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ANALYSIS

The dynamics of innovation ecosystems: A case study of the US biofuel market

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ABSTRACT

This paper extends the research on innovation ecosystems in several ways. It analyzes how the dynamics of markets affect the adoption of technology, links the evolution of the innovation ecosystem to the market dynamics, and shows how these interacting dynamics affect emergence of a dominant design. The paper starts with a review of previous work on innovation ecosystems, concluding that these analyses focus primarily on the inner workings of ecosystems and less on the dynamics of the markets in which the ecosystems exist. It then uses network mapping software to visualize the development of the US biofuels ecosystem between 1980 and 2012. Mapping shows the consolidation of the industry and emergence of a dominant conversion technology and consortium of suppliers. Next a System Dynamics model of the US biofuels market is introduced. The model is used to generate scenarios for 1995-2025 under different assumptions for management decision making and trade policies. The scenarios produce significant variations in industry performance and adoption of next generation technology. Combining the mapping and modeling highlights the effects of market conditions on the dynamics of innovation ecosystems. The paper concludes that opportunities to introduce new technologies are defined by waves of investment in biofuels production capacity. The waves of capacity investment are driven by changes in market conditions. A dominant design emerges during each wave of capacity investment. The timing of technology selection decisions is critical. Narrowing the options too early is overly constraining and may drive one down an inefficient if not wrong path. The biofuels case is quite relevant to the oil and gas sector. Both are similar open innovation systems, with long-lived conversion assets, waves of capacity investment, and cyclical utilization and margins. Both are experiencing an accelerated pace of innovation, e.g., in connection with shale gas and oil.

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1. Introduction

Biofuels involve a complex ecosystem with multiple technology paths. There is ample historical data and it is possible to build on past analyses. And biofuels are an important complementary business to oil and gas involving major investments. Indeed, the biofuels case is highly relevant to the oil and gas sector. Both are similar open innovation systems, with long-lived conversion assets, waves of capacity investment, and cyclical utilization and margins. Both are experiencing an accelerated pace of innovation, e.g., in connection with shale gas and oil. But biofuels are easier to track given they are more circumscribed and have a shorter history.

The biofuels case study provides new perspectives on the relationships between ecosystem architecture and the drivers and timing of changes in market conditions. Thus the research contributes to better business decisions, especially regarding technology.

Over the past twenty years many major companies have evolved from largely self-contained, vertically integrated systems of technology development and adoption to more open systems with a high

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degree of dependency on complex "ecosystems" of external complementors. von Hippel [1] identified external sources of useful knowledge: suppliers and customers; university, government, and private laboratories; and competitors. They create and provide technology across a spectrum from the highly innovative to the mature and commoditized. The technology is embodied in infrastructure, equipment, skilled people, and intellectual property.

What is more, each company shares these ecosystems with major competitors. In the traditional vertically integrated system managers could be directive, employing a company-centric supply chain approach to obtaining required technologies. This approach does not work in today's ecosystems. Instead, major firms must be sophisticated ecosystem shapers and participants, and to do so they must understand the network structures and dynamics of the relevant ecosystems.

The objective of our research is to stimulate and enrich debate regarding the mid-term dynamics of the biofuels market and innovation ecosystem. This is not an attempt to precisely forecast the future. Rather the process should provoke thinking "outside the box" about future market conditions, their implications, and how best to influence the future. The numbers *per se* are less important than the dynamics, trends, opportunities, threats, and conclusions.

2. Previous work on innovation ecosystems

A large body of research into innovation networks and ecosystems already exists. Chesbrough et al. [2] contrast open innovation with traditional vertically integrated closed innovation where internal R&D leads to products that are produced and distributed by the firm. They define open innovation as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation …"

Dhanaraj and Parkhe [3] emphasize the importance of proactive ecosystem orchestration, "Innovation networks can often be viewed as loosely coupled systems of autonomous firms. We propose that hub firms orchestrate network activities to ensure the creation and extraction of value, without the benefit of hierarchical authority."

Quinn [4] goes farther, advocating a strategy of outsourcing innovation, "Strategically outsourcing innovation — using the most current technologies and management techniques — can put a company in a sustainable leadership position. Strategic management of outsourcing is perhaps the most powerful tool in management, and outsourcing of innovation is its frontier. In today's stormy markets, high-level technical, market scanning, sensing and responsiveness skills — and a well-designed platform for continual innovation — are key."

Other researchers have focused on the internal dynamics of innovation ecosystems. The important dynamics include convergence on dominant standards and designs, amplification of variations in market demand, and the evolution of ecosystem architectures. This research emphasizes supplier-customer relationships, recognizing that embedded in ecosystems are supply chains and systems of value creation and capture.

Barabba et al. [5] describe the role of ecosystems in establishing technical standards and dominant platforms. "We believed that three positive feedback processes were important in the telematics industry: (1) building up a large portfolio of apps on the platform; (2) building up 3rd party sales; (3) extending the platform to other vehicle manufacturers. Establishing a widely accepted interface standard was critical to enabling these positive feedbacks."

Croson et al. [6] analyze why variations in demand are amplified within ecosystems. This often is referred to as the bullwhip effect. "The bullwhip effect describes the tendency for the variance of orders in supply chains to increase as one moves upstream from consumer demand. We propose a new behavioral cause of the bullwhip, coordination risk, that arises when players place excessive orders to address the perceived risk that others will not behave optimally."

Fine [7] differentiates between modular and integral architectures. "Modular supply chains consist of relatively flexible and interchangeable relationships among suppliers, customers, and partners. By contrast, integral architectures typically link subsystems with tightly coordinated relationships and distinctive or unique features that cannot be easily connected to other systems."

Pipenbrock [8] builds on Fine's work. He presents a dynamic model of the evolution of business ecosystems, i.e., supply chains and their associated value systems. "Enterprise architectures early in the industry's evolution are integral, for radical product innovation. They then dis-integrate for speed to build a fast-growing market, and for greater cost-leadership and more modest product innovation. As the ecosystem begins to mature, integral enterprise architectures are required for radical process innovation."

The existing body of research concludes that a major paradigm shift has occurred. As Chesbrough et al. [2] observed, "At its root, open innovation assumes that useful knowledge is widely distributed and that even the most capable R&D organizations must identify, connect to, and leverage external knowledge sources as a core process in innovation." It recognizes that innovation ecosystems have complex dynamics that result from the combination of their structure, the behaviors of their components, and changes in their industry.

These analyses are quite valuable but incomplete. First, they focus primarily on the inner workings of ecosystems and less on the dynamics of the markets in which the ecosystems exist. Second, to the extent they consider the market context the paths of cause and effect tend to be unidirectional, i.e., the market affects the ecosystem. In reality the interactions are bidirectional. The ecosystem can have significant effects on the market, e.g., through the establishment of dominant standards and designs.

This paper extends the research on innovation ecosystems in several ways:

- Analyzing how the dynamics of markets affect the adoption of technology;
- Linking the evolution of the innovation ecosystem to the market dynamics; and
- Showing how these interacting dynamics affect emergence of a dominant design.

3. Current research approach

We employ two complementary methodologies: ecosystem mapping and System Dynamics modeling. In order to understand an ecosystem we map the network of relationships and then use a Systems Dynamics model of the relevant market to explain how and why it changes. Combining results from the two methodologies illuminates the interactions between the ecosystem and the market. We analyzed the wind energy and biofuels ecosystems with that approach. Results from the biofuels case study are presented in this paper. The two ecosystems will be compared and general conclusions drawn in a later paper.

Mapping is utilized in social network analysis to provide a visual representation of relationships among parties in an ecosystem or a group. Jeanrenaud [9] is an example. Each party in the ecosystem is represented as a node on a map, and links between the nodes denote relationships. Supplier mapping represents the relationships between integrators and their key suppliers. The supplier mapping divides suppliers into two types: in-house suppliers and external (third-party) suppliers. This differentiation permits analysis of whether having more external or more in-house suppliers improves an integrator's

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