Biomass Supply Strategy for Building a Sustainable Cellulosic Biofuel Business

Rajdeep Golecha

ABSTRACT

Companies venturing into the cellulosic biofuels business will be required to make portfolio decisions based on feedstock availability and variations in biomass supplies. Fundamental differences exist in biomass supplies for first-generation corn ethanol and second-generation cellulosic biofuels. While first-generation ethanol in the U.S. is produced primarily from corn, a tradable commodity that is transported long distances, second-generation cellulosic biofuels are produced from cellulosic biomass and there are greater limitations due to transportation distances. As a result, cellulosic biofuels producers will be exposed to local variations in biomass supplies. Studies have shown that 20-30% variations in collectable stover supply are typical. Such large variations translate into business risk and impacts issues associated with sustainability. Hence, companies venturing into cellulosic biofuels will be required to develop strategies to reduce the impact of feedstock supply variations. A sustainable biomass supply chain will need strategies for developing supply market structures, contracting programs with farmers, and a feedstock diversification program that reduces the impact of these large variations. This study focuses on identifying potential options for managers to consider when developing sustainable feedstock supply programs, and key trade-offs that help reduce costs and manage feedstock supply risks.

Key words: Corn Stover, Supply Variability, Feedstock Diversification, Biofuels, Efficient Frontier

INTRODUCTION

Cellulosic biofuels have gained enormous attention in recent years as a result of the focus on climate change. Emphasis has been placed on the advancement of biofuels produced from agricultural and forestry residues [1]. Several commercial-scale cellulosic biofuel plants have been commissioned, and a few are expected to be operational soon [2]. The U.S. EPA (Environmental Protection Agency) target is to produce 76 billion liters per year of second-generation ethanol by 2022 [3,4]. The majority of this is expected to be produced from cellulosic biofuels.

In the U.S., corn stover is considered to be the largest source of agricultural residues for use in cellulosic biofuel production [5]. However, one of the fundamental challenges with cellulosic biomass is long-distance transport and storage [6–13]. Unlike corn ethanol, cellulosic biorefineries will be required to source the biomass locally, exposing them to regional supply constraints [11,12,22,23].

The dependence on regional supply will in turn limit the ability for cellulosic biorefineries to diversify their supply portfolios. In the absence of a feedstock strategy and an optimal contracting strategy between the biorefinery and the farmers, these regional supply demand imbalances in biomass supply will transform into significant variations in biomass price and biofuel supply, potentially creating sustainability issues for cellulosic biofuel business. This is explained in Figure 1.

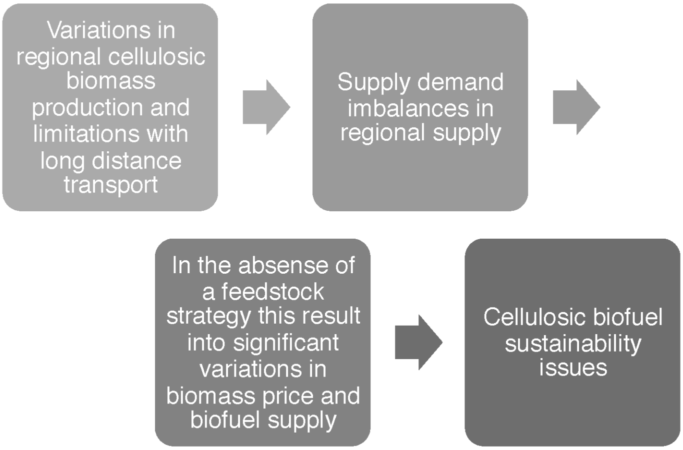


Figure 1. Importance of feedstock strategy for sustainable development of cellulosic biofuel.

In this article, we examine strategies for mitigating the impact of these variations using supply market structure, contracting strategy with farmers, and feedstock diversification strategies. These will aid in designing biomass supply chains, devising biorefinery operation plans, and developing national strategies and policies to facilitate the development of a sustainable cellulosic biofuel industry.

ASSESING BIOMASS DIVERSIFICATION

Annual Variations in Biomass Availability

Variations in biomass supply using corn stover supply in the U.S. provide an interesting example for feedstock variability. Since stover yield is proportional to corn grain yield, we use a stover-to-grain ratio of 1.0 based on previous studies [3,4,6,9,17,18]. Using corn production data from the U.S. Department of Agriculture (USDA) [19], we can quantify total corn stover production in the U.S. Because 100% of corn stover cannot be collected, a minimum amount of stover is required to be left on the field for soil and water conservation purposes and to maintain organic matter in the soil (SOM) [4,18,20]. Assuming the minimum amount of stover left on the field as 3.5 (t ha-1), historical variations in collectable stover supply within a 50 km radius for the U.S. county of McClean in Illinois is shown in Figure 2.

Strategies to Mitigate Biomass Supply Variations

Figure 2 shows that a biorefinery dependent on corn stover supply for biofuel production could be exposed to significant variations in supply. Strategies available to mitigate the impact of such large supply variations are discussed next.

Biomass Supply Market Structure

Regional biomass supply will be likely be dominated by a few farmers, while the demand will be dominated by few major biorefineries. Hence, it is possible that the market structure can take the form of oligopoly facing an oligopsony [21,22]. Presence of such oligopolistic-oligopsonistic structures is common in the agricultural sector [22]. The risks of operating in an oligopolistic-oligopsonistic unconstrained market is high volatility and unstable pricing [22]. To avoid the exposure from the high price volatility in, an optimal biomass supply market

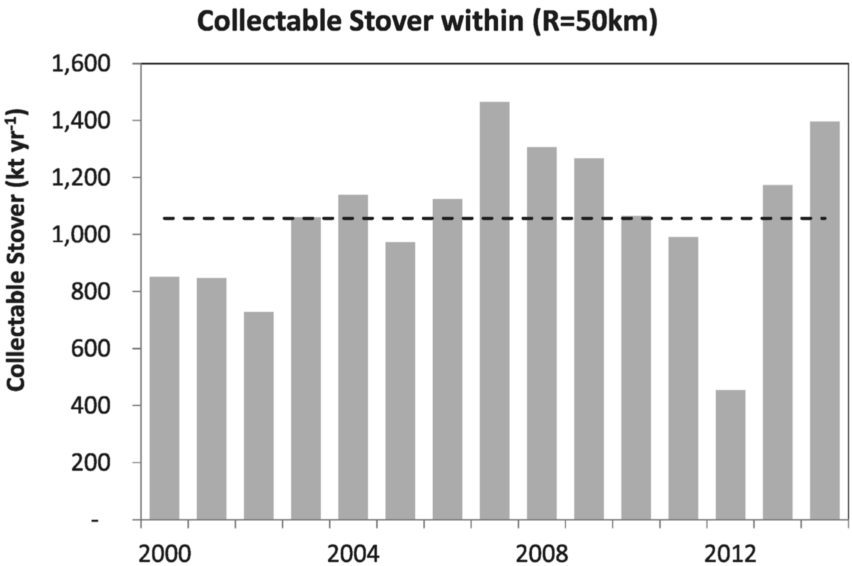


Figure 2. Collectable corn stover within a 50 km radius using 2000-2014 data for the corn producing county of McClean in Illinois. The dotted line shows the average.

structure is required. Considering the large variations in biomass supply, the optimal supply market structure could be a fixed price structure, using a larger than average supply region. Contracting a larger supply region with fixed price contracts could significantly reduce the exposure from volatility in supply, but would also increase supply costs since a larger supply region would need to be maintained. Therefore, biorefineries should evaluate the trade-offs between risk reduction versus the additional cost of maintaining a larger supply region.

This is graphically represented in Figure 3, where R_{Avg} is the radius required for meeting the biorefinery capacity. However, due to year-to-year variation in stover supply, the biorefinery contracts a larger supply region R_2 or R_3.

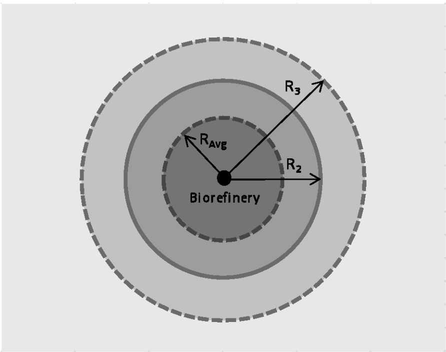


Figure 3. Biorefinery supply radius to meet capacity requirements.

Biomass Contracting Strategy Between Farmers and Biorefineries

Under fixed price long-term supply agreements, the biorefinery pays a fixed price for the quantity of collectable stover from participating farmers. Establishing fixed price agreements requires a sound understanding of trade-offs. The total biomass cost results from intricate relationships among factors that include biomass transport costs, farmer participation, the cost of variation in biomass supply, capacity of the biorefinery, and alternative feedstock availability. Owners of biorefineries will need to understand the relationships among these variables and should consider optimizing the value chain costs holistically. Focusing on one variable and not evaluating these relationships holistically leads to the possibility of suboptimal solutions. In considering the risks associated with each strategy, biorefineries can consider using principles of Modern Portfolio Theory and evaluate based on Return Over Unit Risk (i.e., changes in biomass supply variations for the premiums paid to reduce risks).

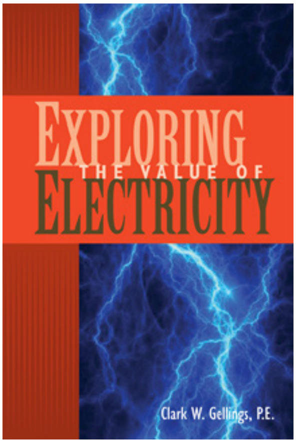
Feedstock Diversification Strategy

The concept of risk reduction through diversification can be explained using the principles of Modern Portfolio Theory [23–26]. If the correlation coefficient between diversifying feedstocks is less than

10% Online Discount
Use Code JR10

EXPLORING THE VALUE OF ELECTRICITY

Clark W. Gellings



Intended for electric utility managers, directors, R&D and power system planners, economists, energy engineers, electrical manufacturers, and others involved in the field, this first-of-its-kind book provides an in-depth look at both the hard facts and some of the falsehoods about measuring the value of electricity. Coalescing the many wide ranging and disparate value estimates, it examines how we might better quantify the significance of avenues by which electricity plays a role in sustaining and improving the quality of life - i.e., via warmth, illumination, transportation, motive power, medical diagnostics, and life-prolonging treatments. The author elucidates the numerous approaches to estimating value, including electricity's contribution toward the U.S. gross domestic product, its role in medicine, and its ability to power communications. Traditional measures such the cost of outages, the impact of storms, the cost of restoring power systems after storms, the value of lost load (VOLL), consumer willingness to pay to avoid outages, and consumer surveys are also discussed.

ISBN: 0-88173-748-8

6 x 9, 254 pp., Illus., Hardcover

$110
ORDER CODE: 0708

CONTENTS

BOOK ORDER FORM

① Complete quantity and amount due for each book you wish to order:

Quantity	Book Title	Order Code	Price	Amount Due
	Exploring the Value of Electricity	**0708**	**$110.00**	
			Applicable Discount	
			Georgia Residents add 6% Sales Tax	
			Shipping $10 first book $4 each additional book	**10.00**
			TOTAL	

② Indicate shipping address: CODE: Journal 2014

NAME (Please print) BUSINESS PHONE

SIGNATURE (Required to process order) EMAIL ADDRESS

COMPANY

STREET ADDRESS ONLY (No P.O. Box)

CITY, STATE, ZIP

③ Select method of payment:
☐ **CHECK ENCLOSED**
☐ **CHARGE TO MY CREDIT CARD**
☐ *VISA* ☐ *MASTERCARD* ☐ *AMERICAN EXPRESS*

Make check payable in U.S. funds to:
AEE ENERGY BOOKS

CARD NO.

Expiration date *Signature*

MEMBER DISCOUNTS—A 15% discount is allowed to AEE members (discounts cannot be combined).
☐ **AEE Member (Member No.________________)**

④ Send your order to:
AEE BOOKS
P.O. Box 1026
Lilburn, GA 30048

INTERNET ORDERING
www.aeecenter.org/books
(use discount code)

TO ORDER BY PHONE
Use your credit card and call:
(770) 925-9558

TO ORDER BY FAX
Complete and Fax to:
(770) 381-9865

INTERNATIONAL ORDERS
Must be prepaid in U.S. dollars and must include an additional charge of $10.00 per book plus 15% for shipping and handling by surface mail.

10% Online Discount
Use Code JR10

SMART GRID PLANNING AND IMPLEMENTATION

Clark W. Gellings

This book describes the elements which must be considered in planning and implementing a "smart grid" electrical delivery system. The author outlines in clear terms how the grid can be modernized in such as way that it monitors, protects and automatically optimizes the operation of its interconnected elements—from the central and distributed generator through the high-voltage network and distribution system, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances and other household devices. Comprehensive in scope, the guide highlights emerging concepts of cyber and physical security, resiliency, and the newest architecture, "the integrated grid." Energy and utility professionals, power system planners, regulators, policy makers and others in the field will gain a broader understanding of how a two-way flow of electricity and information can be used to create an automated, widely distributed energy delivery network.

ISBN: 0-88173-750-X

6 x 9, 520 pp., Illus., Hardcover

$135
ORDER CODE: 0710

CONTENTS

BOOK ORDER FORM

① Complete quantity and amount due for each book you wish to order:

Quantity	Book Title	Order Code	Price	Amount Due
	Smart Grid Planning and Implementation	**0710**	**$135.00**	

② Indicate shipping address: CODE: Journal 2014

NAME (Please print) BUSINESS PHONE

SIGNATURE (Required to process order) EMAIL ADDRESS

COMPANY

STREET ADDRESS ONLY (No P.O. Box)

CITY, STATE, ZIP

Applicable Discount	
Georgia Residents add 6% Sales Tax	
Shipping $10 first book $4 each additional book	**10.00**
TOTAL	

MEMBER DISCOUNTS—A 15% discount is allowed to AEE members (discounts cannot be combined).
☐ **AEE Member (Member No.___________________)**

③ Select method of payment:
☐ **CHECK ENCLOSED**
☐ **CHARGE TO MY CREDIT CARD**
☐ *VISA* ☐ *MASTERCARD* ☐ *AMERICAN EXPRESS*

Make check payable in U.S. funds to:
AEE ENERGY BOOKS

CARD NO.

Expiration date *Signature*

④ Send your order to:
AEE BOOKS
P.O. Box 1026
Lilburn, GA 30048

INTERNET ORDERING
www.aeecenter.org/books
(use discount code)

TO ORDER BY PHONE
Use your credit card and call:
(770) 925-9558

TO ORDER BY FAX
Complete and Fax to:
(770) 381-9865

INTERNATIONAL ORDERS
Must be prepaid in U.S. dollars and must include an additional charge of $10.00 per book plus 15% for shipping and handling by surface mail.

+1.0, the variance of the diversified feedstock will be less than the variance of any individual feedstock. This explains how diversification reduces variations in overall feedstock supplies. In the case of cellulosic biomass, constraints with long distance transport of bulky biomass materials and their storage requirements limit the ability for feedstock diversification. Regardless, some level of diversification is still achievable. In the U.S. corn belt, biorefineries can diversify corn stover with switchgrass, a native perennial grass that has the potential as a dedicated energy crop using marginal cropland [27–29], and produces comparable ethanol as corn stover [30]. Wheat straw is another alternative for feedstock diversification [31–34]. In Figure 4, we show the historical yield for corn stover, wheat straw and hay (as a proxy for switchgrass since historical data is not available for switchgrass).

The impact of feedstock diversification on reduced biomass supply variations is evaluated using USDA 2000-2014 yield data (t ha-1) of corn stover, wheat stover and hay stocks for the mid-western U.S. state of Iowa. The variations are analyzed by first using 100% corn stover, and then assessing a scenario using diversified feedstock portfolio, using 50% corn stover, 25% wheat stover and 25% hay. Results show undiversified corn stover as having a 17% variation, while the diversified feedstock has 10% variations. This results in a 40% reduction in biomass supply variations through diversification of feedstock. Biorefineries should also consider the cost of diversifying feedstocks and develop optimal diversification considering risk reduction vs. premiums paid.

CONCLUSIONS

High year-to-year variations in the supply of cellulosic biomass create challenges for the cellulosic biofuel industry. Through this study we identify strategies that biorefineries can use to reduce the impact of these variations.

Establishing an optimal supply market structure between biorefineries and farmers would reduce the exposure from price volatility under oligopoly-oligopsonist market structures. Biorefineries and farmers can use fixed price structures and maintain a larger supply region to reduce exposure due to feedstock supply disruptions, thus reducing financial risks.

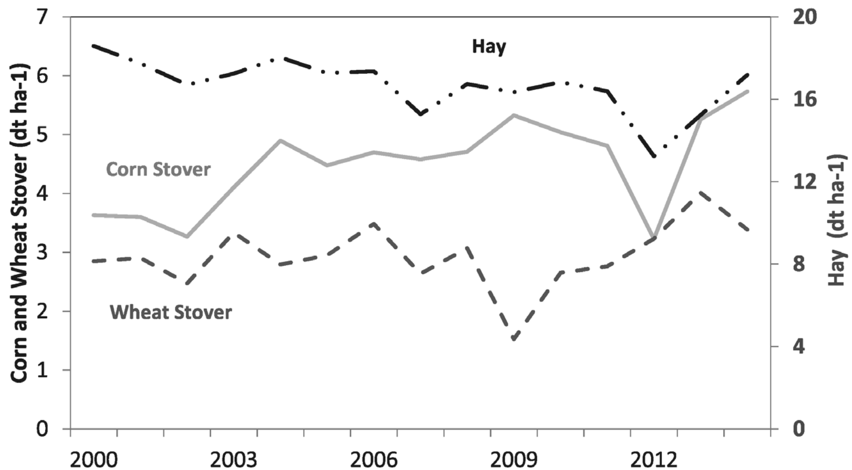


Figure 4. Corn Stover, Wheat Stover, and Hay Yield.

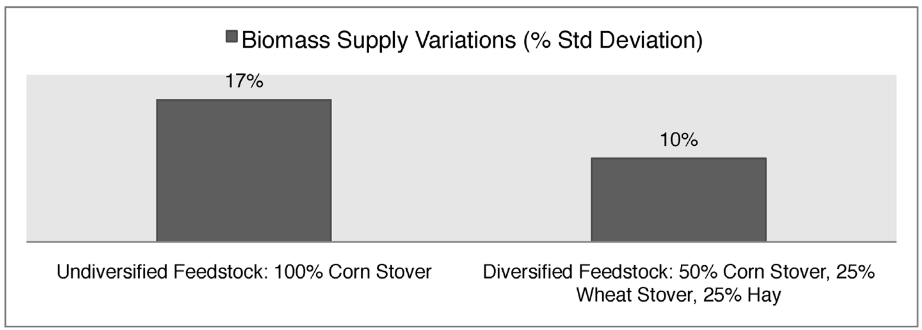


Figure 5. Impact of Feedstock Diversification for the U.S. State of Iowa.

When establishing fixed price contract agreements with participating farmers, biorefineries should consider using a biomass cost function that minimizes biomass costs by evaluating trade-offs. Using the principles of Modern Portfolio Theory, the ideal framework for such contracts should consider the Cost of Unit Risk reduction.

Diversifying feedstocks is an effective strategy to minimize the impact of supply variations. This assessment determined that diversification of corn stover with wheat straw and hay reduces variations in biomass supply by more than 40%.

These results have important implications for biomass supply chain design, policy, and national-level assessments for cellulosic biofuel production. Developing biomass densification technologies and long term storage technologies that enable long distance transportation of cellulosic materials biomass will allow managers to create more effective feedstock diversification strategies.

References

[1] R.E.H. Sims, W. Mabee, J.N. Saddler, M. Taylor (2010). An overview of second generation biofuel technologies, *Bioresour. Technol*. 101, 1570–1580. doi:10.1016/j.biortech.2009.11.046.

[2] T.R. Brown, R.C. Brown (2013). A review of cellulosic biofuel commercial-scale projects in the United States, Biofuels, Bioprod. Biorefining. 7, 235–245. doi:10.1002/bbb.1387.

[3] Biomass Research and Development Initiative (2008). Increasing feedstock production for biofuels: economic drivers, environmental implications, and the role of research. Washington, D.C. 146 pp.

[4] W.W. Wilhelm, J.M.F. Johnson, D.T. Lightle, D.L. Karlen, J.M. Novak, N.W. Barbour, et al. (2011). Vertical distribution of corn stover dry mass grown at several US locations, *Bioenergy Res*. 4, 11–21. doi:10.1007/s12155-010-9097-z.

[5] A.F. Turhollow, R.D. Perlack, L.M. Eaton, M.H. Langholtz, C.C. Brandt, M.E. Downing, et al. (2014). The Updated Billion-Ton Resource Assessment, *Biomass and Bioenergy*. 70, 149–164. doi:10.1016/j.biombioe.2014.09.007.

[6] R.D. Perlack, A.F. Turhollow (2003). Feedstock cost analysis of corn stover residues for further processing, Energy. 28,1395–1403. doi:10.1016/S0360-5442(03)00123-3.

[7] S. Tokgoz, A. Elobeid, J. Fabiosa, D.J. Hayes, B.A. Babcock, T.H. Yu, et al. (2005). Emerging biofuels: outlook of effects on U.S. grain, oilseed, and livestock markets. <Go to ISI>://CABI:20083002548.

[8] D.R. Petrolia (2007). The economics of harvesting and transporting corn stover for conversion to fuel ethanol: A case study for Minnesota, *Biomass and Bioenergy*. 32 (2008) 603–612. doi:10.1016/j.biombioe.12.012.

[9] W. Alex Marvin, L.D. Schmidt, S. Benjaafar, D.G. Tiffany, P. Daoutidis (2012). Economic Optimization of a Lignocellulosic Biomass-to-Ethanol Supply Chain, *Chem. Eng. Sci*. 67, 68–79. doi:10.1016/j.ces.2011.05.055.

[10] A.A. Rentizelas, A.J. Tolis, I.P. Tatsiopoulos (2009). Logistics issues of biomass: The storage problem and the multi-biomass supply chain, *Renew. Sustain. Energy Rev*. 13, 887–894. doi:10.1016/j.rser.2008.01.003.

[11] L. Axelsson, M. Franzén, M. Ostwald, G. Berndes, G. Lakshmi, N.H. Ravindranath (2012). Perspective: Jatropha cultivation in southern India: Assessing farmers' experiences, *Biofuels, Bioprod. Biorefining*. 6, 246–256. doi:10.1002/bbb.
[12] B.M. Jenkins, L.L. Baxter, T.R. Miles, T.R. Miles (1998). Combustion properties of biomass, *Fuel Process. Technol*. 54, 17–46. doi:10.1016/S0378-3820(97)00059-3.
[13] F. Preto (2007). Strategies & Techniques for Combustion of Agricultural Biomass Fuels Advantages of Energy from Biomass. http://www.gtmconference.ca/site/downloads/presentations/1B3 - Fernando Preto.pdf.
[14] M. Carriquiry, X. Du, G.R. Timilsina (2011). Second generation biofuels: Economics and policies, *Energy Policy*. 39, 4222–4234. doi:10.1016/j.enpol.2011.04.036.
[15] J.R. Hettenhaus, R. Wooley, A. Wiselogel (2000). Biomass Commercialization Prospects in the Next 2–5 Years.
[16] A.D. Maker (2007). Estimating a Value for Corn Stover, Iowa State Univ. Extension, *Ag Decis. Mak. Doc.* FM-1698. 4–7.
[17] J.M.F. Johnson, R.R. Allmaras, D.C. Reicosky (2006). Estimating source carbon from crop residues, roots and rhizodeposits using the national grain-yield database, *Agron. J.* 98, 622–636. doi:10.2134/agronj2005.0179.
[18] R.L. Graham, R. Nelson, J. Sheehan, R.D. Perlack, L.L. Wright (2007). Current and potential U.S. corn stover supplies, Agron. J. 99, 1–11. doi:10.2134/agronj2005.0222.
[19] USDA, Crop Production Historical Track Records (2013).
[20] W.W. Wilhelm, J.M.F. Johnson, D.L. Karlen, D.T. Lightle (2007). Corn stover to sustain soil organic carbon further constrains biomass supply, *Agron. J.* 99, 1665–1667. doi:10.2134/agronj2007.0150.
[21] F. Wirl (2009). Oligopoly meets oligopsony: The case of permits, J. Environ. Econ. Manage. 58, 329–337. doi:10.1016/j.jeem.2009.04.006.
[22] C.E. Ferrer (2013). Oligopsony-Oligopoly the Perfect Imperfect Competition, Procedia Econ. Financ. 5, 269–278. doi:10.1016/S2212-5671(13)00033-6.
[23] H. Markowitz (1952). Portfolio Selection, J. Finance. 7, 77–91. doi:10.2307/2329297.
[24] W.F. Sharpe (1964). Capital Asset Prices: A Theory of Market Equilibrium Under Conditions of Risk, J. Finance. 19, 425–442. doi:10.2307/2329297.
[25] B. Blackwell (1959). Illustrative Portfolio Analysis, in: Portf. Sel. Effic. Diversif. Investments. Wiley, Yale University Press.
[26] E.F. Fama (1977). Risk-adjusted discount rates and capital budgeting under uncertainty, J. Financ. Econ. 5, 3–24. doi:10.1016/0304-405X(77)90027-7.
[27] M.A. Sanderson, R.L. Reed, S.B. McLaughlin, S.D. Wullschleger, B. V. Conger, D.J. Parrish, et al. (1996). Switchgrass as a sustainable bioenergy crop, in: *Bioresour. Technol*., pp. 83–93. doi:10.1016/0960-8524(95)00176-X.
[28] S.B. McLaughlin, L.A. Kszos (2005). Development of switchgrass (Panicum virgatum) as a bioenergy feedstock in the United States, *Biomass and Bioenergy*. 28, 515–535. doi:10.1016/j.biombioe.2004.05.006.
[29] A. Kumar, S. Sokhansanj (2007). Switchgrass (Panicum vigratum, L.) delivery to a biorefinery using integrated biomass supply analysis and logistics (IBSAL) model, Bioresour. Technol. 98, 1033–1044. doi:10.1016/j.biortech.2006.04.027.
[30] G.E. Varvel, K.P. Vogel, R.B. Mitchell, R.F. Follett, J.M. Kimble (2008). Comparison of corn and switchgrass on marginal soils for bioenergy, *Biomass and Bioenergy*. 32, 18–21. doi:10.1016/j.biombioe.2007.07.003.
[31] T.A. Maung, C.R. Gustafson, D.M. Saxowsky, J. Nowatzki, T. Miljkovic, D. Ripplinger (2013). The logistics of supplying single vs. multi-crop cellulosic feedstocks to a biorefinery in southeast North Dakota, *Appl. Energy*. 109, 229–238. doi:10.1016/j.apenergy.2013.04.003.
[32] R.G. Nelson (2002). Resource assessment and removal analysis for corn stover and

wheat straw in the Eastern and Midwestern United States - Rainfall and wind-induced soil erosion methodology, *Biomass and Bioenergy*. 22, 349–363. doi:10.1016/S0961-9534(02)00006-5.
[33] R.D. Perlack, B.J. Stokes, L.M. Eaton, A.F. Turnhollow (2011). U.S. Billion-Ton Update. https://bioenergykdf.net/.
[34] F. Talebnia, D. Karakashev, I. Angelidaki (2010). Production of bioethanol from wheat straw: An overview on pretreatment, hydrolysis and fermentation, *Bioresour. Technol*. 101, 4744–4753. doi:10.1016/j.biortech.2009.11.080.

ABOUT THE AUTHOR

Rajdeep Golecha is an industry expert in Bioenergy. His expertise is in business portfolio development for a sustainable Biofuel business, and commercial optimization to reduce input costs. He has served as the Commercial Manager for a major energy company's multi-billion dollar biofuel portfolio, where he led the development of Cellulosic Biofuel projects, and brought significant improvements to capital efficiency and reduction in feedstock (biomass) costs through effective feedstock supply and business strategies. His current focus is on developing optimal market structures for Cellulosic Biofuel programs.