What is Sustainable Manufacturing?
Background information for 2014 project for 2.83 and 2.813

The term "sustainable manufacturing" is now used commonly. There are conferences on the topic, company reports, web pages, journal articles and claims about products or activities being improved so they are sustainable.[1] But at a recent NSF workshop that brought experts together to discuss the topic, they identified the lack of a good definition for "sustainable manufacturing" as one of the biggest challenges that faces this research area. While there are many who are investigating the general topic of sustainability in other fields of study, there seems to be little efforts to apply their results to manufacturing. The issues encountered in these investigations are challenging; they include scale, aggregation, valuation and weighting, substitution, interactions and responsibility to name just a few. And they go immediately beyond engineering into such disciplines as economics, moral philosophy, ecology and planetary physics. Yet engineers and manufacturers need to make decisions and so they need to adopt working definitions until more is learned about the topic. The three most common fallback positions are:

(1) DEFINITION: the Brundtland Commission report (WCED 1987) provides the most commonly used definition of sustainable development,
(2) SCOPE: the so-called Triple Bottom Line (TBL) provides the commonly used scope of the sustainability problem used by many companies, and
(3) EVALUATIONS: rely on comparisons with previous or alternative examples using normalized performance measures to provide estimates of progress.

These appear to be good starting positions and are widely embraced by many manufacturers. But will the actions suggested by (2) and (3) above, lead to the goals in (1)? And is the goal (1) properly stated? In this project, we will critique this current approach to sustainable manufacturing by comparing it to the guidelines offered in other

[1] A quick Google search will provide many examples

fields, in particular; 1) Triple Bottomline[2], 2) Economics[3], 3) Resilience[4], and 4) Planetary Physics[5].

Briefly a couple of our observations are as follows:
1) The Brundtland Commission statement has been widely used by manufacturers, engineers, economists and others as a working definition of sustainability. It defines sustainable development as, "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs". This definition is compatible with several other interpretations of sustainability (Arrow 2004). Two key points are that it focuses on "needs", a rather modest goal (Dasgupta 2010), and it differentiates between the present and future generations. This distinction, between current needs and future needs is important and will tend to shift the emphasis from what is provided for human well-being today (usually a flow of goods and services), to what is needed to support human well-being in the future (usually a maintenance or accumulation of stocks). For example, when applied to a company, the emphasis would shift from profits (today), to assets such as factories and equipment (with potential for tomorrow).

2) The general scope of sustainability as suggested by the TBL identifies three important realms to consider for sustainability accounting including the economic, social and environmental realms, (also sometimes referred to as people, planet and profits). These general areas roughly agree with the point of view of the economists referenced here, who have interpreted the Brundtland Commission statement to mean that the present generation must maintain a certain "productive base" (stocks) that can be inherited by future generations (Arrow 2004). This productive base would include three types of capital; manufactured capital, human capital and natural capital.

The general idea is that any action for example by a company or a nation will have consequences in multiple domains and each of these should be considered. The specific

[2] see for example (Graedel and Allenby 2011)
[3] see for example (Elkington, 1994, Slaper 2011 and Arrow 2004), (Dasgupta 2001, 2007, and 2010) and (UN 2012)
[4] see for example Gunderson and Holling 2002)
[5] see for example (Rockstrom 2009)

notion behind each domain however can be quite different between the TBL and the productive base. For one thing there are no firm definitions on how to measure the components of the TBL (Slaper 2011), while economists go into considerable detail about the calculations to be employed to estimate the productive base (Arrow 2004; Dasgupta 2001, 2007, 2011; UN 2012).

When identifying multiple objectives, as these two approaches do, one must consider how to make tradeoffs between the different realms. One approach is to identify numerical equivalency between the different realms. This will require some scheme of evaluation and weighting and ultimately will lead to the possibility of substitution. This line of reasoning, of course, leads to the so-called weak sustainability position. The alternative is to manage the different realms as a portfolio. This approach will require a detailed narrative of the different consequences and possible trade-offs. While such a scheme may seem desirable for any small scale individual case, it would essentially make it impossible to calculate a sustainability metric at the large scale.

We believe that the development of the notion of sustainable manufacturing as a research area requires a calculation scheme that is both numerical and consistent with a large scale framework for sustainability. We should keep this in mind while reviewing alternative points of view.

3) We should not put all of our eggs in one basket though. We can easily anticipate significant criticism for adopting a weak sustainability approach that allows substitution between resources. And rightly so, it is not at all clear that natural capital can be easily substituted. Therefore a prudent companion measure would be to simultaneously track natural capital by itself. This approach can borrow from whatever advances and insights are developed by the economists, which will necessarily focus on aggregated accounts in financial units. So the manufacturing community should compliment this approach by tracking physical accounts aggregated for the entire enterprise in absolute units. Some companies already make this kind of data available, while others offer only normalized improvement measures e.g. CO_2 emissions per unit of sales. While there is value in

normalized values, for completeness, the data for absolute measures should also be made available. Rockström outlines several areas of concern (Rockström 2009). A good framework for absolute accounting is offered by (Allwood 2010) who estimates CO_2 emissions from the world manufacturing sector. Another example for absolute direct energy accounting, can be found in (Gutowski 2012). Bakshi outlines how to connect industrial activities to ecosystem services (Bakshi 2011).

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