Developing and Diffusing New Technologies through Eco-value Propositions

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Professor Jeremy Hall, D.Phil.
Beedie School of Business, Simon Fraser University
*Director and Chaired Professor of CSR and Sustainable Business
International Centre for Corporate Social Responsibility (ICCSR)
Nottingham University Business School

*As of Sept. 2015

Presentation Overview

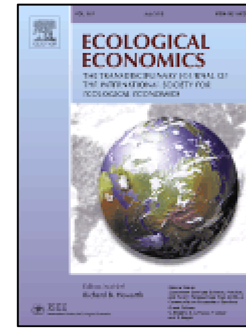
- Introduction
  - The TCOS Lab
  - Editorial activities
- The TCOS approach
- Examples
  - Agricultural transgenics
  - Pathogen detection technology for forest protection
  - Lignin transformation technologies for sustainable biomass products
    - Resins
    - Vanilla
- Implications and Conclusions

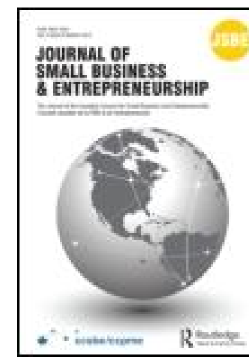
The TCOS Lab

- Investigates the **T**echnological, **C**ommercial, **O**rganizational and **S**ocietal uncertainties of innovation and entrepreneurship
  - Academic, teaching and applied implications
  - Collaborative, multidisciplinary approach, e.g. partners with:
    - Faculty of Forestry, University of British Columbia (UBC)
    - Faculty of Microbiology and Immunology, UBC
    - Brazilian Enterprise of Agriculture Research (EMBRAPA)
    - Hulk Soccer School, a social venture in Campina Grande, Brazil
    - Brazilian Oil, Gas & Biofuels Regulatory Agency (ANP)
- Research team:
  - Drs. Stelvia Matos, Vernon Bachor, Robin Downey, Bruno Silvestre
  - 4 PhD, 6 Masters students
  - Visiting post-docs from Brazil and China
- Funding: Genome Canada and SSHRC (~$1.4 million)

Recent Special Issues

- Hall, 2014. Innovation & Entrepreneurial Dynamics in the Base of the Pyramid, *Technovation,* 34
- Boons, Baumann and Hall, 2012. Managing Sustainability in Global Product Chains, *Ecological Economics*, 83
- Hall and Wagner, 2012. The Challenges and Opportunities of Sustainable Development for Entrepreneurship and Small Business, *Journal of Small Business and Entrepreneurship,* 25
- Hall, Danake and Lenox, 2010. Entrepreneurship and Sustainable Development, *Journal of Business Venturing*, 25





Editor-in-Chief (2011-present): *Journal of Engineering & Technology Management*

- 2013 Impact Factor: 2.106
  - 28/110 journals for Business
  - 40/172 for Management
  - 5/43 for Engineering (Industrial)

JET-M Submissions and Impact Factors

Year	Submissions	IF
2014	331	N.A
2013	276	2.106
2012	266	0.967
2011	220	1.032

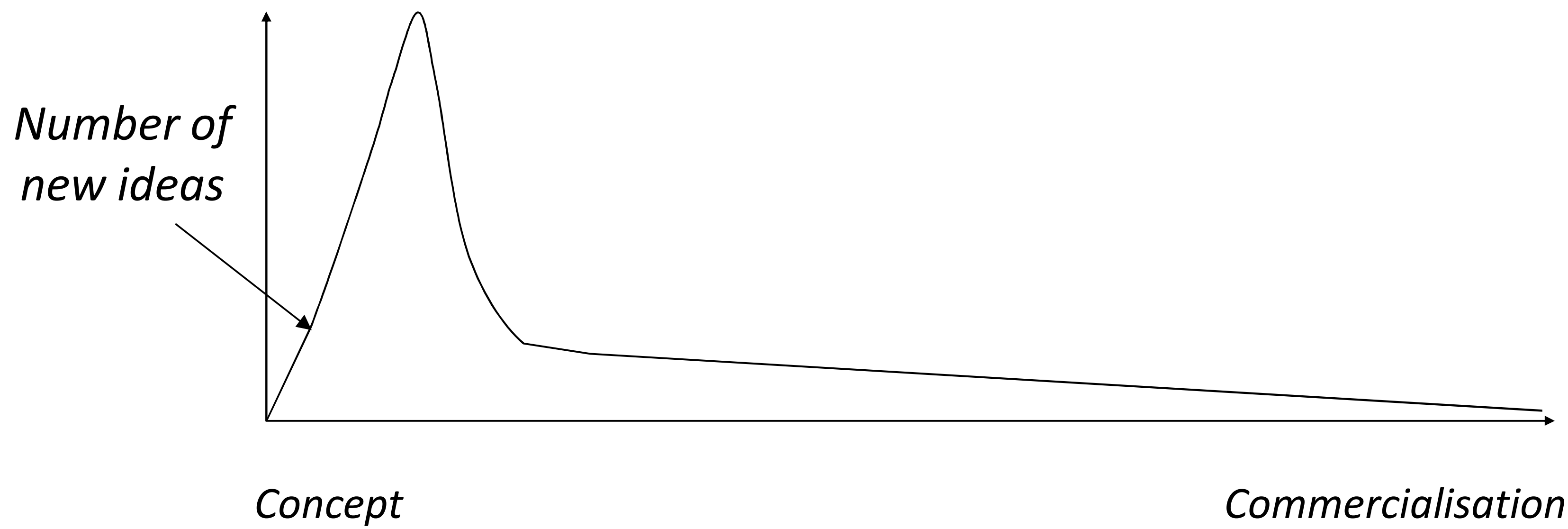
2013 Impact Factors for TIM Journals

Technovation	2.704
Research Policy	2.598
JET-M	**2.106**
Tech. Forecasting & Social Change	1.959
Journal of Product Innovation Mgt	1.379
Industrial & Corporate Change	1.330
Journal of Technology Transfer	1.305
R&D Management	1.266
Industry and Innovation	1.116
IEEE Trans. on Engineering Mgt	0.938
Tech. Analysis and Strategic Mgt	0.841
Research Technology Mgt	0.745
Creativity and Innovation Mgt	0.714
International J. of Technology Mgt	0.492
Innovation: Mgt, Policy & Practice	0.439
Asian J of Tech. Innovation	0.167

The TCOS Approach

The Challenges of New Product Development

Clark and Wheelwright, 1993



The Challenges of New Product Development

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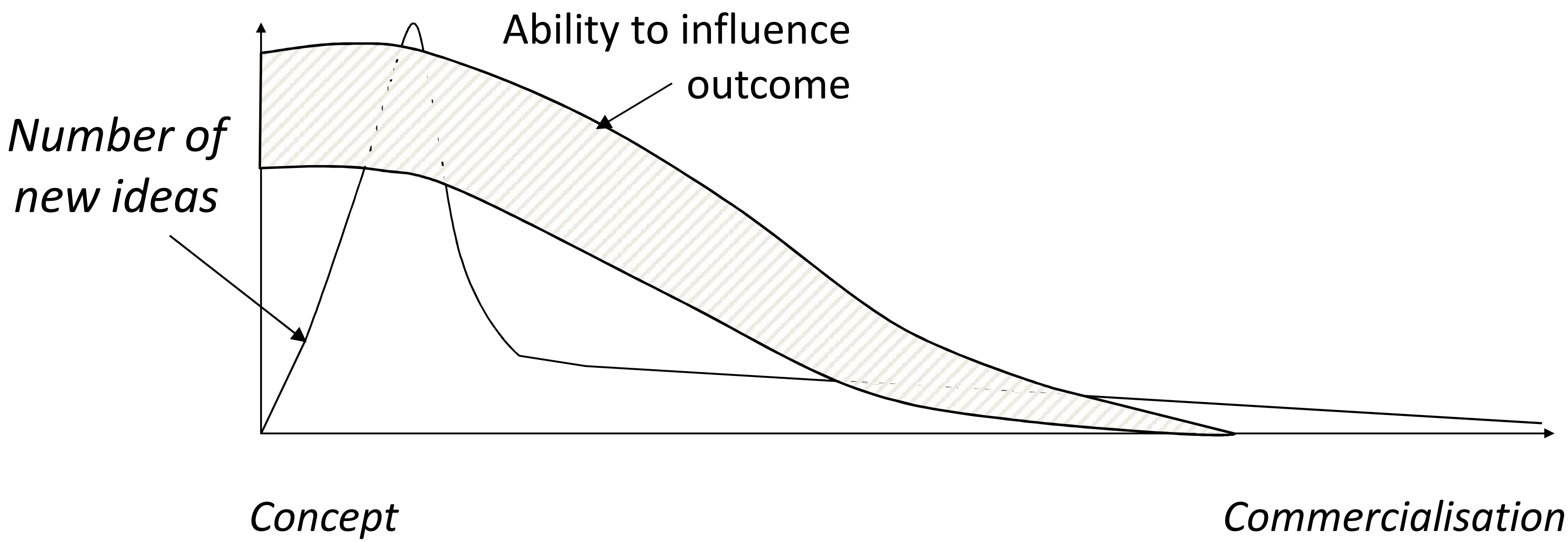

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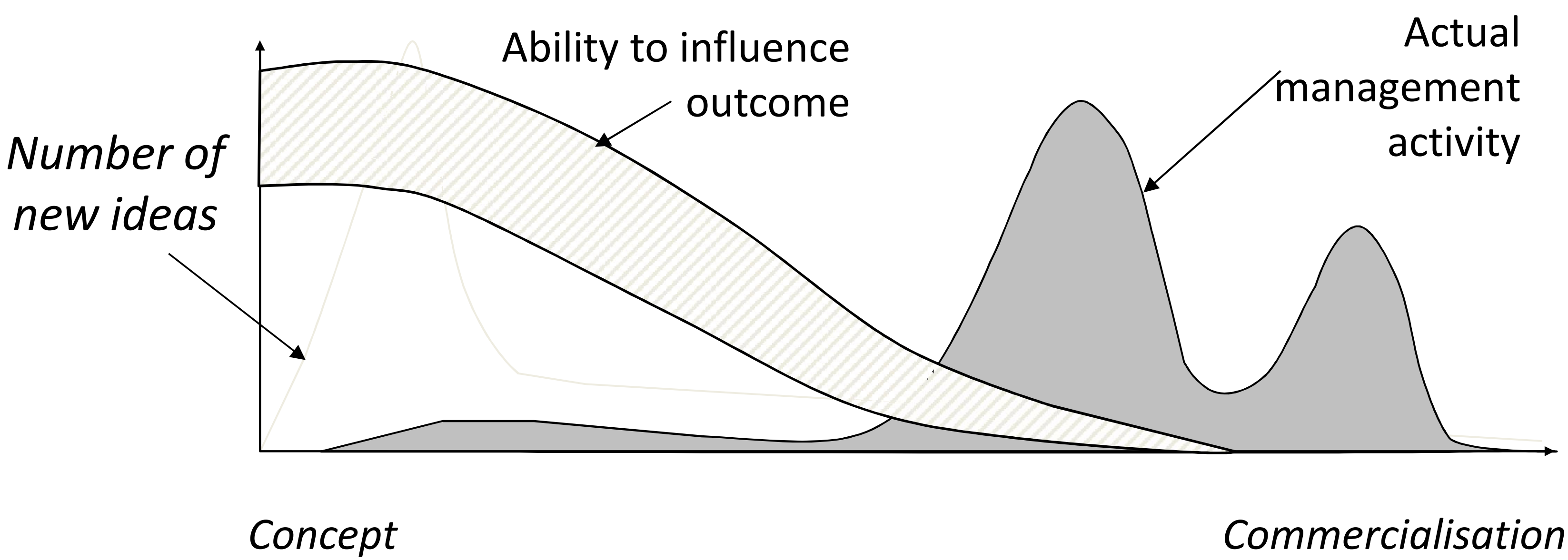
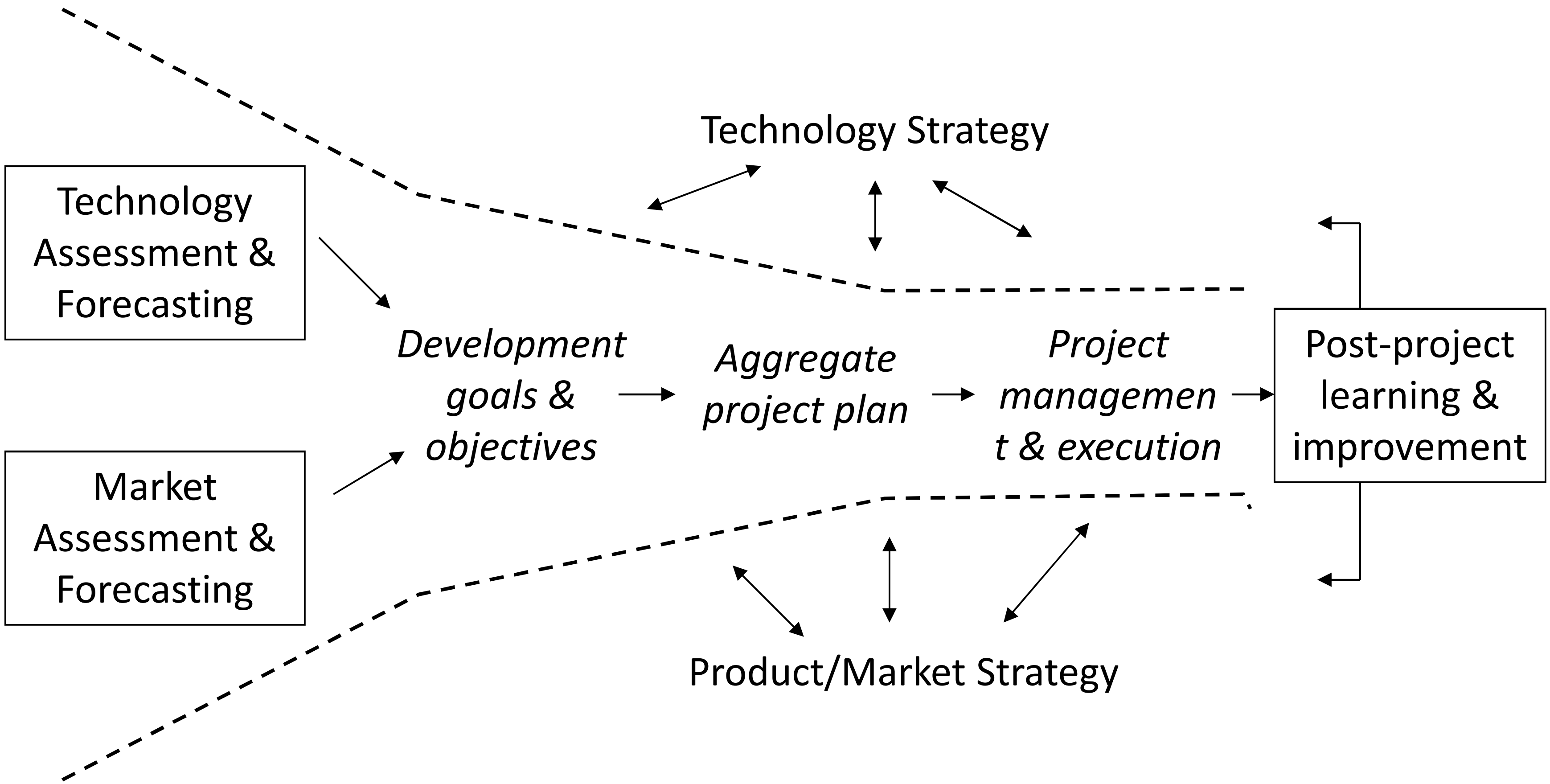


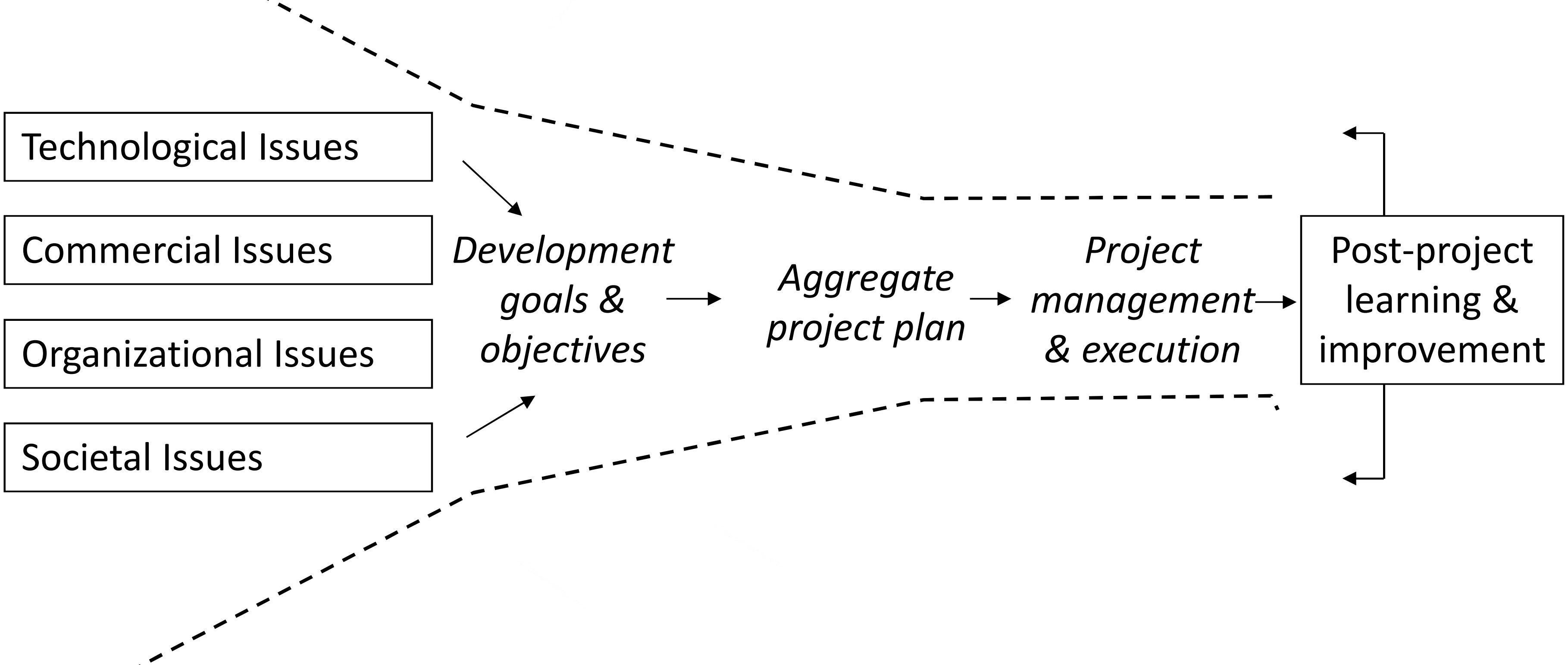
‘Contemporary’ Development Funnel

Clark and Wheelwright, 1993

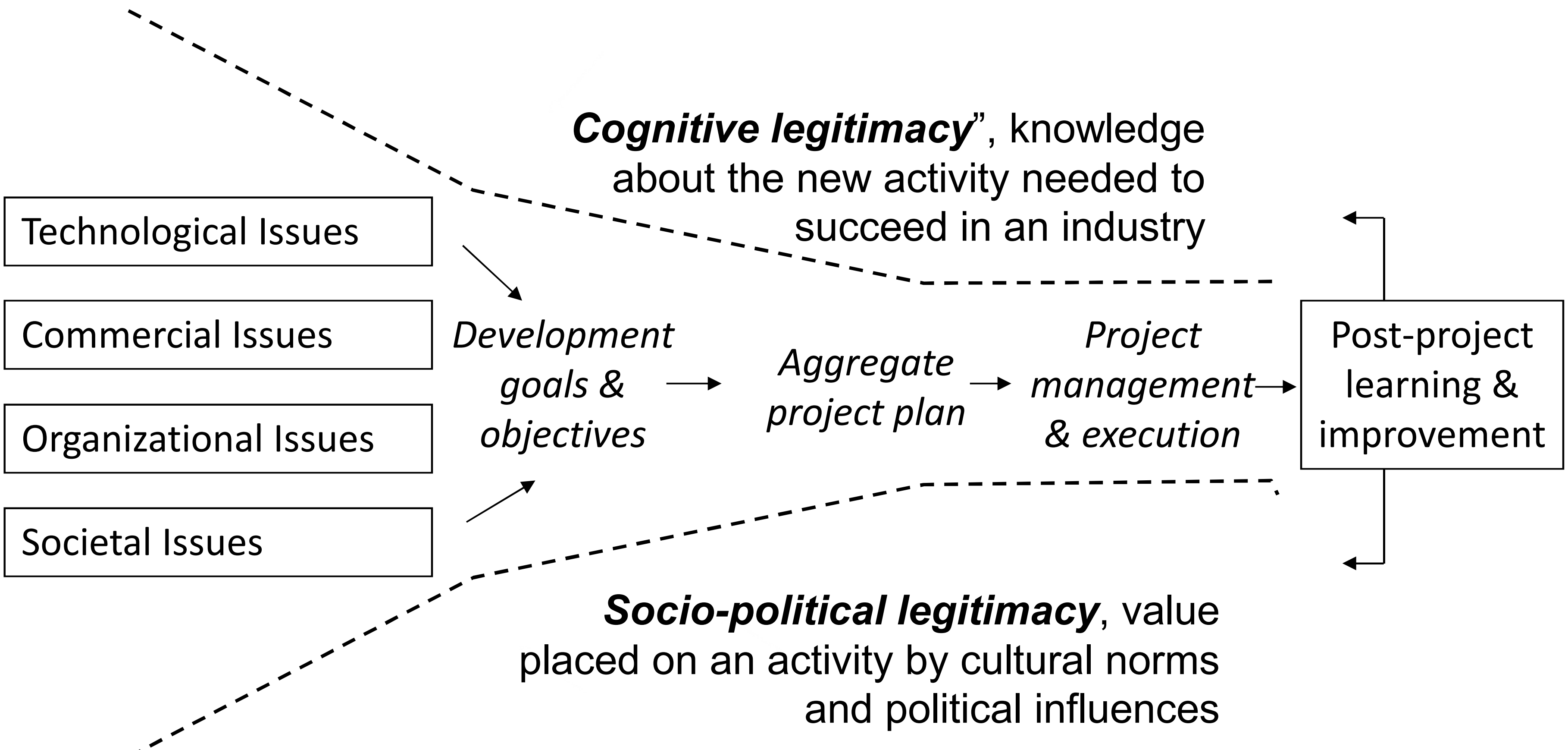


TCOS Framework

- Development Funnel plus:
  - Organizational Issues, e.g. firm specific capabilities, intellectual property protection, complementary assets (Teece, ’86; Martin, ‘84)
  - Societal Issues, e.g. stakeholder concerns, environmental impacts, legal issues, social trends, etc.



TCOS Framework



TCOS Framework of Innovative Uncertainties

Hall & Martin, *R&D Mgt,* 2005
Matos & Hall, *J of Op Mgt*, 2007
Hall et. al., *TFSC*, 2011
Hall et. al., *Technovation*, 2014
Hall et. al., *CMR,* 2014

1. **Technological uncertainty:**
   - Does it work?
   - Domain of scientists, engineers
2. **Commercial uncertainty**
   - Is it commercially viable?
   - Domain of marketing, business analysts
3. **Organisational uncertainty**
   - Does the org. have the complementary assets/ capabilities to appropriate the benefits?
   - Domain of the strategists, business development experts
4. **Societal Uncertainty**
   - Is it acceptable to civil society?
   - Domain of ??

TCOS Theoretical Foundations

Hall et al, TFSC, 2011

Paradigmatic issues Kuhn, 62	• Creative destruction (Schumpeter, 34; 42) • Changes in selection environments; breaking org. routines & heuristics (Nelson & Winter, 82) • Competency-enhancing vs. destroying innovation (Abernathy & Clark, 85; Henderson & Clark, 90) • Impact on innovation value-added chain (Afuah, 98)			
	↓ *Impact/Influence*			
TCOS Uncertainties Hall & Martin, 05; Freemen & Soete, 97	**Tech.**	**Commercial**	**Org.**	**Societal**
Risk Characteristics Knight, 21; Simon, 59	*Variables & interactions can be identified, probabilities estimated*		*More variables (complexity), some not easily identified (ambiguity)*	
Type of Legitimacy Aldrich & Fiol, 94	Cognitive			Socio-political
Heuristics Popper, 45, 59	Conjecture – refutation			Piece-meal social engineering

Hall & Martin, *R&D Mgt,* 2005
Matos & Hall, *J of Op Mgt*, 2007
Hall and Crowther, *JCP,* 2008

Legitimization Processes in Ag-Biotech

- Industry leader Monsanto promoted their transgenic technologies as sustainable:
  - Reduced environmental impacts, improved output, "replacing stuff with information"
  - "Roundup Ready" transgenic seeds/herbicide
- Judicious intellectual property management policies protecting $1billion/yr. R&D investments:
  - Acquired competencies, complementary assets through acquisition, alliances, networks to procure IP
  - Spent considerable resources on legal mechanisms (patents, plant breeder's rights, trademarks, biological mechanisms e.g. hybridization, genetic use-restriction technologies, etc.).
- Generally well received by North American agribusinesses accustomed to contracts, but encountered considerable difficulties overseas

Hall et. al., *TFSC*, 2011
Hall et. al., *Technovation*, 2014
Hall et. al., *CMR,* 2014

Monsanto's Sociopolitical Challenges

- Canadian Canola farmer Percy Schmeiser 'David vs. Goliath'
- Controversies in India
  - Terminator technology
  - Debt-suicides
  - Child labor concerns
  - Bio-piracy, etc.
- '**Stealth transgenics**': seeds saved, cross-bred, repackaged, sold, exchanged, planted in *an anarchic agrarian capitalism that defies surveillance and control of firms and states* (Herring, 2007)
- Legal action often infeasible
  - Small scale, widely dispersed farmers
  - Little public support due to controversial status

Transgenic Soybeans in Brazil

Hall et al, *JCP,* 2009
Hall & Matos, *IJPDLM*, 2010
Hall et al, *IJPR*, 2012

- Research excellence through EMBRAPA: Brazilian Agricultural Research Corporation (*Empresa Brasileira de Pesquisa Agropecuária*)
- Rapid growth in soybeans: from 0 to 2nd largest:
  - Government policy in the 1960s – 'Green Revolution' and 1990s reform policies
  - Successful adaptation to the Brazilian climate
  - Low production costs
- Major controversies over farming concentration and 'social exclusion' resulted in delays in regulatory approval

Policy Ambiguity for Transgenic Soybeans 2002-05

Hall, Matos & Langford, *JBE,* 2008

Ministerial Ambiguity:

- Ministry of Science and Technology: PRO
- Ministry of Environment: AGAINST
- Ministry of Agriculture: PRO
- Ministry of Agricultural Development: AGAINST
- Ministry of Trade: ‘STUCK IN THE MIDDLE’
- Ministry of Hunger Defense: NO RELATION

State policies also vary:

- RS: PRO; PR: AGAINST

Brazilian Soybeans: The *Can-geria* Dilemma?

Hall, Matos & Langford, *JBE,* 2008

Subsistence Farmers	Export Oriented Farmers
• Strengths in traditional knowledge but often technologically unsophisticated	• Technologically sophisticated, understand global markets and opportunities
• Low education, absorptive capacities	• High education, absorptive capacities
• Typically based on diverse indigenous plants	• Based on concentrated non-indigenous plants
• Social issues (e.g. self sufficiently, urban migration) key	• Economic issues (e.g. export development) key

According to one senior EMBRAPA official: ***EMBRAPA has the market and Monsanto the technology—a match made in heaven…***

However, the persistent controversies surrounding Monsanto hindered the technology's diffusion and tainted EMBRAPA's reputation as a national technology contributor, resulting in the same a *official concluding it was … a* ***match made in hell****.*

While successful with cognitive legitimacy, they continue to struggle with socio-political legitimacy

Hall et. al., *CMR,* 2014
Hall et al, (2013). Genome Canada GPS Policy Brief No. 7
www.genomecanada.ca/medias/pdf/en/InnovationContinuum_Policy-Directions-Brief.pdf

Genome Canada Large-Scale Applied Research Projects

- Genome Canada not-for-profit mandated to "*develop and implement a national strategy for supporting large-scale genomics and proteomics research in Canada*".
- "GE3LS" (Genomics-related Ethical, Environmental, Economic, Legal and Social) component:
  - Proactive approach to address public concerns over genomics
  - Recognition that linear "technology push" model left promising technology sitting on the shelf
  - All grants need to emphasize "benefits to Canada"

GenomeCanada

TCOS Methodology

Consultation with Scientific Teams to identify potential applications, key issues, stakeholders

Identify/ interview key stakeholders for potential applications using TCOS as interview guide

Feedback to science teams, publications

TCOS Analysis using Atlas.ti

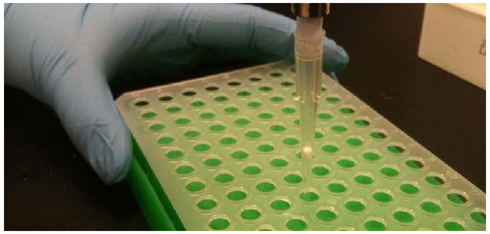
- ***Tech. Issues*** (e.g. production scalability, product consistency, durability, etc.)
- ***Commercial Issues*** (e.g. Industry structure, competitive dynamics; consumer needs; willingness to pay, etc.)
- ***Org issues*** (e.g. IP protection, requisite complementary assets, competencies)
- ***Societal issues*** (e.g. reg. hurdles, public perception, env. impacts; social/env. benefits over incumbent technologies, etc.)

Hall et. al., *R-TM*, 2014
Hall et. al., *CMR,* 2014

71 stakeholder interviews

Pathogen Detection Technology for Forest Protection

- Pathogen infestation can cause widespread environmental harm, $billions in damage and trade loss
- Incumbent system based on visual inspection, which has major limitations (e.g. some plants may be infected but don't show visible signs)
- 'TAIGA' (Tree Aggressors Identification using Genomic Approaches) explores how superior genomic technologies for detecting foreign pathogens can be developed as a regulatory tool
- Potential applications in much larger (and controversial) agricultural sectors



Summary of Key Technological Hurdles and Levers

Hurdles

- Some CFIA & provincial policy stakeholders concerned that risk information will add complications, be difficult to manage
- Some policy stakeholders concerned technology won't detect specific species and strains
- Most stakeholders concerned about ability to detect false positives/ negatives

Consistent, effective communications strategy can turn these concerns into 'levers'

Levers

- Increased sensitivity, ability to identify specific pathogens will eliminate false negatives, greatly reduce false positives and overall simplify risk assessments
- Users, other value chain members will not require new competencies – e.g. can be framed as an ***incremental innovation***
- Prior DNA-based technology (e.g. for Sudden Oak Death)
- Interest from Int. scientists, regulators (Aus., EU, NZ, UK, US)

Key Commercial Hurdles and Levers

Hurdles

- Price-sensitive sector, often passive re: technology adoption
- Lack of cost data, willingness to pay by primary users (e.g. regulators)
- Phytosanitary issues often seen as another cost, complication
- Supplier-dominated industry (e.g. Pavitt, 1986), often lacking resources for innovation.
- Often reactive mindset
- Potential to create trade restrictions

Levers

- More effective, faster method can avoid costly shipping quarantines/ returns, provide assurances for increased trade, enable early detection, etc.
- Committed primary user (CFIA), provides assurances to other key stakeholders of commercial viability
- Partnering with Industry Canada or Ag. & Agri-food Canada can help market technology abroad

Organizational Issues

- Restrictions patenting life forms: part of the process (probes) are patentable but may be unviable due to limited market
- Academics under pressure to publish
- Complementary assets currently limited or need to be developed – calls for collaborators
- Small market, domestic government customers produce small margins - viable business model needs to capture market majority
- University Tech. Transfer Offices (TTOs) resource constrained - difficulties handling non-patent IP or inventions for small markets, ***passive industries*** (e.g. Hall et al, R-TM, 2014)

Societal Issues

Hurdles

- Lack of standardized pest risk approaches among National Plant Protection Organizations
- New risk assessments create complications, disrupt current approaches
- Increased risk information may lead to greater trade restrictions
- Lack of awareness re: emerging pathogen risks (*this may be changing…)*
- CFIA often scrutinized *(sometimes unfairly – e.g. blamed for Brazilian ban on Celine Dion music... – see Hall et al, 2005)*

Levers

- Widespread support for forest protection biodiversity management & climate change adaptation
- Future applications can be developed as policy solutions for biodiversity management and climate change adaptation
- Support from First Nations
- Opportunity to promote through voluntary schemes (e.g. FSC)
- ***Overall strong socio-political legitimacy***

Policy Implications

- General consensus TAIGA approach could provide major benefits to forestry in Canada and elsewhere
- Key question not ***"****can we trust that pathogen DNA was found with this tool?*", but rather "***what should be done if one is found****?*"
- **How the risk is interpreted -** *"one nation's bunch of grapes is another nation's repository of carcinogenic pesticide residue"*
- ***Stakeholder ambiguity,*** where various stakeholders have access to the same information but interpret it differently (e.g. Hall & Vredenburg, 2005; Matos & Hall, 2007, Hall et al, 2014):
    - Difficulty to identify during data collection & non-probabilistic
    - ***Need to be prepared in case it emerges***

Business Implications

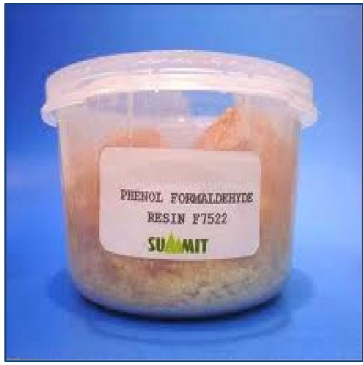
- Commercial viability somewhat unique:
  - Regulator as primary user
  - Price-sensitive, arguably reactive industry
  - Perhaps better to translate through CFIA at no cost to establish cognitive legitimacy, which can then be used as marketing strategy for other regulators, tertiary applications
- ***Need - and opportunity - for consultancy business that can provide technical and policy advice to complement the specific technologies being developed by the TAIGA project***
  - Little concern regarding the technology *per se* - real challenge/ opportunity is how information will be used
  - Relatively low initial investment
  - Consistent with academic orientation, IP constraints
  - Forestry a good launching point

Lignin transformation technologies for sustainable biomass products

Hall et. al., *R-TM*, 2014
Hall et. al., *CMR,* 2014
Matos & Hall, 2013
81 stakeholder interviews + preliminary LCA studies using SimaPro

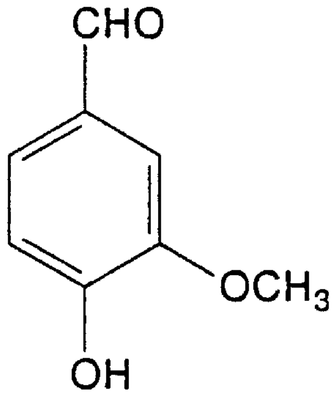
- Explores how genomic approaches can transform lignin to replace petroleum in food additives, resins, carbon fibres, biofuels, etc.
- Application of
  - TCOS analysis (qualitative)
  - LCA analysis (quantitative)
  - TCM: Technical-economic Modeling (quantitative)

Examples of Sustainable Innovation Analysis



- **Lignin/Phenol-formaldehyde resins**
  - Resins are synthetic polymeric material that improves hardness, stability, chemical resistance of plywood and other wood composites
  - Partial replacement of petroleum-based phenol with lignin

- **Lignin-based vanillin**
  - World's most widely used flavouring, aroma agent
  - Proposed fermentation process uses soil bacteria strains to convert lignin into vanillin



Vanillin

Summary of Lignin-based Resin TCOS Analysis

Technological

L	• Demonstrated proof of principle • Good performance re: heat of cure, peak curing temperature
H	• Yet to meet incumbent performance at high lignin concentrations • Requires building code certification (e.g. temp., moisture, etc.)

Organizational

L	• Patentable; can be out-licensed • Potential 'low hanging fruit' to establish legitimacy of lignin products
H	• ***University tech-transfer offices not equipped to deal with passive, low margin industries***

Commercial

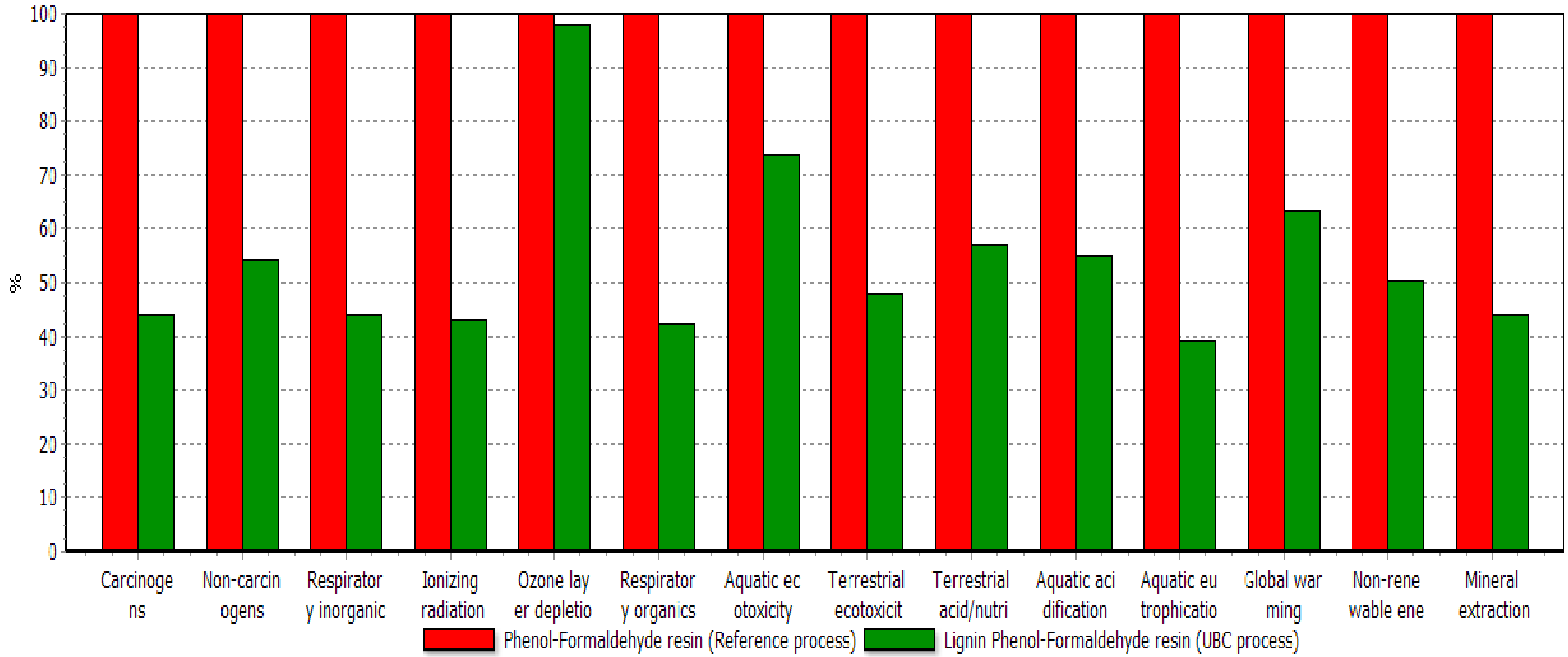
L	• ***Growing demand for eco-products*** • ***More stable costs compared to petroleum feedstock*** • Potential reduction in input cost
H	• ***Narrow industry margins*** • Need for reliable supply • Cyclical industry sector • Sensitive to transport costs

Societal

L	• Renewable • No formaldehyde concerns • ***Overall lower environmental impacts (LCA analysis)***
H	• Need regulatory approval • Need to demonstrate environmentally sound practices throughout life cycle

Preliminary LCA
Incumbent (PF) Resin vs. Lignin-based Resin (LPF)

Under preparation, *Env. Science & Technology*



- Lignin-based resin has ***<u>overall lower environmental impacts</u>*** – e.g. decreased PM & SO_2 emissions: human health improvement and potential C$103 reduction on health costs per ton of LPF resin
- Helps identify areas for improvement (e.g. reduce formaldehyde usage)

Summary of Lignin-based Vanillin TCOS Analysis

	Technological		Organizational
L	• Demonstrated proof of principle • Advantages of producing at lower temperatures/ pressures	L	• Patentable, can be out-licensed • Potential ‘low hanging fruit’ to establish legitimacy of lignin
H	• Lab yield still low - “***The key issue is really the productivity***” • Process needs to be changed to meet lucrative ***“natural”*** market	H	• ***Small market, high investment may not meet TTO thresholds*** • Lack skills for managing regulations (e.g. ‘natural’)

	Commercial		Societal
L	• Petroleum free • Abundant, renewable, stable supply • ***Varying vanillin prices - potential eco–product sold at a premium***	L	• ***Increasing concerns over petroleum-based ingredients*** • Lower CO_2 emissions
H	• Skepticism re: lignin-based products • Requires major investment from a pulp mill for small global market • ***Varying vanillin prices – low margin if not approved as ‘natural’***	H	• **Regulatory ambiguity re: ‘natural’** • NGO protests against synthetic vanillin: “*extreme genetic engineering in our food*” , “*very un-natural new ingredient”, “what it means for [poor] vanilla farmers.”*

RHOVANIL®
NATURAL

Varying Vanillin Prices – Hurdle or Lever?

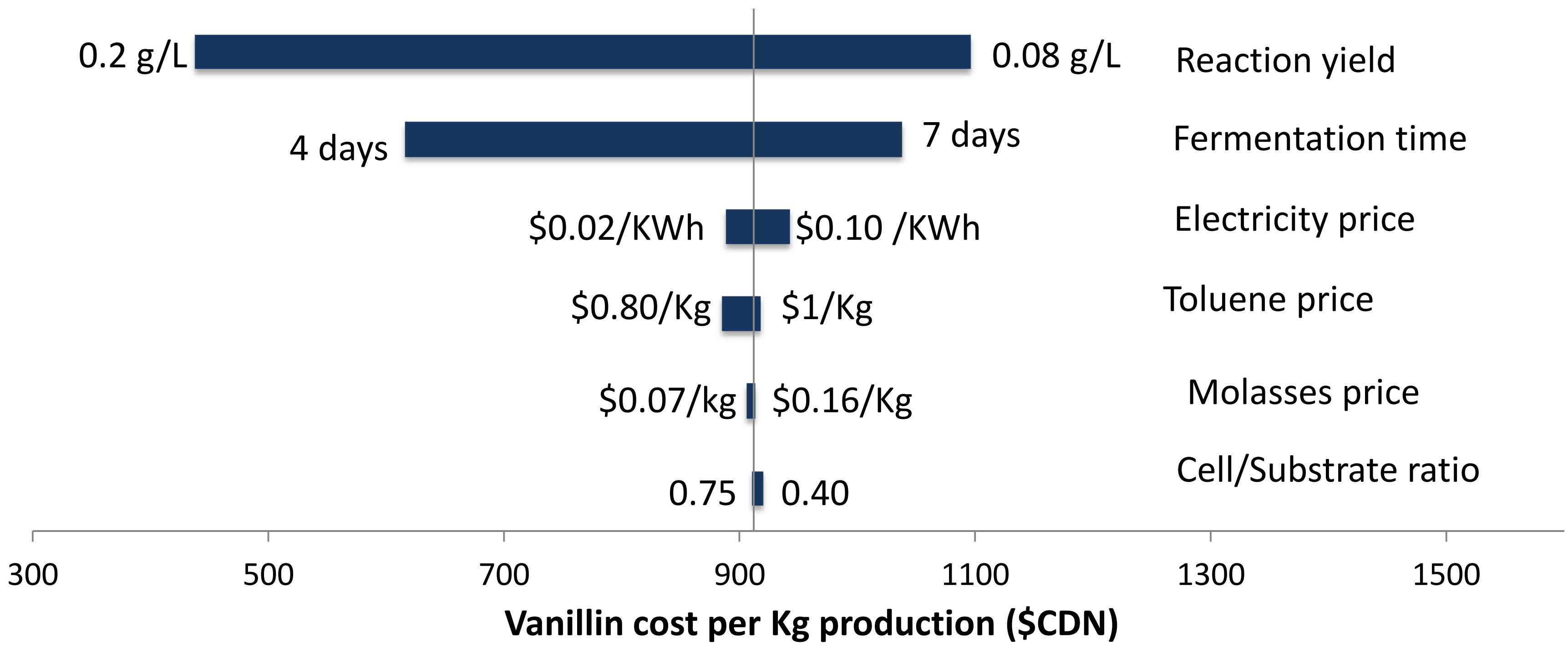
Source of vanillin	**Market price**
Guaiacol vanillin (synthetic)	\$12-15/Kg
Borregaard lignin vanillin (synthetic)	\$13-16/Kg
Rhodia clove oil vanillin (*<u>‘natural like’ (!?) in US only</u>*)	\$70/Kg
Rhodia ferulic acid vanillin (natural)	\$700/Kg
UBC’s wheat straw fermentation (preliminary est.)	\$912/Kg
Vanilla bean (natural)	\$1200-4000/Kg

Preliminary Vanillin Cost Analysis

Multidisciplinary effort from Faculties of Microbiology, Chemical Engineering & Business

Key production cost drivers (Technical-economic Modeling)

- Higher reaction yield reduces costs from $912 to $440/kg
- Shorter fermentation time reduces costs from $912 to $620/kg



Implications

LPF Resin:

- Creating awareness difficult – small, widely dispersed industry; companies don’t operate large R&D departments
- Need to actively seek out and provide credible value propositions for industry (e.g. ***comply with regulatory requirements, consumer demands for low-formaldehyde products***)

Vanillin

- Complications due to regulatory definitions, market trends
- Small market but relatively high investment requirements may not meet Tech Transfer Office threshold criteria
- ***Sustainability-based value proposition may motivate industry participation***, which could help compensate for small markets

Conclusion 1: Need for a Multidisciplinary Perspective

- Sustainable development innovation requires coordination of social, environmental and economic dimensions
  - Legitimacy emerges as technical performance and social acceptance co-evolve, reducing uncertainty
  - Cognitive, sociopolitical legitimacy are often at odds
  - We have a good grasp on cognitive legitimacy, but more work is needed to understand socio-political legitimacy
- TCOS analysis can identify challenges (hurdles) and opportunities (levers) for improved technology development and commercialization
- Requires different heuristics!

Conclusion 2: TTOs and Science Teams need to Proactively Engage Industry

- Standardized IP approaches, in which the Tech Transfer Offices await industry interest, often leaves promising technology on the shelf:
  - TTOs are resource constrained, have difficulties handling non-patent IP or inventions/ innovation for small markets, regulators, passive industries
  - Need capabilities to proactively engage with users for technology translation
  - Worth the effort, as many passive industries are in need of innovation, particularly more sustainable technologies
  - Aligns with University mandate and public policies (e.g. Bayh-Dole Act, Genome Canada that universities) use their IP for public good

Conclusion 3: Eco-value Proposition

- If only **T** or **C** are explored, then technologies would probably sit on the shelf: **S** seems to be the key driver, and can be substantiated with the LCA study – '**eco-value proposition'**
  - Composite wood products manufacturers need solutions for carcinogenic concerns over formaldehyde
  - Consumer demands for the much more lucrative but ambiguous 'natural' vanilla key driver
  - Forest protection about as appealing as motherhood
- Only works if supported with evidence (e.g. LCA, cost models)

Future Research: Change the Process or the Regulatory Definition?

- Can a publishing strategy lead to regulatory change?
  - What are the credible (peer reviewed) journals used by regulators, policy makers?
  - How do regulatory agencies make their assessments in practice? What do they read?
  - Problem may be too many niches (e.g. regulators, forestry, genomics, int.' trade, etc.); difficult to hit a sweet spot
  - Our other studies found similar need for inducing reform e.g. improved offshore oil & gas regulatory safety (*Energy Policy,* 2014)