Panel Discussion on Broader Applications and Impact of SFF

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Manufacturing research in the area of SFF is at a crossroad. Can the relatively mature SFF technologies have a significant impact on other areas of manufacturing research? Can other technologies be effectively adapted to leverage concepts and principles developed from SFF? What were the pioneering developments in SFF that accelerated original research and development? What is the next significant direction for SFF and from where will the resources come to advance the new course? These questions were posed to a panel of leaders in the field of SFF. This paper is an edited transcript of the panel discussions.

Moderator (Harris Marcus): The objective of this panel discussion is to determine how a relatively mature technology such as SFF can have an impact on a wide variety of other technologies bringing value added benefit and what can be done to promote this happening.

<u>Question 1</u>: Where can the relative mature field of SFF have a significant impact on other technologies?

Clint Atwood: First of all, I want to acknowledge the success of the rapid prototyping (RP) industry. The use of rapid prototyping is pervasive around the world. One of the main findings of our recently completed World Technology Evaluation Center (WTEC) study of Europe, was that the use and applications of RP was the same as it is in the U.S. Therefore, we can assume that other regions of the world have access to RP and use it for similar applications. The industry is not as large as many of us had anticipated, but it is certainly widely used and still growing. I also want to acknowledge the contributions of many people in this audience as well as others who have made contributions to the success of the industry.

Now, related to the question, I believe that most rapid prototyping units are stand-alone units that are used to fabricate individual parts during the design process. One consideration is the integration of RP systems with other manufacturing processes that would allow the use of these technologies to be an option for fabrication complex, low volume production parts. Traditional design and production processes do not exploit the capabilities of SFF processes. Having the option to add material to existing parts or fabricate complex features would reduce part count and minimize assembly in many cases.

A potential new market and application is in microsystem packaging. For example, packaging of microscale components for biomedical devices that can provide real time internal analysis of body functions may be a niche market for micro RP systems. Micro fluidic packaging is another possible new application. Very small micro-components need to be assembled and packaged to make usable products. Clearly, at this point in time, to use SFF processes to fabricate production quantities, the parts have to be small. Another area for consideration is developing a true multi-axes direct metal deposition system. Historically, machine tool hardware, such as rotary tables or robotic arms, have been used for multiple axes deposition. These multi-axes positioning systems may not be optimal for SFF direct metal deposition processes. An optimal multi-axes system would allow for repeatable accurate deposition on any surface. Another potential growth area is in reverse engineering of parts that have no documented design specifications. Another area is the validation of materials for complex critical components in aerospace, automotive, and other areas where people tend to say, “well, we have always done it this way with known materials.” Validation of materials would help minimize risk and encourage use of SFF technologies for fabrication of complex parts.Finally, what we learned during the WTEC Study in Europe is that even today materials development is still a valid growth area.

Kent Firestone: I took a different approach to this question. My main issue is with the statement relative to the mature field. From an RP standpoint the industry is definitely mature. We have a lot of different technologies and the competition has really brought the machine prices down so it’s mature from that perspective. I think from the rapid manufacturing (RM) perspective, we are really just touching the tip of what can be done. When I was working at DTM in process development, we realized that the future is going to be determined by how well we can meet manufacturing process specifications and tolerances. We did a lot of work and went out and talked with people that didn’t have RP equipment and tried to figure out “why don’t you have it and what is it going to take to adopt the technology?” What we came back with is basically that repeatability was a huge issue. We knew that and we felt we had done a very good job of improving repeatability or reducing variation in the past few years but they were still telling us it was not good enough. From my perspective, if you split the industry into RP and RM, RM is just beginning where we can go, and I think the true advancement is going to depend on how well we can improve the repeatability of the systems. As far as how it integrates into the other technologies out there today for manufacturing, there are basically two ways: it’s a competitive technology in certain areas and I think as Clint stated it is really a complementary technology as well. We have to figure out where it fits in the process.

David Alexander: I would like to build upon an area that was mentioned earlier, the field of additive manufacturing. I think that within the last decade several processes have been developed that we can integrate into the manufacturing flow path for aerospace components. These are the LENS process developed at Sandia and AeroMet’s LAM process. We have worked in the last 5-6 years on additive manufacturing for gas turbine engine components. For roll-forged engine cases we have a situation where the **buy**-to-fly ratio for some of the cases is approximately 12:1. This means that you are going to lose 90-92 percent of your material in downstream processing. But if we roll out a slim profile forging and then deposit the features that really dictate the overall case weight, the axial flanges, bosses, and the nozzles, we think we can **reduce** the buy-to-fly ratio to something in the neighborhood of 5:1. This brings in a number of things you have to worry about. We know that the deposition process is going to be the highest unit cost operation, so we would like to deposit features to near net shape in an effort to minimize the amount of deposited material. To do this we will need dimensional control of both the deposited features and the substrate, because as your deposits get finer in detail you are concerned whether or not the features will have the correct dimensions and will be in the right places after finish machining. We also know that as you go to more near net shape deposition the cost of deposition will increase due to a slower deposition rate.

Phill Dickens: I think for me I am really concentrating on the RM rather than RP because I think RP is done. That might be a bit of a sweeping statement. Really I think the main thing in terms of RM is the geometry capability, but we still have some material issues and so on. For me, as a manufacturing engineer, an additive process gives terrific freedom in geometry. And I think that's going to be exploited in lots of different areas. For example one of the areas is medical. The medical people really don't seem to have a real way of making geometry in terms of hard or soft tissue. I think this is a terrific opportunity for the RM world, there are going to be lots of other areas where we are going to be able to make use of geometric freedom whether it is in engine design, or improved combustion. I think adding in sensors to objects, whether they are products themselves or medical implants, is another area. The ability to add in sensors as part of the build process will give designers a lot more freedom. And then there are lots of other potential areas, for example in construction, you can imagine that we can use this additive process to give us a lot more complex surfaces, maybe for sound absorption, insulation or whatever and other completely new areas like "smart clothing". So there are lots of different areas where I think this way of working is going to have an impact on other technologies. And I think we are really only just scratching the surface at the moment. I think the potential is fantastic, but it is going to take a lot of work to keep it going.

Moderator: We will take a question or two for the panel on this topic. At the end we are going to have the audience participate in terms of questions or comments. Are there any burning questions? Since there are no questions at this time we will move to the next question.

Question 2: What changes do the other technologies have to make so that they can use SFF type approaches as a cost effective way of doing business?

Phill Dickens: I think if we exclude the processes themselves, the SFF processes and the materials that go with them, the biggest change that I see is in the areas of CAD and design. We had the talk from Rik Knoppers (TNO) earlier representing multiple materials. Certainly multiple materials is going to be an issue but for things like textures and very complex geometries, I really don't see existing CAD systems coping with that. And to go back to my previous comment on geometry capability, if we are really going to exploit that capability, existing CAD systems will not do that. We have got to have a big change in this other area of technology that we are not generally working at in this environment. One of the big application areas for this is going to be personalized goods or custom made goods and that might be body implants or consumer products. We are going to need ways of capturing body data.For example, if we take the ejector seat that I showed earlier, you can capture the geometry of someone's backside with laser scanning.That is no problem, but that is not necessarily the geometry you are interested in. You probably are also interested in the bone structure. So it starts to get quite complicated, and then going back to CAD we need a completely new way for customers to interact with the design process if we are going to get into personalized or custom designed goods and that will mean quite different looking design systems.

David Alexander: I think for SFF to really make an impact on the cost of doing business we need to integrate the processes into the existing manufacturing process flow paths. Areas in which I am most familiar with are the casting and forging industries. Most of the major forging and casting houses are now familiar with the additive manufacturing concept. A number of them have been involved in government contracts with us making prototype parts. However, I don't think all the companies within these industries have embraced the concept of additive manufacturing. You have to understand that both of these industries (forging and casting) have over the last few years been squeezed by cost reductions. I think most of us have heard about lean manufacturing and eliminating waste in the value stream. Some of the companies may view the cost reductions associated with additive manufacturing processes as a potential threat to their revenue and profit. For additive manufacturing to be implemented in these industries, we would like to see a deposition unit on the factory floor within the confines of the forge shop or the casting facility. This helps you in several ways. One, the additive manufacturing operations will now be fully integrated into the manufacturing flow path and you do not have to worry about separate queue times at your deposition vendor or service bureau. In addition, when producing a component you will eventually have something go wrong and the part will not make final check out. Here additive manufacturing can be used for in-process repair. In the end it is all about the business case and the competition between the different processes. When you incorporate SFF processes into your manufacturing lines, it really has to be compelling. If your potential cost savings are relatively small, a commodity manager may respond by saying that he can negotiate such a price reduction from the vendor of the incumbent process. So to make the SFF processes cost effective they have to have a big financial impact. In addition, there are going to be certain risks involved with the new process, such as deposited material properties, process robustness and the vendor base.

Kent Firestone: I want to expand a little on what David just said. I agree, I think we have to get SFF into the process flow, the current manufacturing process flow to really have it be accepted. I think one way to do it is make it cost effective. I also think there has to be a compelling technical reason as to why they would want to bring this in. Cost may not be the best driver. Being able to give a customer better mechanical properties than what they can currently get with the material they are using is one advantage you might see. Obviously you cannot compare nylon with aluminum, but let's say you compare nylon with another type of nylon, there may be things that can be done with any process, but especially in my experience with the SLS process to improve those mechanical properties and make them stable. That is a big draw back currently. You get stable, improved, reliable mechanical properties of your finished parts with a cost reduction. Now you really have something that they might consider and maybe a time bonus on top of that. I think, finding ways to integrate into the existing process flow is what is important, and I think again what we are all trying to say is the changes really have to come from us, from the SFF community.

Clint Atwood: I agree with everything that has been said, but in addition to that, there has to be a cultural acceptance of parts and components fabricated using these types of technologies. Designers of manufactured components have to understand the value and the unique capabilities SFF technologies offer. When we talk about cultural acceptance for instance, that also goes into the medical field. There are rigid requirements for components to be used for medical applications, especially for implantable devices. The transition from rapid prototyping to rapid manufacturing will not happen overnight. However, with persistent inclusion and education of the design and manufacturing community, I do believe it will happen. An example is functionally graded materials. We have devoted significant resources developing techniques for processing functionally graded materials and multiple material combinations. Most people ask, "What can I use FGM's for?"

(Comment from audience)

Joe Allison: I am Joe Allison with Solid Concepts. We are a service bureau or custom manufacturer is the way I like to refer to us. Because, as Clint (Atwood) was saying, when we integrate all the technologies together it is just one complementary tool, so we don't refer to ourselves as an RP service bureau anymore, we are a custom manufacture. I noticed answering that question, two of you, and I have heard it come up a lot here, I am referring to the medical industry and specialty implants. We have done quite a bit of stuff for medical applications but it is more instrumentation type stuff. We haven't really seen growth in that industry yet. I would say aerospace and some other industries, at least in our little corner of the world, have been out pacing that. Do you guys see a big potential there that I am not seeing from our corner of the world in implants and other medical stuff. How do you see them in comparison to aerospace, business machines, consumer products and the other industries? Is there a floodgate waiting to open there?

Phill Dickens: I think there is but it is long term stuff. It is not stuff generally that we are likely to see in the next 10 years, most of it. If we get into tissue generation then I think we are really looking at 20 years. I think for me the big advantage in terms of the medical area is the low volume, generally small objects that you are making, and very custom and specific as well as extremely complex I think fits the RM concepts very well.

Clint Atwood: I want to add to that, when you look at micro-systems and micro-devices and then at what is coming next in nano-technology. Here, again you can make a component really tiny but how do you make several microcomponents into a product? I know for a fact there is a lot of interest in microscale components for many applications including biomedical. My thought is, if we can work in parallel, while micro-sensors are being developed for different applications, we can develop SFF technologies to package them into products.

Moderator: Question 3: What were the key developments that allowed SFF to become a relatively mature field in a reasonable time frame and what would be required, including research, to make the next advances in using and adapting the technology possible?

Kent Firestone: We have to look at the platforms to see where we are today in a segmented view, we have to look at the RP applications and the RM applications. I think from an RP perspective, what really helped advance the technologies to where they are today was improving control systems and materials development. A lot of the development in the last few years has been focused on materials. I think it indicates that we have a quasi-suitable platform to do the work that we need to do, but now there are all these new applications that are coming out. I think that is going to continue to drive it. From a manufacturing perspective you probably could use some material improvements, but I think you are still going to have to focus more on the platform stability side of things to really see the growth there that we have seen in the prototyping sector.

David Alexander: Unfortunately I wasn't involved in SFF when it started so I asked the manager of our RP department about his early experience in the technology. He said that the early materials for SLA models were acrylate based and there were a lot of problems with distortion and shrinkage of the finished products. But in 1994 there was a switch to epoxy resin based materials which was a real key, one that allowed him now to deliver concept parts to engineers that had the full shape, that were dimensionally stable and had the surface finish needed. He had fewer problems with SLS. There really weren't any material problems; it was an evolution of the machine and the software associated with it. As far as the items we think are necessary to make our applications go further in the future, at least from my user standpoint, there are two areas that people are already working on, so these are not new ideas. We really need to have full control of the machine process, a closed loop process control that takes the operator mostly out of the picture. Another item we would like to see is real time NDE. When we are involved in deposition type technologies, you are going to have hiccups; you are going to have some porosity and lack of fusion. The last thing you want to do is to generate a microstructural defect and then bury it under many layers of subsequent good material. We would like to know about the formation of microstructural defects as soon as possible. In addition, the detection of defects through real time NDE may help you determine that your process parameters are incorrect or that outside influences are affecting your process in a manner that your deposition parameters are not able to offset.

Phill Dickens: That is an interesting point about the closed looped control because that is something that I have been pressing for in RP and I still don't believe that we have got there with any of the machines or any of the processes. We have got some but very little. For me this is like deja vu, if you go back to about 1990 and the problems then and I think the major problem then was getting the data to drive the process. The number of people that used a decent CAD system to produce the data was small and the number of CAD systems out there that could produce useful data was almost nonexistent. Until we had more use of CAD and .stl files we couldn't do anything. It was the CAD and .stl files that really kick started the use of RP. The other area that we were really struggling with was again material properties. If you think back to the early days of stereo lithography, the material properties weren't very good and everyone talked about parts fracturing on the table, and accuracy and speed were still problems. We are still going to have those problems again, but instead for prototyping we are going to have them for manufacturing. They are the same issue, but they are just coming around again and we have got to solve them for a different output, a much more demanding output.

Clint Atwood: The question that I answered was what happened that enabled RP or SFF technologies to be successful and as Phill (Dickens) stated earlier, one of the enabling technologies was CAD solid modeling. It started out with Pro Engineer and some other very complex software, and then came along Solid Works and the development of the ..stl file that became a defacto industry standard. In addition, much of the success can be attributed to the formation of industry partnerships to help guide the development of SFF technologies. While collectively developing technology we are developing applications for industry partners who are often from different industry segments. I will tell you that at Sandia, the reason we became involved in RP was to make patterns for investment casting; that was the only reason. We developed a consortium that was focused on that single application and one of our major contributions to the RP industry was developing the processes required to use SLA and SLS patterns for investment casting. In addition to that, I think a large part of it has been the inclusion of SFF technologies and developments in professional societies. If you look at the manufacturing societies such as the Society of Manufacturing Engineers (SME), they started a new association, the Rapid Prototyping Association, to focus on sharing the developments and new applications of SFF technologies. The material associations, ASM, and others have had numerous forums to discuss SFF materials and the development of the technologies. ASME has had, for the past ten years, a separate forum for SFF technologies and, in fact, Chuck Hall received the Ennor award a few years ago. Others such as the Laser Institute of America (LIA) have provided opportunities through the ICALEO Conference. The bottom line is that there has been a lot of direct marketing through service bureau, OEMs, and others, and there has been a lot of indirect marketing through conferences which I think has really raised the awareness of these technologies not only in this country, but worldwide. As a community we need to continue to participate in forums that educate others and ourselves about the advances and possibilities for SFF technologies. This will help facilitate the transition from RP to RM.

Moderator: Any questions from the floor? Then we will move on to the next and last question.

Question 4:We have heard a lot of the things that may be done, that should be done; where would the resources come from to promote the various issues that have been discussed?

David Alexander: Within the aerospace community the resources are a combination of internal company funding and government contracts. Usually, the initial concept phase is company funded, developing it at least to see if the concept is going to be feasible; after that funding is often sought through government contracts. In this next phase, you are not only in the process of continued materials development, but also in characterizing the mechanical and physical properties. The final phase is taking the process you have developed, perfecting it and moving it to the factory floor. At the same time you are collecting more material properties, normally on multiple lots of material and obtaining material from more than one source. As you get closer to production implementation, company funding becomes a greater portion of the total funding picture. I might say that within this whole process, you are constantly being monitored by some type of stage gate or technology readiness level process. You are being monitored for technical progress, business case development, and whether or not the infrastructure is there. When you get ready for manufacturing, are the machine tools going to be ready for you? If you are going to source to the outside, will a vendor base be available for you? You must pass each gate review to go to the next level. You have to face the fact that there is no guarantee you are going to get funded to the very end. Programs do get terminated mid stream, where you have met technical challenges that could not be solved or the business case was not pervasive enough.

Kent Firestone: I think there are two basic areas that advancements are going to come from. The first is machine manufacturers, but I think if we rely on machine manufacturers to make all the advancements that are needed for the manufacturing field, we are going to be in the same boat as we are right now 10 to 20 years down the road. What this tells you is really it is up to the users, it is up to the people applying this technology that are opening the new applications and opening up the new markets. They are really going to have to drive this and where they get the funding from I am sure will be a variety of sources. Maybe SBIR grants or things like that, but what I think has to happen is there has to be an active role played by the people that are developing the applications. That is going to require them to support it, much like the early adopters of RP technology were required to make it to work for their application. We are faced with the same kind of thing, and we just have to make it work. You are going to have to spend your own time and money in developments to improve the process to the point where it meets the requirements you need. I don't want that to sound like a cop-out, but I think it is our responsibility. The people who really need the machines or the processes to perform at a certain level are going to have to take some responsibility to get them there.

Clint Atwood: I think it is going to be no different than how resources have been identified and provided up to this point. What I mean by that is that all the stakeholders are going to have to contribute, and funds are going to have to be leveraged. It is obvious that government is going to continue to support the transition from RP to RM. As you know, there is a huge emphasis in this country on manufacturing. For example, NASA has been a very strong contributor to this development and use of SFF technologies, and I believe it will probably continue to support developments in the near-term and long-term. NSF, DARPA, ONR, and others will likely continue to support as well. I also believe industry will continue to participate in the development of new applications. Another funding source is the investing of royalties from intellectual property for new and advance technology development.

Phill Dickens: I agree with everything that has been said so far on this point. There are really the two main funding sources and they are really long and short term and we have some really long-term stuff. Such as the medical stuff or we have some generic stuff such as standards. We really have no standards for example in this area at the moment and it is going to need a significant input to sort out the standards. How do we test the materials? Well if we are testing steel we have all that sorted. How do you test a functionally graded material? I have no idea. What standards do we have for these machines? We have virtually no standards. We have an enormous gap there at the moment. I really don't think companies, whether they are machine suppliers or the users, are going to be able to direct money to meet that. That has to come from government bodies of one sort or another through some sort of route. Then we have the near term market applications, which I think will be very much driven by companies and partially or wholly funded by companies.

Moderator: We now have a few minutes left to direct questions towards the panel or comments on what has been discussed. There is still a question that has been touched on. The industry has got to want to use this technology in the manufacturing mode and in order for them to use it they have to change some of the ways they design, some of the stuff Phill (Dickens) talked about today so this fits in an economic way and has an economic impact. There are people here that know a lot more then I do, is there anyone that wants to comment on that?

Dave Bourell (University of Texas-Austin): I think we as a community can learn from the computer industry, from the way they have developed. We as users of computers have an insatiable desire for speed. However fast it is, our desire is for it to be faster. I think one of the areas that all the SFF technologies need to move into is they need to be faster i.e. really be rapid. I think we can open new markets if we can decrease our build time by an order of magnitude and when we do that I think we can open more new technologies if we close that loop by another order of magnitude. I haven't really seen at lot of work recently, well actually there have been several talks today where people have talked about speed. Speed is going to be one area that maybe isn't getting a lot of attention that should be. The other lesson that I think we should learn from computers is I doubt that there is anyone in the room that is operating a DOS system right now. Everyone is running Windows and the reason why is because Bill Gates or someone made the computer smart enough that dumb people like me can use it without a lot of training. I think that is another area that is probably addressed by software issues and the CAD issues. We need to look at ways to take these SFF technologies and smarten them up so much so that we can use them in a more intuitive manner and perhaps make it less fearful for someone to engage with those machines to actually do the work. I think those are two things along with a lot of other things that might have an impact.

Moderator: I would like to comment on Dave's suggestion for speed. Speed alone without reproducibility and reliability will mimic the computers "garbage in-garbage out" syndrome. Although speed will assist in the RM mode I do not think it will be the pacing item.

Chadee Persad (University of Texas-Austin, Institute for Advanced Technology): I have been observing this SFF technology since its birth here at Texas. Several times, I have gotten an update on what is happening. One of the things I really think you need to pay some attention to is **affordability**. One of the cost metrics we use is dollars per gram. This technology still seems to be as $100 per gram technology. You have to look at the application, for example when looking at manufacturing there aren't many $100 per gram parts. You have to look at some remanufacturing costs. For example, from my experience, you rebuild parts at those kinds of costs [$100 per gram]. For example if you did a pump shaft bearing surface rebuild, you would put down a few grams of material and then grind, so it takes you something like 16 man hours to complete the job. That adds up to more than $100 per gram in remanufacturing costs. Therefore, you have to look at the very high value side of remanufacturing as one of your entry points for thus SFF technology.

Moderator: Any comments from the panel?

Clint Atwood: I think what we need to look at are niche markets instead of trying to be all things to all people. Niche markets, as you said, are identifying areas where these unique technologies can do things that no other technology can. Examples are: picking and placing material on existing parts; multiple materials, laminated materials, and functionally graded materials. Another option for improvement, as Dave Rosen (Georgia Tech) said this morning, is the development of and open architecture controller for SFF processing systems. It took the machine tool industry thirty years to adopt open architecture; hopefully it won't take that long for SFF technology to do the same thing.

Joe Allison: We are talking about what can be done to promote this happening and that is going to move it to the mature state. I agree, I think prototyping is already mature. Everybody uses the technology and the tolerances are acceptable for prototypes in some cases and in some cases subsequent CNC machining is more necessary, if you need material properties or need to get more accurate. The frontier now is RM and I can tell you that I don't have any problems with the pricing or breakeven points. There is all sorts of potential out there at the price that we can do RM parts for, to start getting into a market. We don't need to do the ones where they need a million cosmetic pieces; there are plenty other markets. The present speed is OK. especially since there is a limit you hit when people stop asking for it to be faster. There are discrete incremental steps where you need it faster and faster, then you hit a plateau and it is OK. For instance the Vanguard HS just hit one of those plateaus. I can load that machine, start it up in the morning and start loading parts on it and no matter how many parts I put on there, it's done the next morning and that's a plateau. The only place to go from there is starting it and having it done in the next hour. Nobody's expectations are jumping that far. Where it all breaks down is where we are out there pitching it, and here are the material properties we got. Nylon has a lot of applications where the material properties are good enough. Where it really breaks down is when we are told here is our engineering drawings, here are our requirements and you start going but you cannot have those tolerances and you cannot have that surface finish. That is where it really breaks down and perhaps you miss a couple deliveries because the equipment breaks down a lot. What that really comes down to is that there is a lot of development along a lot of the stages and in this room I see most of them. They are the reason I come here because I find it really exciting. This is the inventive level, people coming up with ideas that can be done and the next is proof of concept, proof that it can be done, and the next one is transitional and that is the longest, hardest part, it is the eighty-twenty rule. This proof of concept, even though it seems a lot of work to you guys, is really only ten percent of the work, and the rest is all a lot of effort in that transitional stage. It takes years to get to that point where the customers are completely confident. That is what makes customers buy is confidence in that product and proof of concept does not develop confidence, it gets them interested but they buy based on confidence and lot of money has to go into developing that and the people spending that kind of money are people like us and we are doing it on speculation. There are other big companies, Pratt & Whitney's, and they are spending a lot of money on speculation. It is kind of like if you go to build a building and lease it out. If you are lucky you've got a leaser all ready before you break ground. If you don't, you break ground speculating that you will go find someone. In 13 years of business I haven't had one customer yet say I am going to give you this money on the speculation that you can get from here to there. They talk about it and get interested but they don't actually cut that check. There is a lot of money that has to be spent to get that last twenty percent and we have to spend the eighty percent of the money and it has to be done on speculation. And I think that is why a lot of people go for the incremental approach to changes. It is really hard to write a big check based on speculation of something that is going to happen tens of years from now. I hope our government helps out in areas like that because maybe they have long-term goals in mind.

Moderator: That completes the time available for this panel discussion. The panel and the audience have brought out many areas of future needs in the SFF/RP/RM layered manufacturing approaches to enhance its impact.