A system dynamics model of early-stage transition dynamics in the bioproducts industry

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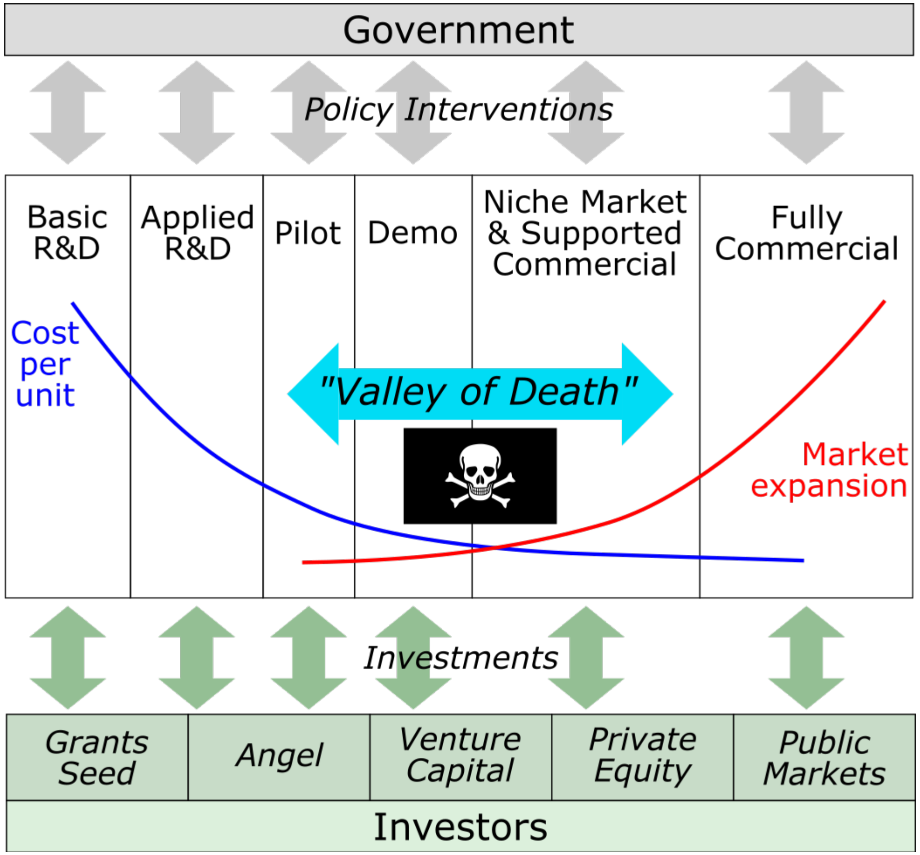
Technology Development Process



Adapted from Bürer and Wüstenhagen, *Energy Policy*, 37 (2009)

- How do developer-investor interactions and other factors impact low TRL stages of bioproduct development?
- (How) Can the likelihood that a bioproduct reaches commercial production, or is sold as IP, be influenced, and by whom?

Technology Readiness Level (TRL): Numeric representation of technology maturity, from 1 (beginning of applied R&D) through 9 (technology fully developed and at operational scale)

Bioproduct Transition Dynamics Project

Objectives

Understand the environment and drivers that impact bioproducts industry growth: **investor decision-making**, **bioproduct techno-economics**, and **end use factors**

Identify **synergies** between the **bioproduct and biofuel industries**

Outcomes

Transparent, analytic **system dynamics model** of early-stage industrial transition dynamics in the bioproducts industry

Why System Dynamics Modeling?

While systems are…	…our thinking processes often…
Constantly changing	…are static, equilibrium oriented
Tightly coupled/interdependent	…draw very narrow boundaries around issues and problems
Rich in feedback	…treat drivers of performance as external and independent
Nonlinear	…assume linear responses
History dependent	…neglect to consider path dependence, accumulations, and delays
Adaptive and evolving	…fail to pay sufficient attention to the sources of unintended consequences

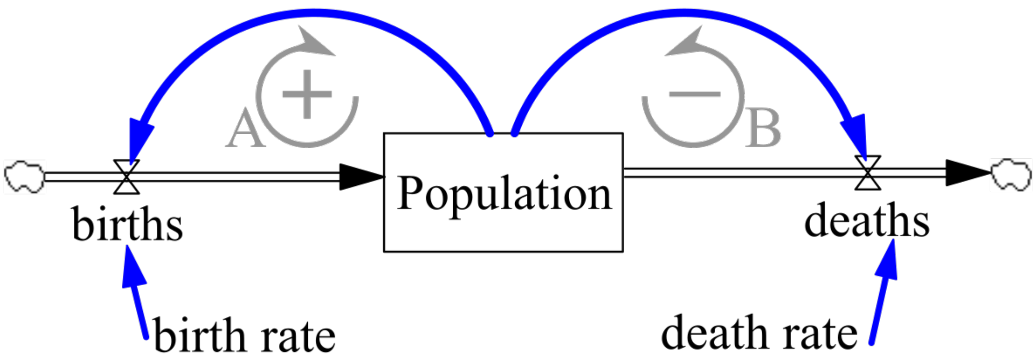
Adapted from Sterman, *Am J Public Health*, 96:3 (2006)

Introduction to System Dynamics

System Dynamics Model

A system of coupled, nonlinear, first-order differential or integral equations

- SD models are based on system structures and capture patterns of behavior



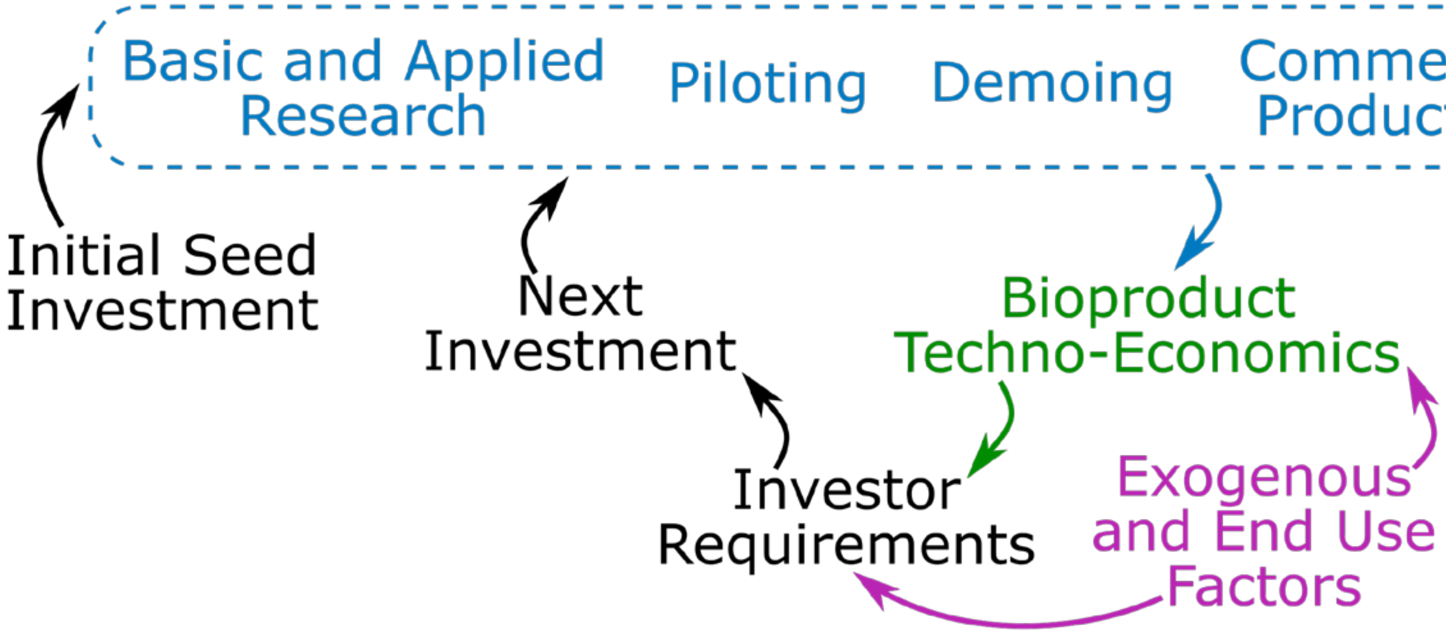
$$births(t + dt) = birth\ rate\ \times Population(t)$$

$$deaths(t + dt) = death\ rate\ \times Population(t)$$

$$Population = \int_{t_0}^{t} [births(t) - deaths(t)]dt$$

- **Flows** (*births*, *deaths*) are the rates of change of stocks
- **Stocks** (*Population*) are the integrals over time of flows
- **Feedback loops** (*A*, *B*) exist among stocks, flows and model parameters
- Feedback loops are either *reinforcing* or *balancing*
- A is *reinforcing*
- B is *balancing*

BTD Model Structure



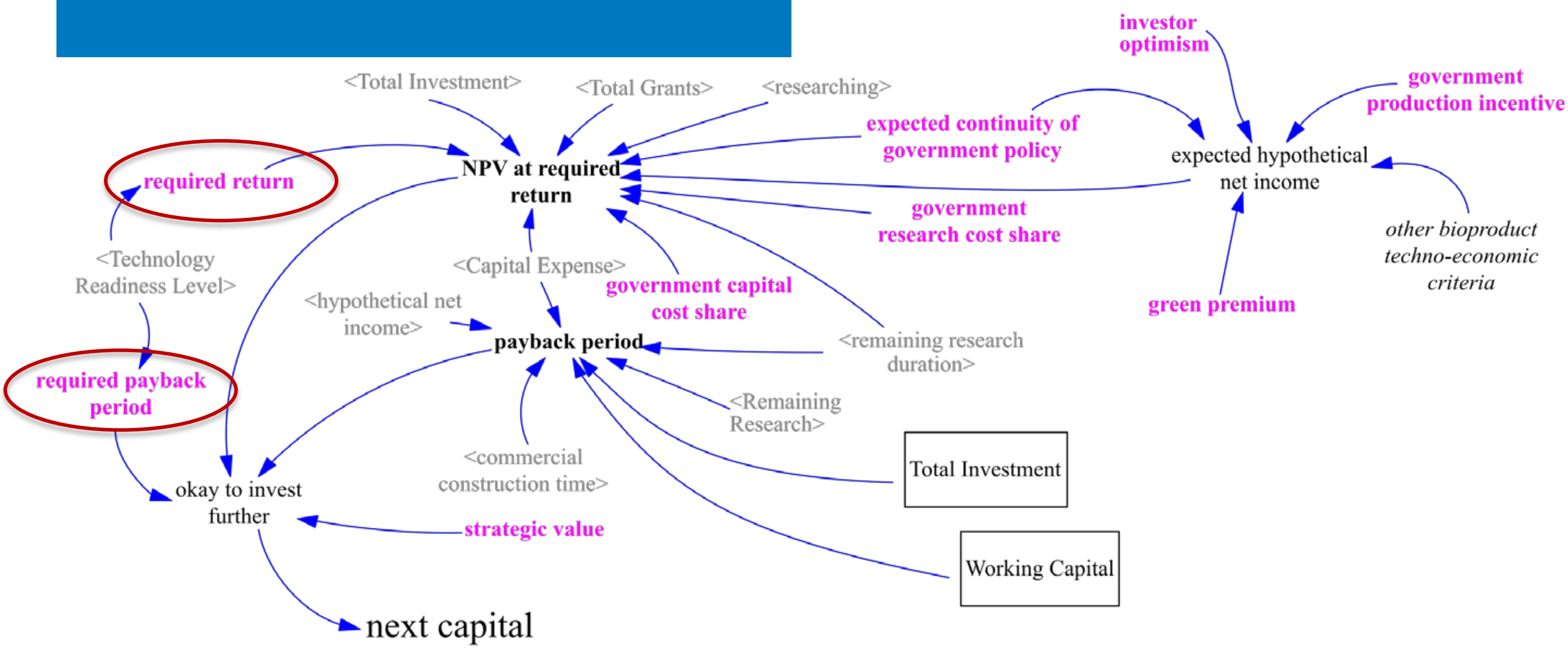
Actors include…

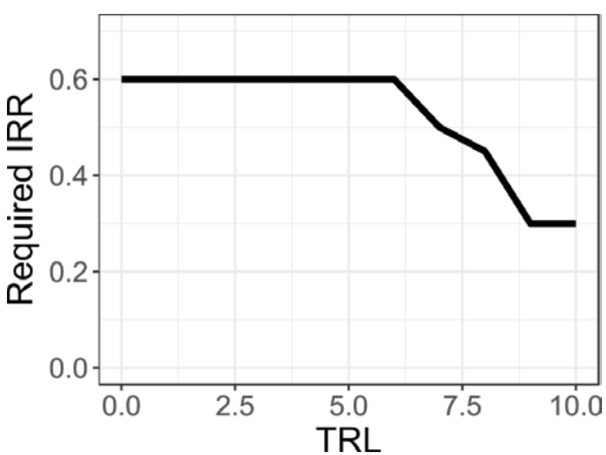
- Bioproduct developers
- Investors
- Bioproduct purchasers
- Government agencies

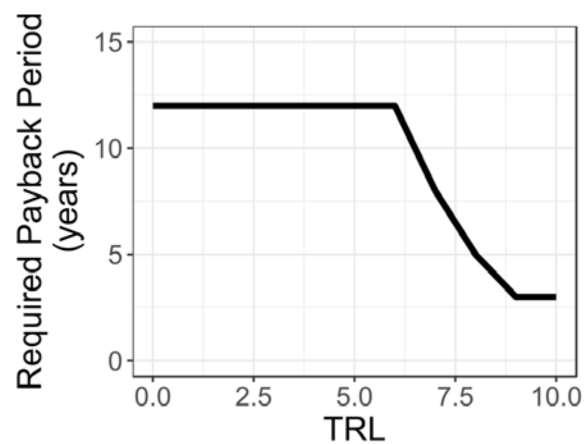
Model structure was derived from…

- Interviews with bioproduct industry experts
- Research on investor decision-making and innovation processes
- Shared learning models
- End use structure research

Investor Decision Making



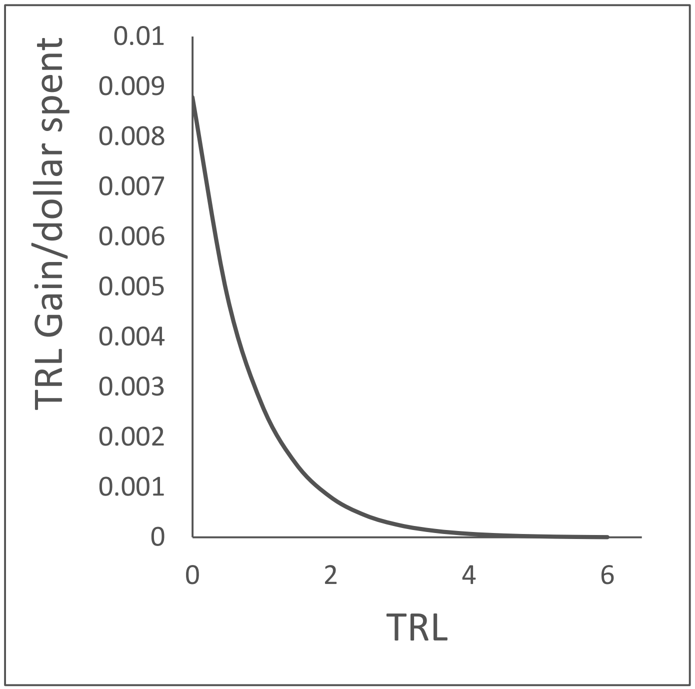


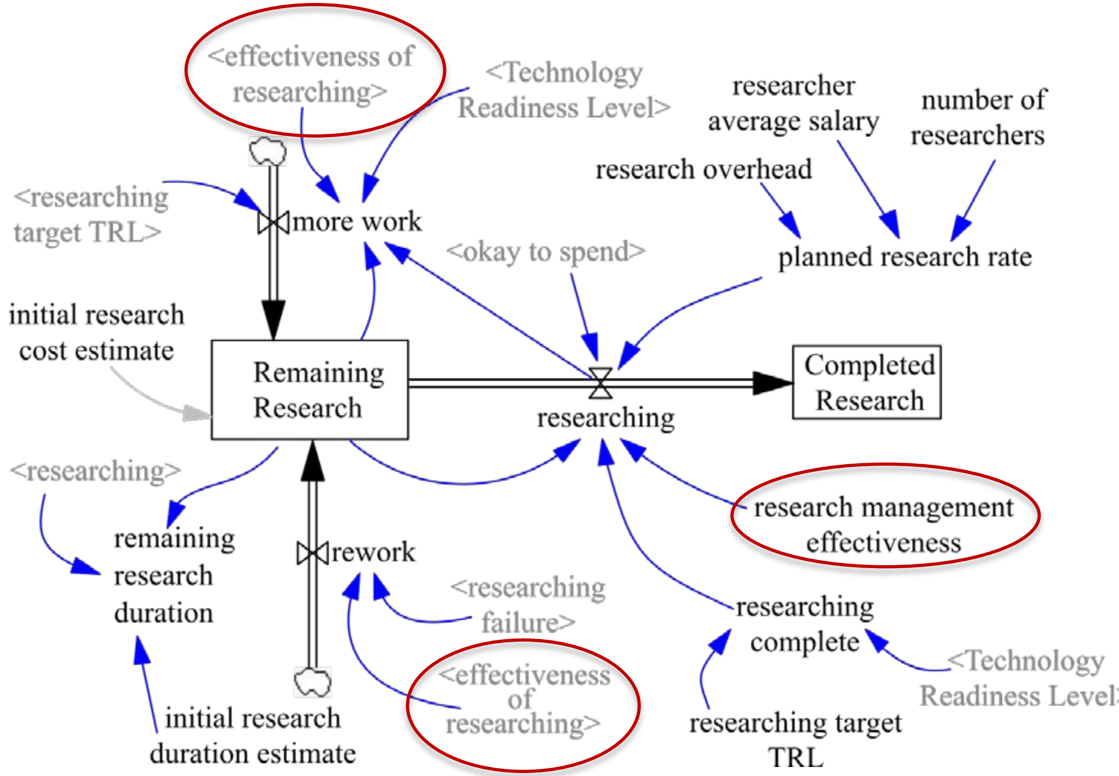


Investor requirements vary by development stage. (Damodaran, 2009)

Research Process

Effectiveness of researching controls the rate at which TRL is gained during research.

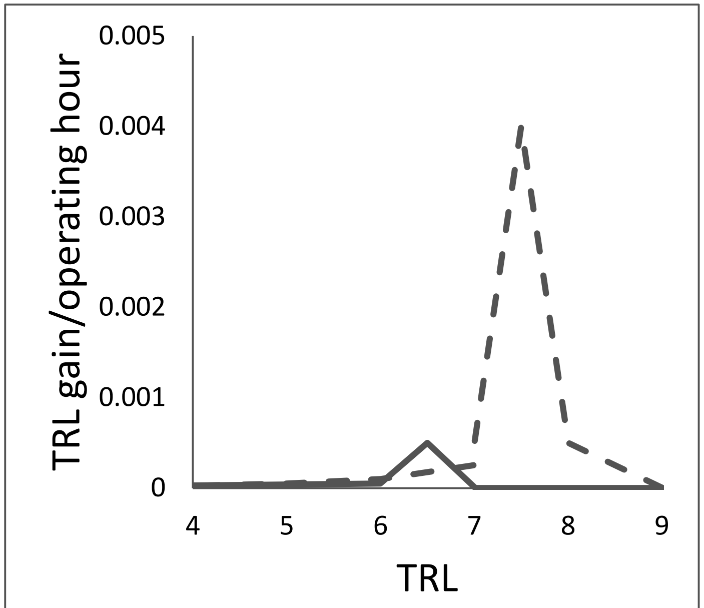


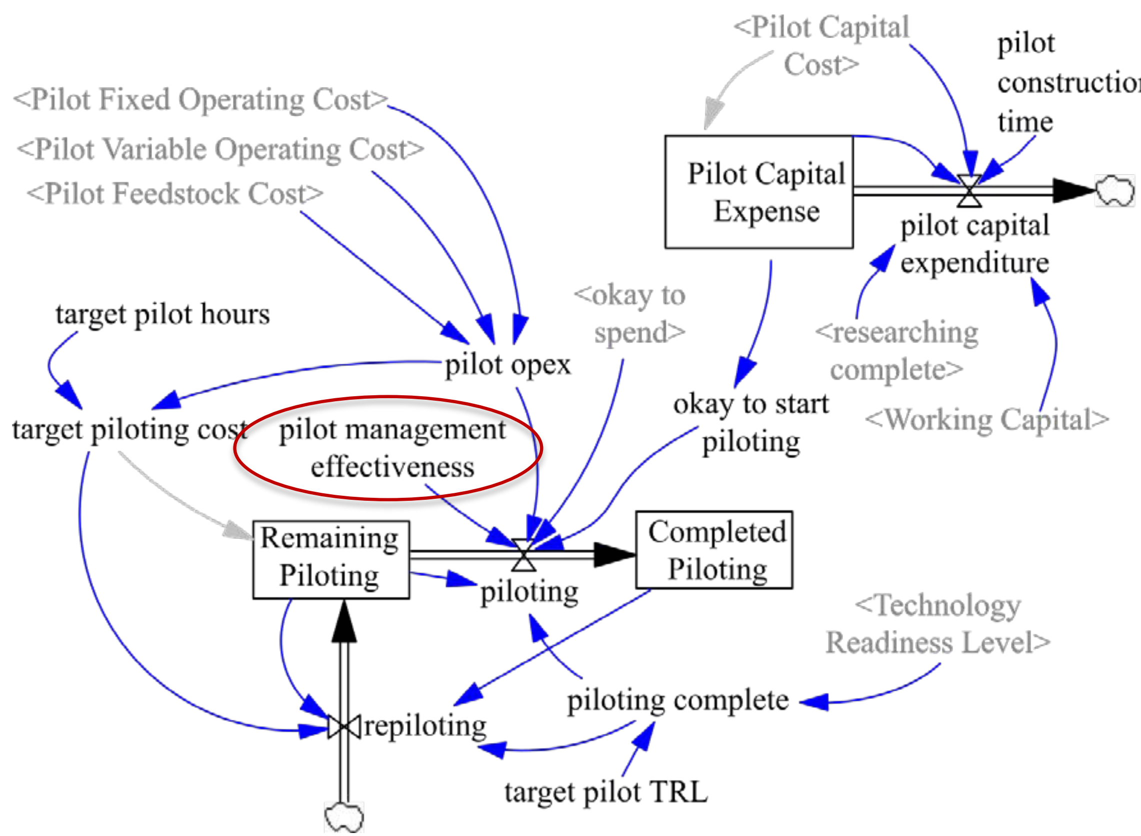


Research management effectiveness controls how much of each dollar spent is available for conversion into TRL gains.

Piloting and Demoing Process

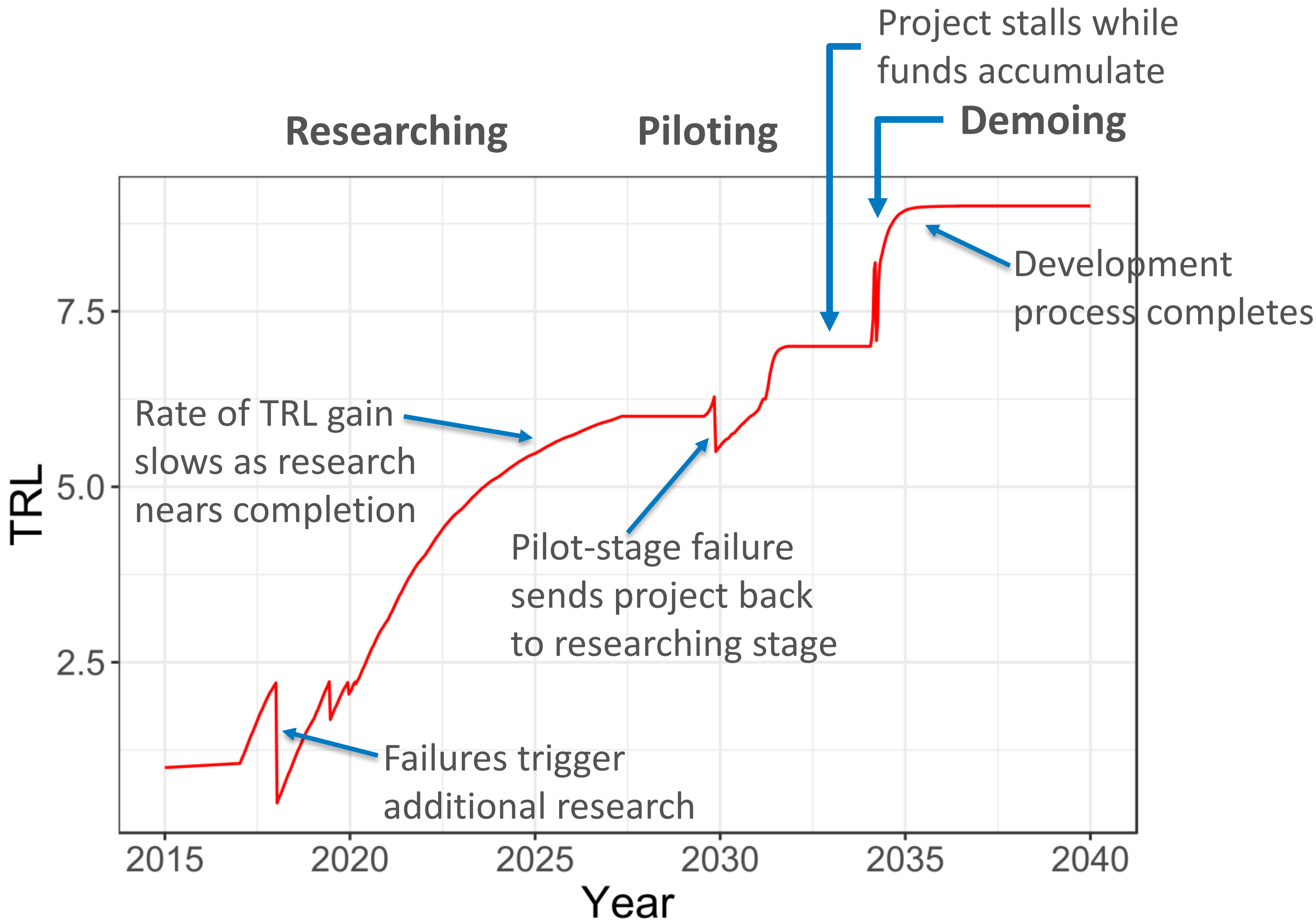
Piloting effectiveness and *demoing effectiveness* (not shown in diagram) control the rate at which TRL is gained during piloting and demoing.





Pilot and *demo management effectiveness* are both analogous to the *research management effectiveness* parameter.

Sample TRL Path and Events



Sensitivity Analysis and Model Verification

- 14.8 million simulations
- Assess sensitivity to investor, developer decision-making parameters and bioproduct (succinic acid) techno-economics

- **Selling price potential**
  - Selling price
  - Size of green premium
- **Government policy**
  - Research cost share
  - Capital cost share
  - Production incentive
- **Developer effectiveness**
  - Research stage

Investor behavior
  - Optimism
  - Bioproduct strategic value
  - Expected government policy continuity

Management effectiveness
  - Research stage
  - Pilot stage
  - Demo stage

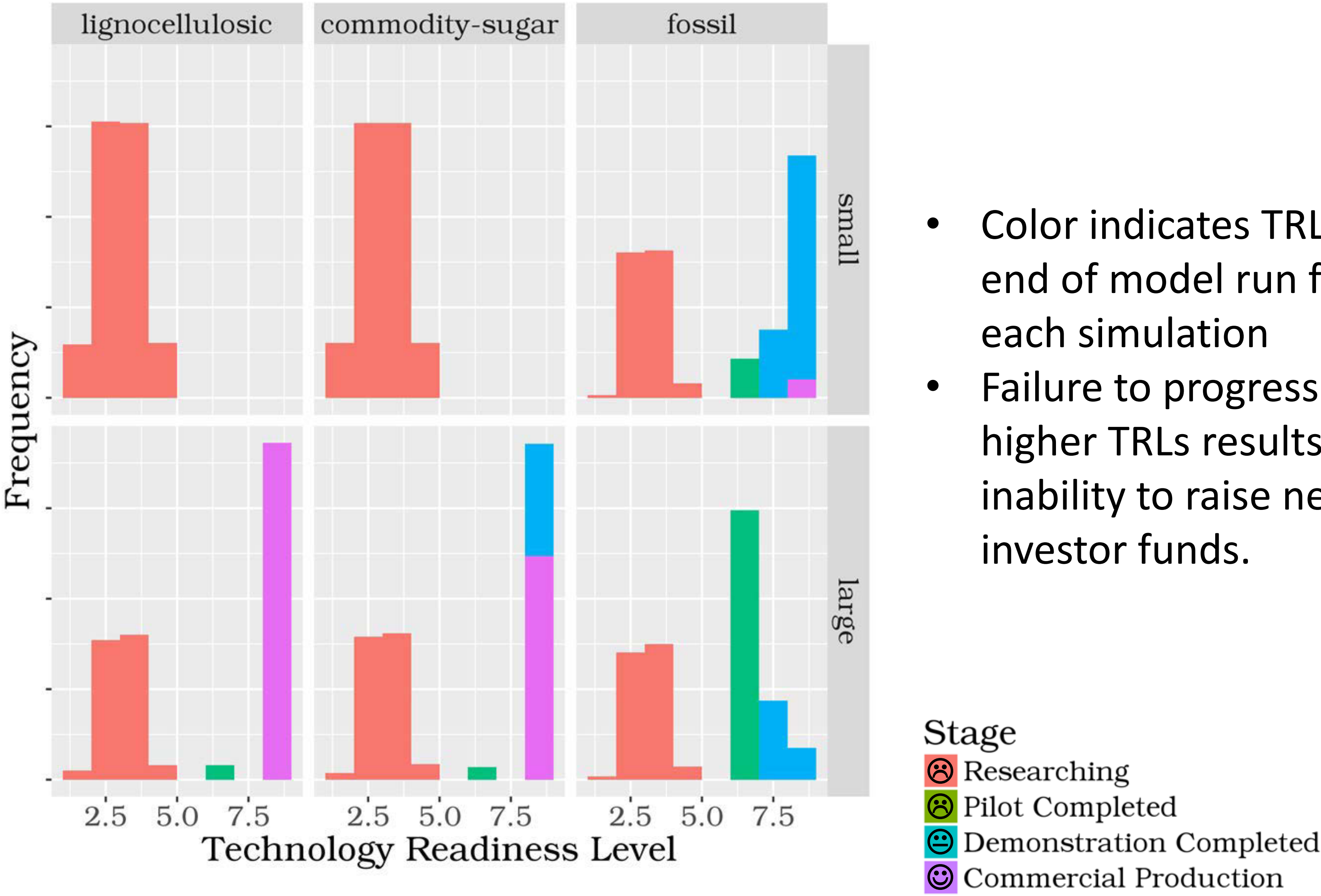
Succinic Acid Techno-Economics

The three pathways differ significantly in their cost structure.

N^{th} Plant Parameters		Lignocellulosic		Commodity Sugar		Maleic Anhydride (fossil)		
		Large	Small	Large	Small	Large	Medium	Small
Capacity	Ton product/year	286,300	28,630	283,465	28,627	83,00	41,500	20,750
Capital cost	USD	$1,253M	$462M	$906M	$401M	$131M	$92.8M	$70.9M
Feedstock cost	USD/ton	$100		$263		$1,500		
Fixed operating cost	USD/year	$27.0M	$12.8M	$21.0M	$11.4M	$10.8M	$8.57M	$7.29M
Variable operating cost	USD/ton product	$494	$815	$504	$1,219	$29		
Process yield	Ton product/ton feed	0.409		0.770		1.179		
Lifetime	Years	30						

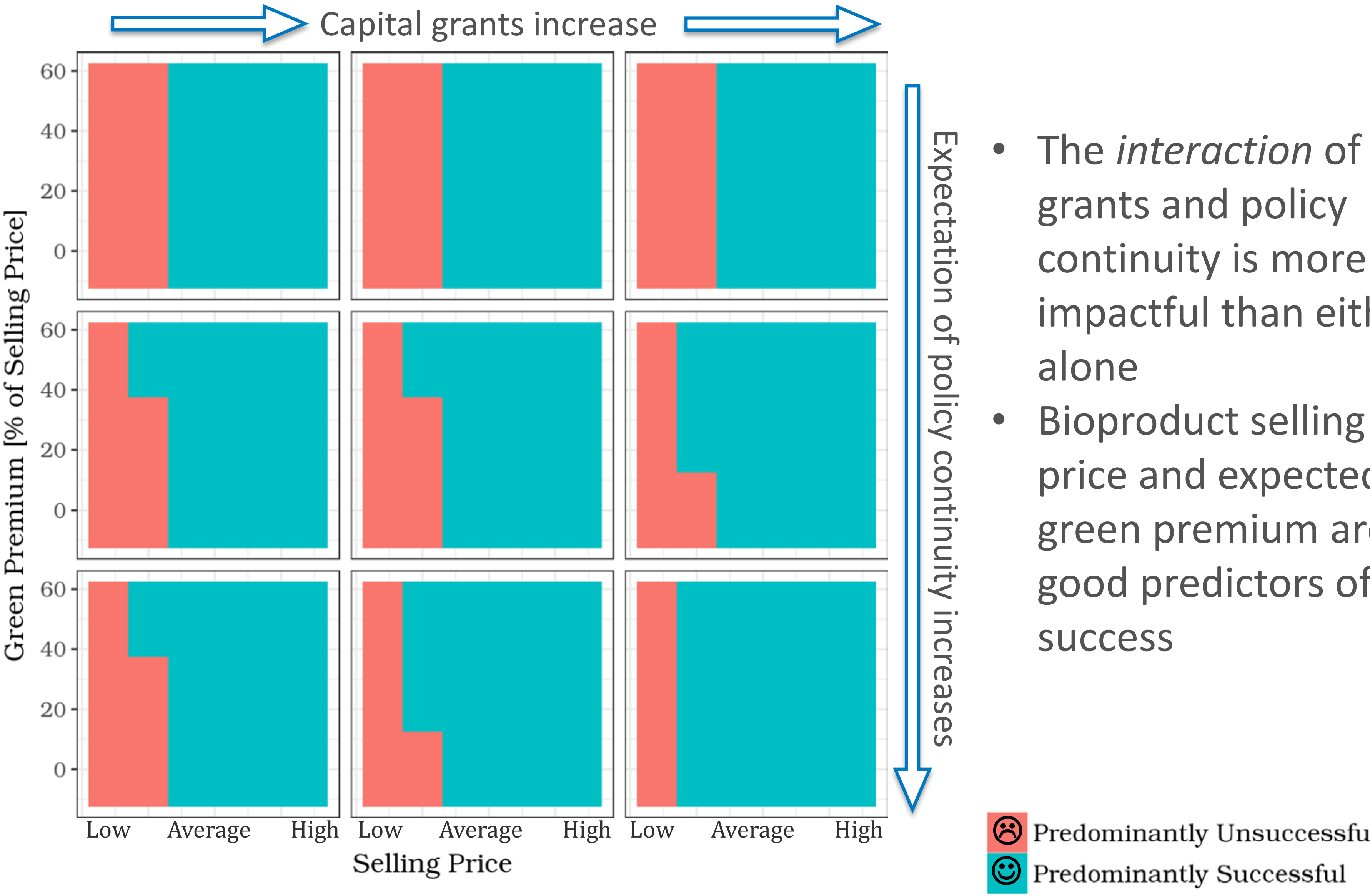
Feedstock	Capital Cost	Operating Cost	Feedstock Cost
Lignocellulosic	High	High	Low
Commodity Sugar	Moderate	High	Moderate
Maleic Anhydride (fossil)	Low	Low	High

Results: Highest TRL Reached



- Color indicates TRL at end of model run for each simulation
- Failure to progress to higher TRLs results from inability to raise new investor funds.

Results: Success Likelihoods

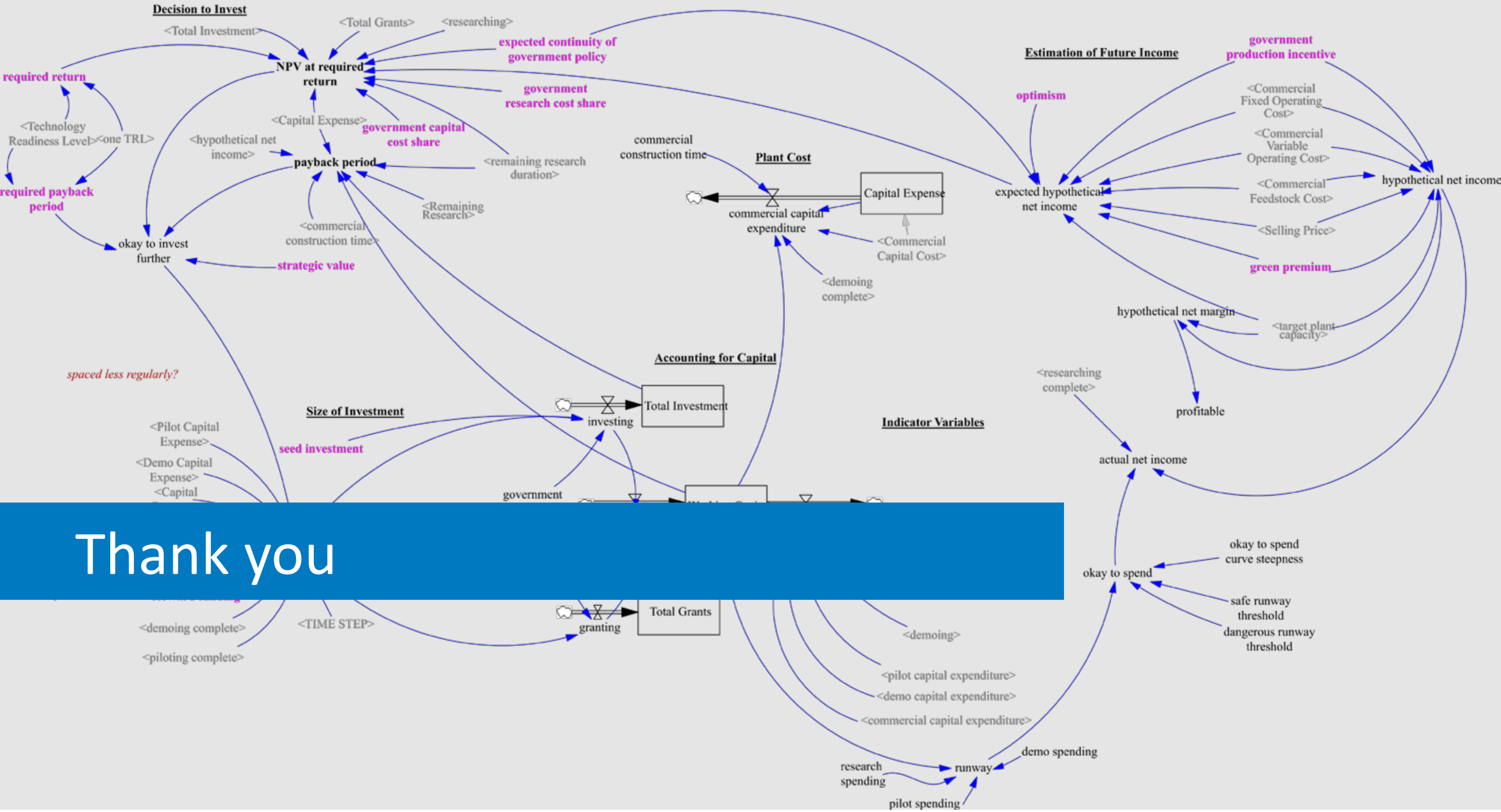


- The *interaction* of grants and policy continuity is more impactful than either alone
- Bioproduct selling price and expected green premium are good predictors of success

Conclusions and Next Steps

The Bioproduct Transition Dynamics model captures the bioproduct technology development process from basic research through commercial production, including interactions between developers and investors.

- BTD workshop will be held July 16, 2018 to solicit guidance on model logic, enhancements and validation
- BTD model development and validation will continue through 2019
- An NREL technical report is planned for release in September 2018, with the potential for additional publications in the future



Thank you

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