Biodesic 2011 Bioeconomy Update

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Genetically modified (GM) crops continue to see extensive global adoption. Revenues are growing rapidly and are substantially larger than commonly reported. Within the United States, more than 50% of cropland is now planted in GM seed resulting in 2010 revenues of nearly $110 billion. Together with 2010 revenues from biologics of $75 billion and revenues from industrial biotechnology of $115 billion, I estimate that total 2010 revenues from genetically modified products exceeded $300 billion, or the equivalent of more than 2% of Gross Domestic Product (GDP).

U.S. GM Crop Revenues

Farmers continue to adopt GM crops in the United States. As of 2009, approximately 50% of U.S. cropland was planted with GM seed[1]. GM corn, cotton, and soy have all reached approximately 90% market penetration, which may represent the saturation point for these crops (Figure 1). Sugar beets have achieved similar levels of penetration just two years after market introduction. New guidelines from the U.S. Department of Agriculture (USDA) that allow companies seeking approval of GM crops to prepare their own environmental impact studies may speed up the introduction of new strains[2].

Clarifying the Economic Benefits of GM Crops

Sufficient experience with GM crops now demonstrates solid evidence of yield improvements and reductions in primary inputs such as fuel, water, and chemicals (Figure 2). Internationally, a summary of peer-reviewed surveys of farmers in 12 countries found average yield increases generally in the range of 20–30% across multiple strains of GM corn, soy, and cotton[3]. One recent study estimated that on 10 million acres, Bt corn provides the following benefits: $231 million additional revenue from yield gains, a reduction in use of 5.5 million pounds of insecticide, a reduction of 5.5 million gallons of water from reduced insecticide application, a reduction in 70,000 gallons of aviation fuel not used in insecticide application, and improved environmental conditions for non-target organisms and wildlife[4].

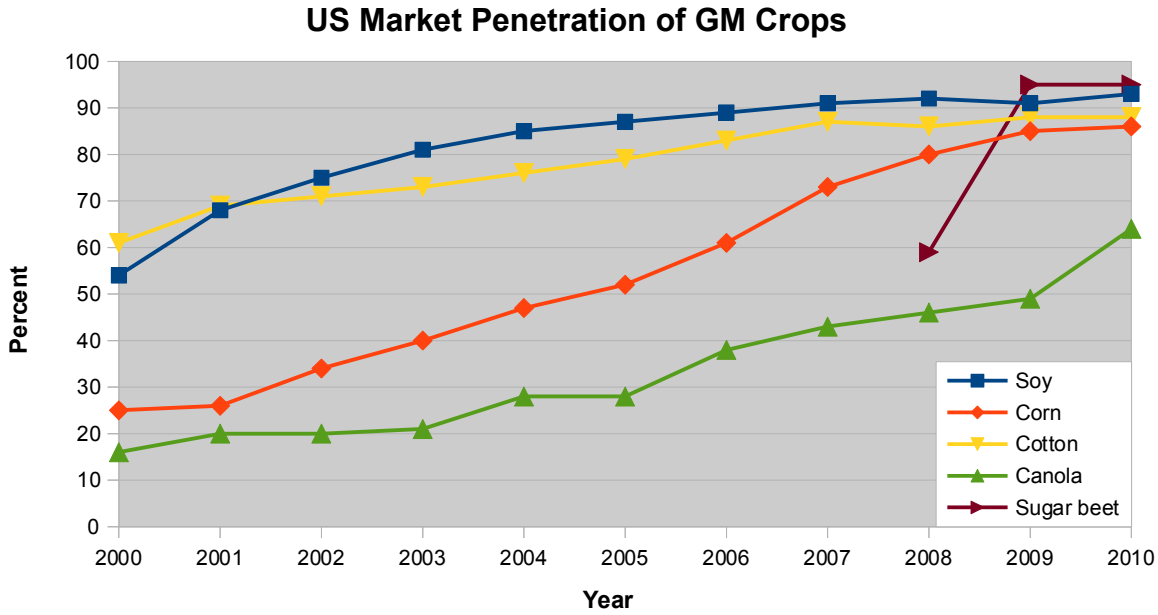

Figure 1: Acreage of GM crops has been increased rapidly, with GM corn, soy, cotton, and sugar beets reaching >90% market penetration. Source: USDA.

The realization of specific yield increases often depends on environmental factors such as the sandiness and moisture content of the soil, which affect the viability of pests and their larvae.

Adoption of GM crops often brings substantial additional benefits. For example, the use of Herbicide Resistant (HR) strains is correlated with an adoption of reduced-till or no-till practices, which result in increased soil carbon and nitrogen content[5]. Moreover, the use of Bt corn has resulted in regional declines in the European corn borer population that are estimated to have saved growers of non-Bt corn $3.9 billion over 14 years[6].

Despite growing evidence of economic benefits, contradictory reports continue to emerge regarding the overall economic impacts of GM crops. These discrepancies occur in large part due to differences in how pesticide use is recorded (for example, by total volume or by active ingredient volume) and similar experimental issues, although a literature review by the National Research Council found substantial variation in performance and yield across different farms and different crops[7]. Given the variability in assessing crop performance, I feel the best indicator of the farm scale benefits of GM crops is simply the continued use and increased adoption by farmers worldwide.

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Proof of demand by farmers can be found in 1) the increase in acres planted and 2) the increase in composite seed price indices of between 30 and 100% for GM corn, soy, and cotton seeds. The price increase includes the effects of demand and greater value (seed plus insecticide in one package, for example)[8]. Finally, farmers also report substantial labor savings (20–30%) from using GM crops in reduced application of pesticides or weed management[9]. For small farmers, in particular, this labor savings can be monetized by using this time for off-farm employment, thereby further amplifying the indirect benefits of planting GM crops.

Putting the Numbers Together

GM Crops

Revenues from GM crops are growing rapidly and are substantially larger than generally reported. A diverse range of publications continue to confuse revenues from GM seed sales

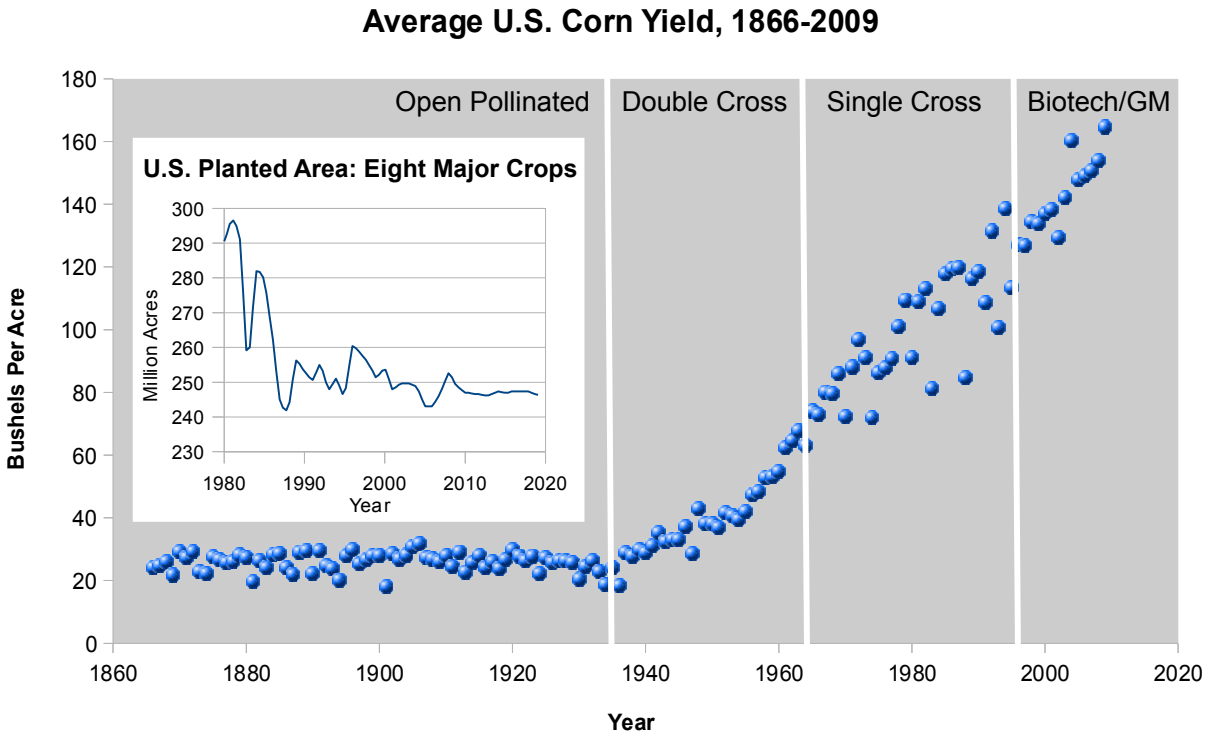

Figure 2: Corn yield improvement over eight decades through breeding and genetic modification. Inset: Total U.S. land under cultivation has declined over the last 30 years[10].

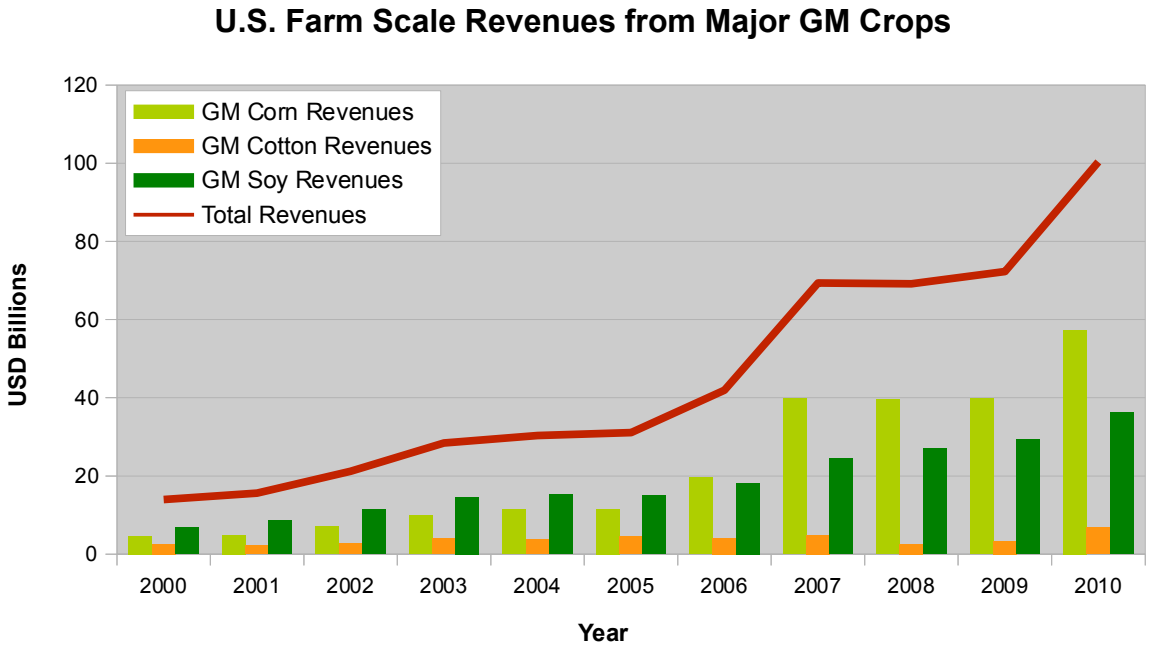

Figure 3: Farm scale revenues from GM corn, soy, and cotton. Source: USDA.

with actual farm scale revenues from GM crops. In 2010, global revenues from GM seeds and associated licensing amounted to $11.2 billion, approximately half of which was in the United States[11]. The sale of GM crops at market, however, earned substantially more. The three largest crops—GM corn, soy, and cotton—earned $100 billion in U.S. farm scale revenues in 2010 (Figure 3). I estimate that GM sugar beets contributed just over $1.5 billion[12], with GM papaya, canola, and other crops contributing roughly another billion dollars. This brings total U.S. revenues of GM seeds and crops to over $105 billion. Continued increases in GM crop acreage in the next few years will certainly raise the total, with revenues from GM alfalfa contributing $1–2 billion dollars next year assuming planting is not again halted by lawsuits.

U.S. 2010 revenues from GM crops was just under $110 billion.

Biologics

Other sub-sectors of the bioeconomy are also growing rapidly. Estimates of global revenues from biotech drugs (biologics) continue to vary widely, ranging from $48 to $138 billion[13]. In 2010 half this revenue, and about half the annual growth, was generated within the United States[14]. Biologics constitute an ever larger share of annual drug approvals, reaching 28% in 2010, largely due to a multi-decadal declining trend in small molecule approvals[15]. Assessing the sub-sector is complicated by the fact that approximately 85% of companies selling biologics are private, accounting for 50% of employment and 27% of sector revenues, with these figures derived from surveys rather than publicly transparent sources such as financial filings[16]. Based primarily on financial filings of public companies, I estimate that 2010 U.S. revenues from biologics were approximately $75 billion.

U.S. 2010 revenues from biologics were approximately $75 billion.

Industrial Biotechnology

Revenues from industrial biotechnology, here defined as fuels, materials, chemicals, and industrial enzymes, continue to display the most rapid growth within the bioeconomy. However, while data on revenues from biologics and GM crops is relatively easy to come by, the same cannot be said for industrial biotechnology. This dearth of quality data is in large part due to the lack of reporting mechanisms for the biotech industry at the level of most national governments; the data that exists is instead collected by private consulting firms and through voluntary surveys by such organizations as the OECD. Data on other economic activity in the United States is generally gathered via the North American Industrial Classification System (NAICS). NAICS codes are used by the Department of Commerce to attribute employment and revenues to those sectors of the economy for which codes are

defined. There are, however, no codes specifically identifying biotechnology-related businesses.

U.S. 2010 revenues from industrial biotechnology were at least $115 billion.

The methodology used here to assess revenues from industrial biotechnology involves surveying multiple reports from governments and private consulting firms and then removing contributions from products that are not obviously derived from genetic modification, such as biodiesel or chemicals purified from natural sources[17]. In particular, it is challenging to disentangle the portion of revenues due to so-called "bio-based chemicals", which to date are unlikely to be substantially derived from genetically modified systems. Various sources put "bio-based chemicals" at 5–10% of total chemical sales as of 2010. Contributing to the challenge, total global chemical sales are reported in the range of $1.8 to $3.2 trillion, a spread of nearly a factor of 1.5. The largest contribution to increasing U.S. revenues from industrial biotech in 2010 was an approximately 30% increase in ethanol sales[18]. Extending prior revenue figures in the subsector, I estimate that 2010 U.S. revenues from industrial biotechnology were at least $115 billion[19].

Revenues are likely to climb sharply starting in 2011 with the market introduction of chemicals, fuels, and co-products such as cosmetics from firms such as Solazyme, Gevo, and Amyris. In particular, I estimate that chemicals produced by the new wave of genetically modified microbes could see sales of nearly a billion dollars next year.

The three aforementioned companies are the most discussed, but many companies that began life as venture capital-funded "biofuels" companies in 2005–2008 have come to the inevitable realization that competing in the global liquid fuels market will be challenging. Consequently, while these companies refine their production processes to reach profitable production of fuels with retail values of ~$1/L, they are beginning to enter markets for higher-value petrochemical replacements that sell for $10–1000/L. The next five years will bring many more entrants into this market, particularly as barriers to entry fall with decreasing costs of modifying and using organisms to produce biochemicals that are drop-in replacements for petrochemicals[20].

And So Goes the World...

Governments around the world see biotechnology as an opportunity for economic development and a route to increased independence and influence. In addition to major investments by growing economic powerhouses India and China, countries such as Indonesia, Pakistan, and Brazil are intent on developing domestic biotech research and development capabilities. Malaysia has bootstrapped itself from receiving none of it's GDP from biotech in 2005 to a self-reported 2.5% as of 2010. Table 1 displays estimates of 2010 biotech revenues, estimated growth, and 2020 target revenues for selected countries[21].

Developing economies are rapidly harvesting the fruits of this investment. Nearly 50% of GM crops are grown in developing countries, with a 17% annual increase compared to 4% for industrialized countries[22]. Yield improvements are thus accumulating faster in developing countries, and increased global yields of GM cotton have contributed to a decrease in price that is reportedly causing California growers to rotate away from cotton to more profitable crops[23]. Growth in revenues from biologics suggests that developing economies are poised to generate substantial value in this sub-sector as well; China's 2010 contribution of 5% of global sales growth is more than double the share of sales themselves[24]. In industrial biotechnology, in addition to substantial domestic investment in technology development, many emerging economies are able to import skills and technology in the form of partnerships with companies looking to use abundant local biomass to generate renewable fuels and chemicals.

The next five years will see a substantial increase in such products entering global markets. New players will emerge constantly, en-

Country	2010 Biotech Revenues	2010 Est. Growth	2020 Target Biotech Revenues
Malaysia	2.5%	25%	10%
China	2.5%	20%	5–8%
United States	>2%	10–15%	NA
India	0.24–0.40%	20%	1.6% (2015)
Pakistan	1.6%	<5%	NA
Europe	<1.0%	5%	NA

Table 1: Biotech Revenues as Share of GDP. Source: Biodesic.

abled in large part by falling cost barriers and proliferating skills and infrastructure[25]. Upcoming Biodesic Technical Notes will focus on global biotechnology investment and shifts in the scale of production as small companies begin to compete directly in petrochemical markets.

About the Author:

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Rob Carlson is a Principal at Biodesic, LLC, an engineering, design, and consulting firm in Seattle, WA. At the broadest level, Rob is interested in the future role of biology as a human technology. He has worked to develop new biological technologies in both academic and commercial environments, focusing on molecular measurement and microfluidic systems. Carlson is the author of the book “Biology is Technology: The Promise, Peril, and New Business of Engineering Life”, published in 2010 by Harvard University Press, which was named to Best Books of 2010 lists by *The Economist* and the writers of *Foreign Policy*. Dr. Carlson earned a doctorate in Physics from Princeton University in 1997.

Notes

1 The Impact of Genetically Engineered Crops on Farm Sustainability in the United States, NAS/NRC, 2010, pg. 30.
2 "New self-reporting for GM crops", Lucas Laursen, Nature Biotechnology 29, 558 (2011)
3 Peer-reviewed surveys indicate positive impact of commercialized GM crops, Janet E Carpenter, Nature Biotechnology 28, 319–321 (2010)
4 NRC, pg. 139
5 NRC, pg. 70
6 NRC, pg. 87
7 NRC, pg. 150
8 NRC, pg. 147
9 NRC, pg. 174
10 Sources: USDA-NASS; Troyer, Crop Science 46.2 (2006): 528; Rupert and Butzen, Crop Sci, 19(2).
11 Global Status of Commercialized Biotech/GM Crops: 2010, Clive James, ISAAA, 2011.
12 Based on 2010 USDA figures for 95% GM sugar beet penetration and an 8% increase in total harvest over 2009.
13 What's fueling the biotech engine—2009–2010 Saurabh Aggarwal, *Nature Biotechnology*, 28(11), November 2010; "Top 30 Biologics 2010 ", R&D Pipeline News, La Merie Business Intelligence. www.bioportfolio.com; Bullish On Biologics, Scientific American Worldview, http://www.saworldview.com/article/bullish-on-biologics
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15 Fresh from the biologic pipeline—2010, Jim Kling, *Nature Biotechnology*, 29(3), March 2011
16 *Biology is Technology: The Promise, Peril, and New Business of Engineering Life*, Robert Carlson, Harvard University Press, 2010.
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21 Biodesic will soon release a report further elaborating global investment in biotechnology.
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23 NRC, pg. 162
24 Bullish on Biologics, 2011.
25 *Biology is Technology*, 2010; "Microbrewing the Bioeconomy", 2011.