Workers future studies to incorporate price variabilities among

workers and hence the labor costs by ± 50% for the 1 hectare algae cultivation, microalgae cost varied by more than ± 15% from the baseline scenario. Furthermore, capital cost of equipment, piping and fittings and reactor costs as well as nutrients and raw materials costs are important parameters in commercial scale microalgae cultivation as evident from the economic sensitivity analysis. With the increase in microalgae productivity and decrease in different parameter costs, it was possible to reduce microalgae cost by approximately 35% to 2340 $ t-1 from the baseline of 3602 $ t-1.

Figure 5. Economic sensitivity analysis of commercial microalgae cultivation in flat panel photobioreactors. Baseline microalgae cost in a hypothetical plant in New Mexico is 3581 $ t-1 3. 4 Geospatial effects on microalgae productivity and production costs Geospatial variations for the different locations studied resulted in variable microalgae productivity as shown in Figure 4. These productivity differences along with differences in electricity and land costs resulted in variable microalgae production price at a given location. The land and electricity prices for the different locations studied were adopted from previous study on microalgae production in open raceway ponds 5.

In order to simplify the economic analysis in the present study, it was assumed that only land and electricity costs were different among the regions whereas raw materials and nutrients costs and employee wages were assumed constant for the different locations. To determine microalgae price variation in a more robust manner, it is important in future studies to incorporate price variabilities among all the different factors including land

and electricity costs. Resultant microalgae production costs in commercial scale photobioreactors for the four geographical locations are provided in Figure 6. There is a widespread variation in microalgae production cost in flat panel photobioreactors among the regions, ranging from about 9, 940 $ t-1 (~10 $ kg-1) for the Twin Cities region to about 3000 $ t-1 ($3 $ kg-1) for Phoenix (Arizona) region. This was expected as microalgae productivity in Phoenix was more than three times than the productivity in Twin Cities region. Further, it can also be inferred from the analysis that microalgae price was similar for Phoenix, San Diego and Albuquerque, ranging between approximately 3000 $ t-1 (3 $ kg-1) to 3600 $ t-1 (3. 6 $ kg-1), primarily owing to the similar climatic conditions among the locations characterized by high temperature and long hours of sunshine over an extended period of the year indicating that they may be more suitable for microalgae cultivation.

Thus, from a design perspective and to ensure commercial and economic success microalgae cultivation in outdoor photobioreactors, geographic location does play a critical role and they need to be carefully considered. Also, quantifying microalgae production costs accurately is essential as upstream feed stock production has important implications on microalgae downstream processing and corresponding price of value-added chemicals and bioproducts and 34. Figure 6. Cost of microalgae cultivation for the different locations3. 5 DiscussionThe main motivation of the current analysis was to determine microalgae productivity in outdoor commercial scale flat panel photobioreactors and corresponding economic analysis to determine minimum microalgae price. The mathematical microalgae growth model developed in the study was based on detailed heat and mass transfer integrated with biological growth kinetics.

The model also incorporated the effect of climatic factors to quantify microalgae price for a location. Experimental data regarding year round operation of microalgae cultivation in outdoor flat panel photobioreactors are scarce. Researchers reported microalgae productivity potential in parallel flat panel photobioreactors located in Netherlands, France and Algeria to be 12000 t km-2 year-1, 12900 t km-2 year-1 and 15900 t km-2 year-1, respectively 18. For the Tuscan coast in Italy, productivity of T. suecica was reported to be 3600 t km-2 year-1, based on 8 months of operation 35. Therefore, the result from this study for the four US geographical locations, ranging from 3800 – 13000 t km-2 year-1 is comparable to earlier work. On the basis of the microalgae productivity model, a detailed economic analysis and sensitivity analysis was performed to determine the economic feasibility and the associated sesitivities of commercial scale microalgae cultivation in flat panels. There is limited work available on the economic implications of microalgae cultivation in outdoor flat panel photobioreactors.

Mostly, techno-economic analysis pertaining to microalgae-based biorefinery deals with downstream processing of microalgae to bioproducts with the assumed values for microalgae productivity or microalgae feedstock costs 8–10, 26, 27. These assumptions at the start of analysis often lead to widespread uncertainties. Furthermore, there has been no effort on incorporating the effect of geospatial variabilities on microalgae production costs. Microalgae production costs in large scale photobioreactors ranging from about 0.

50 – 29 $ kg-1 have been reported in literature 3, 36–38. Recently, Tredici et al. performed a detailed economic analysis of T. suecica cultivation in a 1 ha plant in Tuscan coast of Italy and Tunisia and determined a price of 14.

5 $ kg-1 and 7. 3 $ kg-1, respectively 25. The economic analyses in the present study, corresponding to microalgae price range of 3 – 10 $ kg-1 for the different locations, are comparable to the price obtained by other researchers. The critical factor contributing to algae costs in the present study and other techno-economic analyses can be attributed to differences in microalgae productivity potential due to geospatial variations as well as engineering design specifications.