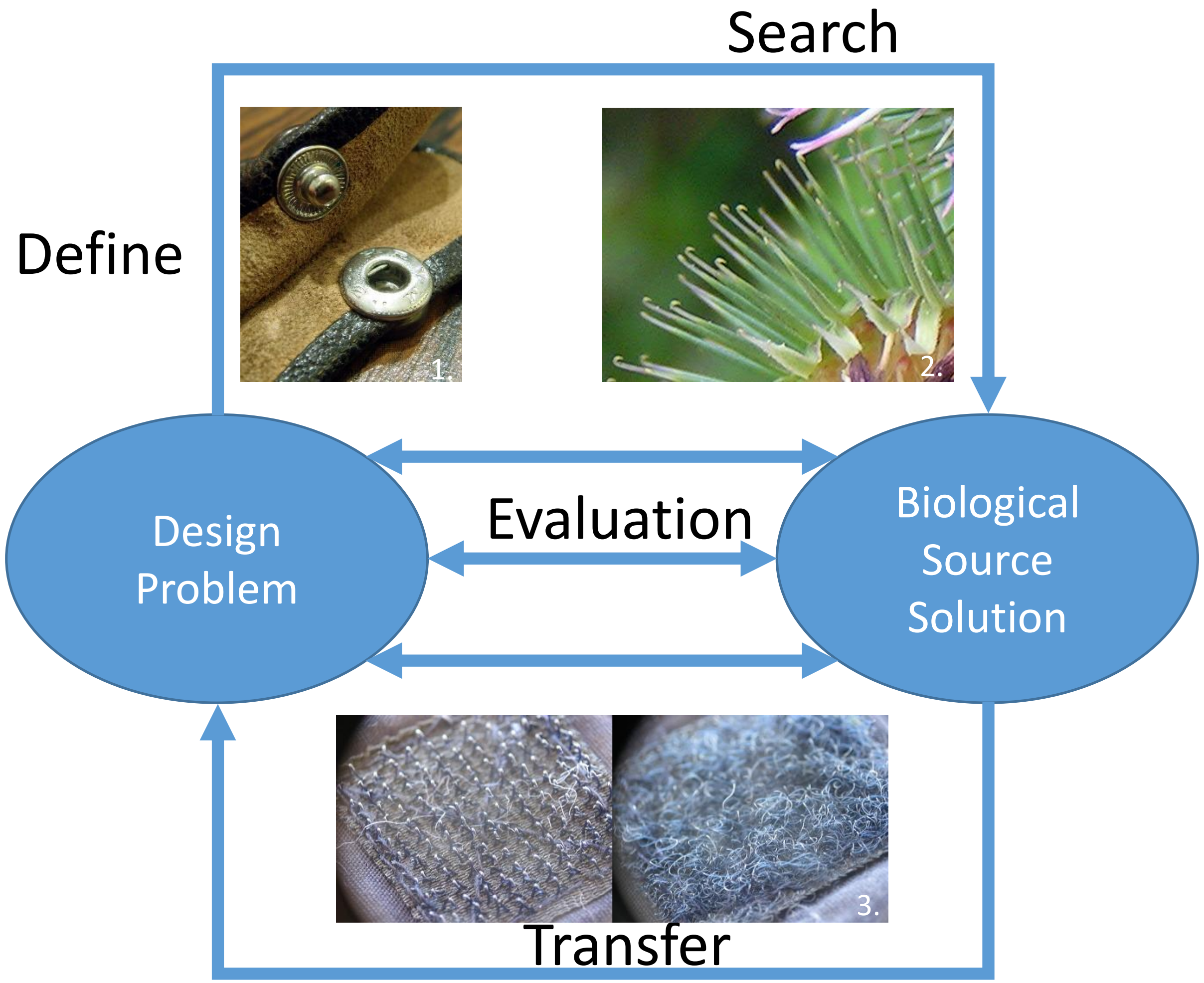
Center for Biologically Inspired Design
At Georgia Institute of Technology

Dr. Jeannette Yen
Prof. Biology
Director CBID

www.cbid.gatech.edu



The biologically inspired design process



Four key processes:

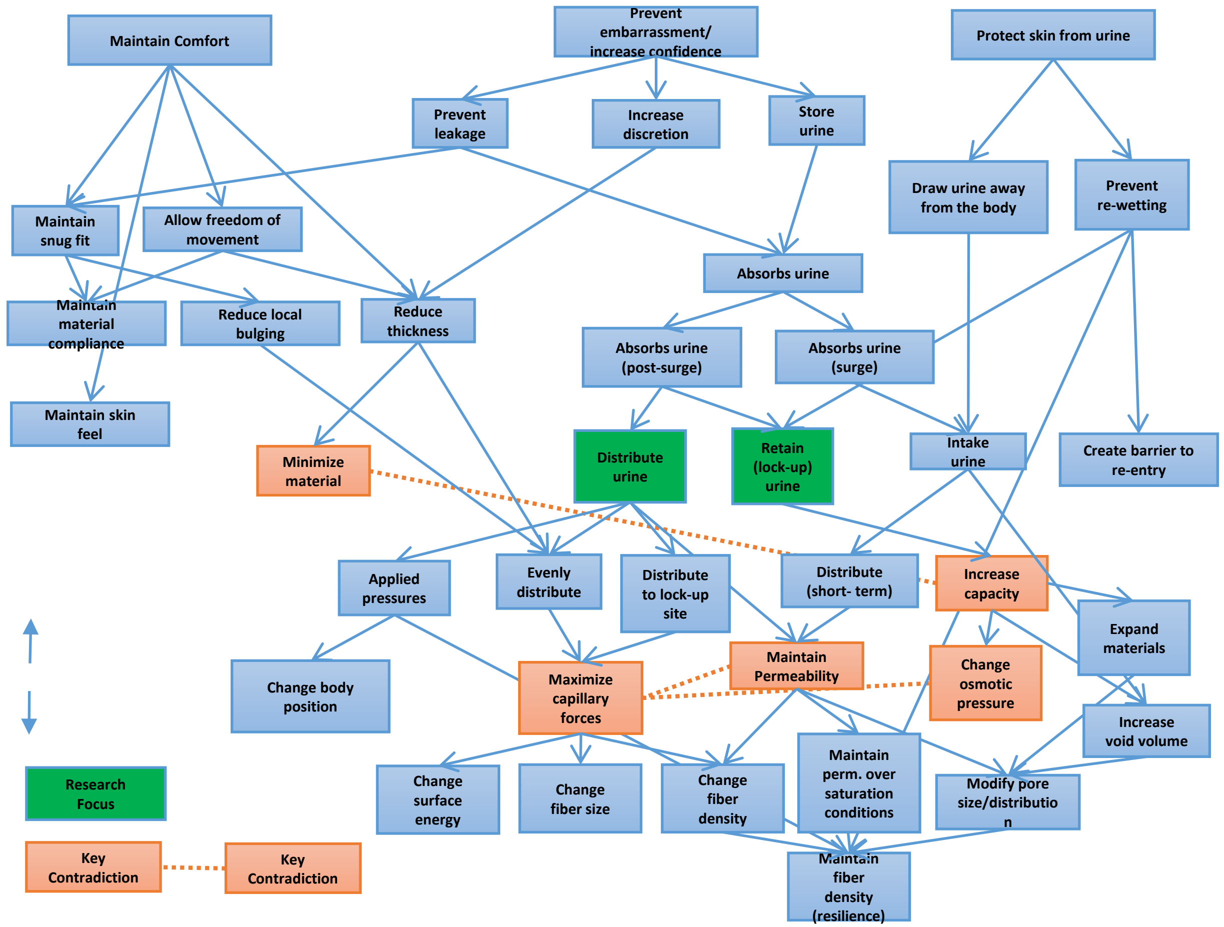
1. **Define** the problem
2. **Search** for biological solutions
3. **Evaluate** the match
4. **Transfer** principles to design

CBID and Kimberly-Clark engage on design project

Retention and Distribution Project: Kimberly-Clark Corporation desires to increase fluid distribution and retention in diapers and adult incontinence products. The functions of distribution and retention involve competing forces (capillary forces and permeability).

Humidity Management Project: Kimberly-Clark Corporation desires to *use specific material features to* reduce humidity at the skin-product interface layer to increase comfort and reduce irritation/rash.

Functional decomposition & 4-box problem specification



Operational Environment

- ~xx insults per use
  - Each insult xx-yy mL/s up to xx mL
  - Insult duration ~xx sec (+/- yy sec)
  - ~ xx minutes between insults
  - Urine
    - ~xx% Water
    - ~xx% urea,
    - ~xx% chloride, sodium, potassium
    - Some differences between adults/infants
    - pH xx – yy (avg. ~zz)
- In use warm (~xx °F)
- During transportation (xx°C – xx°C)
- Varying body positions, shapes, sizes, & movements
  - Varying applied pressures

Functions

- Absorb urine
  - Absorb surge
  - Absorb urine (over time/multiple insults)
- Distribute (free and loosely held) urine to retention points
- Retain (tightly held/locked-up) urine
  - Maintain void volume under pressure
- Dispose of urine
- Prevent leakage/seal
- Maintain freedom of movement
- Maintain comfort
- Maintain discretion (adults)
  - Minimize bulge
  - Minimize overall profile
  - Prevent/reduce odor
- Protect skin from urine (prevent exposure)
- Prevent urine from (prolonged) skin contact

Specifications/Materials

- Wearable undergarment
  - Child & Adult sizes (up to xx cm vertical distance)
- Comfortable against skin
- Compliant materials
- Non-toxic/non-allergenic
- Polymer/textile based
- Specialized surface modifications
- Specialized hierarchical structures (fiber organization)
- Fiber resiliency to maintain void volume
- Resource efficient, lightweight materials
- Low cost materials < $xx/per
- Layered manufacturing

Performance Criteria

- Leak proof (xx%) over multiple (xx+) insults
- Absorb surge within ~xx seconds
  - >xx ml/cm^{2}s
  - xx-yy Darcy
- Absorb & retain multiple insults (xx+)
  - xx mL/cm^3
  - SAM xx g/g; fluff xx g/g
  - SAM/fluff xx-yy Darcy
- Retain over pressures [xx-yy kPa]
- Vertical distribution: distance xx-yy cm
- Vertical distribution: pressure xx-yy kPa
- Surface wetness measures [challenging]
- Aesthetically pleasing/attractive

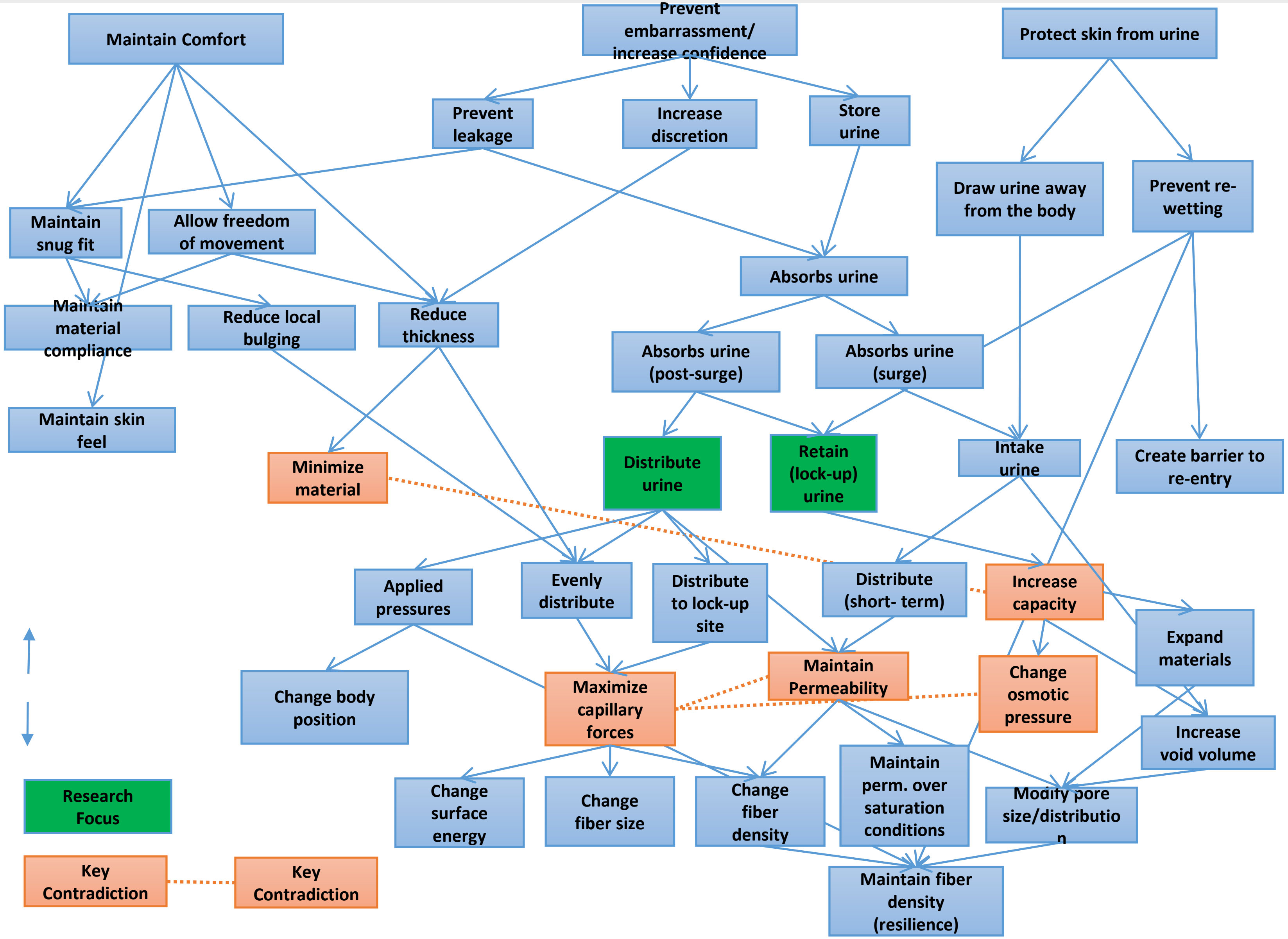
Problem Definition

Key Benefit:
Re-representing the design problem to facilitate search and evaluation specifically for biologically inspired design.

Key Insight:

Functional decomposition provides a visual representation of the problem space. It allows us to identify explicit trade offs, and focus exploration.

Systematic search guided by functional decomposition



Systematic search results in patterns of key principles

Relative Humidity (Aeration)

Temperature Gradient (Temp. Gradient)

Laplace Pressure (LP)

Partial Vapor Pressure (PVP)

Biological Discovery 1(Disc1)

Biological Discovery 2(Disc2)

Organism	Principles
Organism 1	Temp. Gradient, LP
Organism 2	Temp. Gradient, LP
Organism 3	Temp. Gradient, LP
Organism 4	Temp. Gradient, LP
Organism 5	LP, Disc1
Organism 6	PVP, Disc1
Organism 7	LP
Organism 8	Aeration, Temp. Gradient
Organism 9	LP, PVP
Organism 10	LP, PVP, Reaction
Organism 11	LP, PVP
Organism 12	LP, PVP
Organism 13	LP, PVP
Organism 14	LP/Disc2
Organism 15	LP/Disc2

Search results and key levers for Humidity Management

Search

Key Benefit:
Systematic search results in an exhaustive exploration of the problem domain, resulting in deep and broad problem insight.

Key Insight

Understanding what you find in search requires integrating other disciplines into the work – its not just about the biologists perspective. You need to apply scientific rigor to understand the biology deeply.

We systematize and quantify evaluation using 4-box criteria

Organism	Total Score	Func.	Env.	Mat.	Size	Perf.
Organism 1	16	2	2	2	5	5
Organism 2	12	2	2	2	4	4
Organism 3	14	2	3	2	4	3
Organism 4	15	2	3	2	4	4
Organism 5	14	1	2	4	5	2
Organism 6	8	1	3	--	2	2
Organism 7	14	1	3	5	3	2
Organism 8	17	4	2	3	5	3
Organism 9	14	3	3	--	5	3
Organism 10	14					
Organism 11	16					
Organism 12	17					
Organism 13	17					

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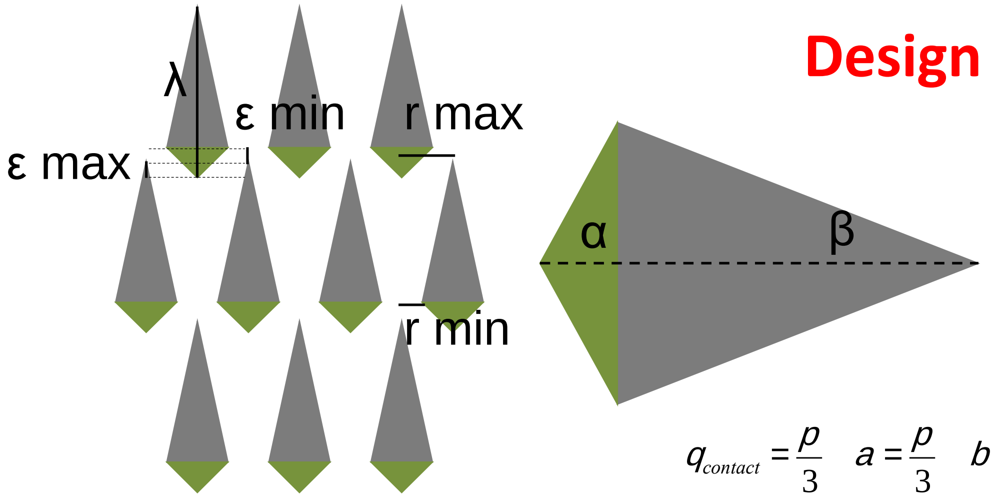
- Dispose of urine

Design Concept



$$q_{contact} = \frac{p}{3} \quad a = \frac{p}{3} \quad b = \frac{p}{12}$$

$$r_{\min} = 1.8 \cdot 10^{-6} \text{ m}$$

Minimum squeeze resistance of 20 kPa

Maximum squeeze resistance of 60 kPa

$$r_{\max} \geq 1.90 r_{\min} \quad \text{let } r_{\max} = 4 r_{\min}$$

$$e_{\max} = 0.131 r_{\max} = 0.524 r_{\min}$$

$$l \approx (r_{\max} - r_{\min})(4.31) = 12.9 r_{\min}$$

$$V_{tot} \approx 4.00 \cdot 10^{-5} \sqrt{t} \text{ m}^3 = 4.00 \cdot 10^{-2} \sqrt{t} \text{ L}$$

$$t \approx 625 \cdot \left(\frac{V_{tot}}{\text{L}}\right)^2 \text{ s}$$

Specific theoretical result

$$\boxed{\rightarrow \underline{0.3 \text{ L in } 56 \text{ s}} \quad \text{and} \quad 0.9 \text{ L in } 506 \text{ s } (8.5 \text{ min})}$$

Evaluation Matrix and Quantitative analysis for Retention and Distribution

Quantification and Evaluation

Key Benefit: A quantified set of design principles considered systematically in the design context.

Key Insight

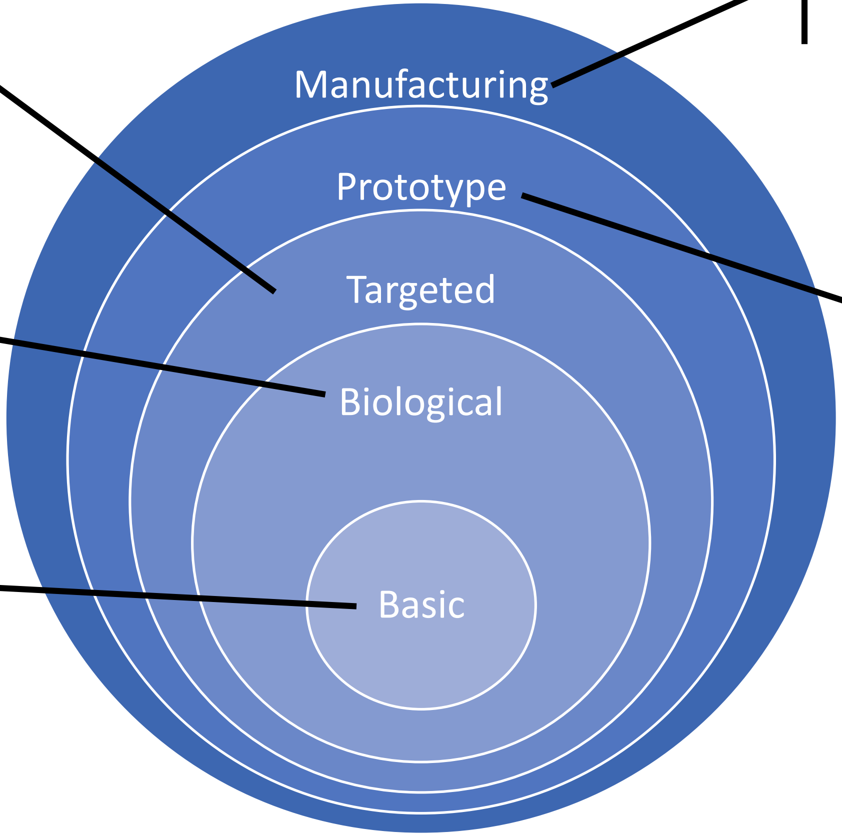
The matrix provides a systematic way to analyze analogies. Instead of “this looks interesting,” it provides a framework for decision making.

We develop recommendations for transfer based on the "biological readiness level" (BRL).

Identifying how different variations and patterns of underlying structures yield results

Discovering the underlying physical structures of the mechanism

Discovering the underlying principles of the mechanism



Learning how to produce at scale and cost, within existing manufacturing constraints

Applying patterns and variations to instantiate a product optimized for context

Research call for proposal (CFP)

CFP Components	
Background	Problem definition
	Biology background
Research	Understanding structure and mechanism
	Computational and theoretical modeling of phenomena
	Small scale manufacturing techniques
	Bench testing against predicted results

Transfer

Key Benefit: Provides a current assessment and path forward.

Key Insight

The CFP crystalizes your understanding of the key biological principles & provides a translation of the output of the BID process into a format that others can use.

Kimberly-Clark Current Results

- Most mature BID project is moving into ***year 5***, and has achieved some internal momentum.

- Currently funding two new lines of research with academic partner institutions as a result of this work.
  - Targeted/prototype research

- Investigating means of “seed funding” for a third line of research.
  - Basic/biological research

The Evolution of Industry Application

1. Improving processes

2. Shifting challenge point

3. Evolving culture

Thank you.

Image source: Shutterstock

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<u>Dr. Michael Helms</u>

Georgia Institute of Technology

PatternFox Consulting

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Kimberly-Clark Georgia Institute of Technology patternfox Evolutionary Designs, Revolutionary Ideas.

Key Skills

Problem Definition	Search & Indexing	Evaluation	Transfer
Problem specification	Biology knowledge and experience	State-of-the-art manufacturing knowledge	Pattern identification
Problem decomposition	Engineering-to-biology translation	Deep science - physics, chemistry, etc.	Biological research techniques and capabilities
Problem abstraction	Biological literature review	Conceptual design	Theoretical and computational modeling
Technical engineering & manufacturing knowledge	Biological science, physics, chemistry, etc.	Quantitative analysis	Prototyping
Customer & market knowledge	Relationship/network management	Dealing with ambiguity	Research for design
	Flexibility		Research management

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- Disposable materials

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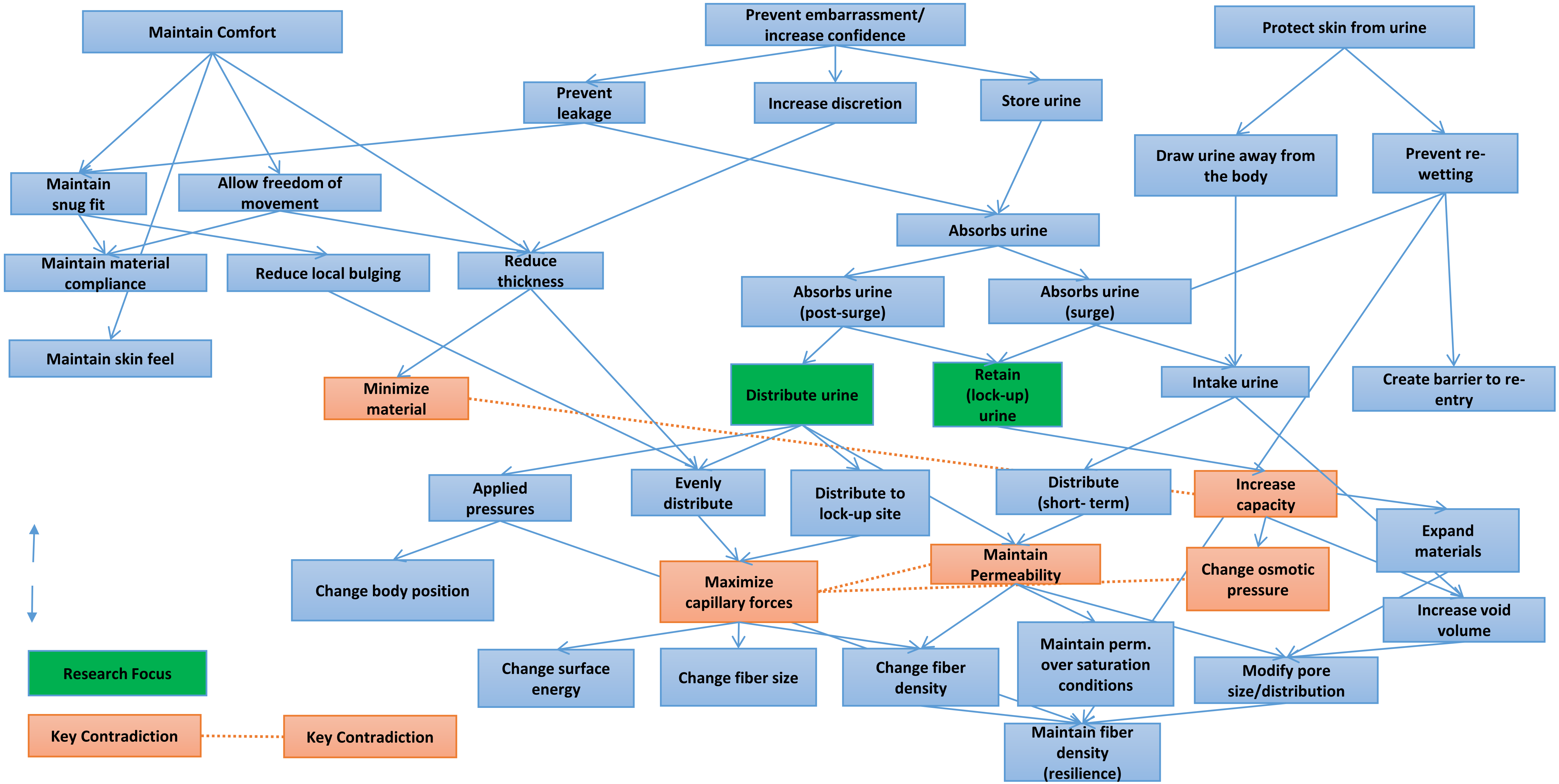
Maintain Comfort
Prevent embarrassment/ increase confidence
Protect skin from urine
Prevent leakage
Increase discretion
Store urine
Draw urine away from the body
Prevent re-wetting
Maintain snug fit
Allow freedom of movement
Absorbs urine
Maintain material compliance
Reduce local bulging
Reduce thickness
Absorbs urine (post-surge)
Absorbs urine (surge)
Maintain skin feel
Minimize material
Distribute urine
Retain (lock-up) urine
Intake urine
Create barrier to re-entry
Applied pressures
Evenly distribute
Distribute to lock-up site
Distribute (short- term)
Increase capacity
Expand materials
Maintain Permeability
Change osmotic pressure
Change body position
Maximize capillary forces
Increase void volume
Maintain perm. over saturation conditions
Change surface energy
Change fiber size
Change fiber density
Modify pore size/distribution
Maintain fiber density (resilience)
Research Focus
Key Contradiction
Key Contradiction

We evaluate system match to problem specification

4-Box Criterion	Very High (5)	Very Low (1)
Function	Matches one or more core functions, and one or more sub-functions (deep tree)	Does not match functions
Environment	Exactly matches more than one key condition, and closely matches multiple others	Does not match any key conditions
Specification: Materials	Material/system can be manufactured now, cheaply	Materials cannot be manufactured with existing methods
Specification: Size	Physical size is same order of magnitude	Physical size is two or more orders of magnitude difference or effect will not transfer at scale
Performance: Scale	Performance is better than or at same scale for key function	Performance two or more OOM greater or cannot possibly improve current performance

Management Expectations, BID materials design project

Team composition

1. Product designers & engineers
2. Biologists
3. Research scientists
4. Strong networking & communication skills

Timelines

1. 3-6 months for described process
2. 2-6 years of research, depending on bullseye

Investment cost

1. Described process: $25k-$200k
2. Academic research partnerships (post-doc): $150-$250k/year
3. Total development cost through prototype: $350k - $2M

This will vary by research domain and BRL.