Final Project Report

Development of Multi Fiber Mini Mill Technology for the Production of Composite Fiberboard Panels From Agricultural and Wood Residue.

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Acknowledgment

I wish to thank the following people for their assistance and input on this project. Without their help I could not have accomplished all the work necessary to bring the project to completion. Their assistance in regards to the project and the sharing of their knowledge has been greatly appreciated.

Erwin 'Bud' Sholtz and Mike Bandli of the ADD grant program, for their assistance in familiarizing me with the ins and outs of the program, and for providing me the necessary contacts in regards to hemp fiber.

Chris Edwardson, Pat Donahugh, Xianzhi Quan and Gerald Bushley of the Natural Resources Research Institute of Minnesota for their assistance in the lab and for sharing their thoughts and knowledge in regards to this project.

Mark Meuller from the Northwest Regional Planing Commission of Spooner Wisconsin for his introducing me to the program and his assistance in writing the application.

The farmers, growers, processors and development council members who helped supply the raw fiber, without which this project would have been impossible.

Don Mente and Limei Lu at BASF for their assistance in regards to the binding and release agents used in the project.

Mark Joel And Gerry Hooper, my colleagues at Allwood / Allfiber for their patience, understanding and assistance with this project.

Agricultural Development and Diversification (ADD)

The following information is provided to familiarize the reader with the scope and intention of this project.

Project Summary

Allwood Machinery has teamed up with Allfiber Industrial and Engineering of Decatur Al, to provide turnkey plants from conception through completion, for the small-scale production of specialty particleboard, MDF and HDF composites. These plants will each produce from 18,000,000 to 120,000,000 square feet of composite per year. Our target is the production of non-commodity products produced from agricultural fibers and agricultural fiber, waste wood blends.

The boards we will be producing will be designed to use the agricultural fibers to provide strength with less weight. We also intend to make them water resistant/ waterproof, fire resistant, decay and insect proof, and formaldehyde free. These materials will be geared towards providing substrates for value added products such as millwork and molding core stock, cabinet side panel and back panel cores, cabinet doors, laminated flooring cores and other materials we wish to hold in confidence at this time.

The agricultural fibers we tested were straw from wheat, soybeans and oats, flax, and hemp. The fillers we examined were straw, flax and hemp by-products from the processing of these plants for their fiber, as well as waste wood products from various sources.

The goal of these trials was to produce sample product for testing and evaluation and for showing prospective customers and investors whom will then build particleboard, MDF and hardboard mills in Wisconsin and other areas. Each mill will require a minimum of 25,000 tons of fiber per year and between 30 to 50 employees. The mills will produce at least 18,000,000 square feet of board per year each.

Identification of Need

There is a robustly growing demand for composite fiber panels and boards used for building materials, furniture, cabinets and moldings. The composite panels as used herein include products known as oriented strand board, medium density fiberboard and high-end particleboard. The market for these materials is growing at 2,000,000,000 to 4,000,000,000 square feet per year worldwide. The US demand for these products is estimated at nearly 50% of the total worldwide market. The composite panels replace plywood at a time when there is growing environmental pressure to restrict the harvest of mature and old growth forests.

Within the last two decades there have been important advances in the use of agricultural fibers such as soybean stalks, wheat stalks and other fibers for the production of medium density fiberboard. Within the last ten years several plants using agricultural fibers have been built in Kansas, North Dakota, Minnesota and Manitoba. These are large-scale plants which require financial investments upwards of $75 to $250 million dollars and require agricultural fibers to be collected from a large geographic area.

Allwood/Allfiber of Medford Wisconsin, Greensboro North Carolina and Decatur Alabama, Is a corporation that was assembled to provide the sales, engineering, installation, commissioning and support of Mini Mill particleboard plants. These plants are relatively small operations that use wood waste and/or agricultural fiber to produce composite panel board products. These products can include particleboard, MDF, HDF and OSB or substitutes their of.

Working in association with Allwood Machinery and Allfiber Industrial Engineering, a consultant in the agricultural fiber composite board industry, Allwood/Allfiber Inc. has collaborated with an Italian machinery manufacturer, Pagnoni Impianti to design a small scale press line with an annual production capacity of 25 to 80 million square feet. The mini mill is designed to use 25,000 to 190,000 tons of fiber from an assortment of agricultural and wood materials. The agricultural fibers could include wheat and oat straw, soybean stalks, flax or industrial hemp. Wood fibers could include sawmill residue, old pallets, construction debris and even logging residue. Its anticipated that a composite panel mini mill will be able to pay $30 to $40 dollars per ton for fibers thereby generating additional markets and incomes for farmers. In some cases, waste wood or agricultural fibers maybe available at a lower price. Processed into composite fiber panels, each mini mill is expected to generate sales of at least $6,000,000 to $25,000,000 annually for commodity products and considerably more for specialty products.

The design and specifications for the mini mill machinery are complete by Pagnoni. The next critical step in our market investigation was to produce sample panels from various agricultural and wood fibers and to conduct laboratory tests for a variety of physical standards including: modulus of rupture, modulus of elasticity, hardness, internal bond, moisture content, thickness swell, linear expansion, waterproofing capability, and fastener retention. This project with assistance from the ADD program has accomplished a critical milestone in the development of this potential industry in Wisconsin and the nation.

Statement of Project Objectives

- To produce sample composite panels using agricultural residues, wood residues and bonding agents to confirm the specifications of Pagnoni Impianti designed mini press

- To subject the composite sample panels to a battery of ASTM and tests for industry standards

- To provide technical and economic data to establish the overall feasibility of composite mini mill technology

- To provide materials for potential customers for testing and demonstration

- To use the results of this project to develop one or more customers for the purchase of composite mini mill technology.

Results and Applicability to Development

- Approximately 31 different blends of sample composite panels were prepared using a number of different recipes and mixes of agricultural and wood residues. From 1 to 4 samples of each blend were produced at thickness' of between 3/8' to 7/8" thick. Sample panels were then produced in dimensions of 4 feet by 8 feet by _ and _ inch thick. Based on availability, sample boards were prepared using agricultural residues of soybean stalks, Durum, Winter and White wheat and oat straw fiber, flax and hemp, and wood residues of sawdust and dunnage fiber. Testing was also done using flax and industrial hemp fiber as an additive. I also did some testing of different blends of the bast and hurd fibers from the hemp.

- New composite products were created which have met industry standards based on laboratory analysis. Testing has shown these samples to exceed industry standards.

- The basic elements of composite mini mill technology using agricultural and wood residue technology were proven. The ability of these mills to make rapid product changeovers will allow custom or "designer" board products to meet very specific customer requirements.

- A new company has been established that will conduct sales of composite technology. The company will undertake engineering and design of composite mini mills, source and provide equipment and manufacture specialized components where not readily available from equipment vendors. This company, going by the name of Allwood/Allfiber Inc. presently has offices in Medford WI, Greensboro NC, and Decatur AL.

- Within two years, we expect to develop a new Wisconsin company that will be established to manufacture and sell composite panels using agricultural and wood residue. The expected investment required for the composite mini mill is expected to be in the order of 5 to 15 million dollars. The mini mill will employ about 30 to 50 people. The mill will create a new market for agricultural fibers for farmers and will remove thousands of tons of wood waste from our landfills and wood smoke from our air.

Plan of Work

This project consisted primarily of producing prototype product samples at the Natural Resources Research Institute (NRRI) Laboratory of the University of Minnesota Duluth. This lab has a press and related equipment to produce composite sample panels to the specifications we required. The lab also has the capability to test the samples for the appropriate industry standards. It is one of the only labs in the United States, which has the capability and willingness to perform this type work for outside customers.

1. Planning and mobilization: I collected sample fiber from several locations in Wisconsin, Iowa, Washington State, Minnesota and North Dakota. My hemp samples came from Ontario and Manitoba Canada, as it is not yet legal to grow this fiber in the US.

2. With assistance from the researchers at the NRRI lab in Duluth MN I conducted preliminary evaluation on all of these sample panels. After each batch that I ran was tested, I modified the blend where applicable to achieve specific results. I was finally able to use 2 of the specific blends that I developed to run full size panels using hemp. I begged the assistance of one of my customers to have some of the panels ripped, and machined into product for evaluation and comparison to a product that they presently run. This product was quite impressive and I now have close to 200 feet of sample product to show potential investors and customers for the plants we anticipate building. I also have enough full size panels to make several pieces of display furniture, again for showing to potential investors and customers.

3. Time and budget constraints did not allow me to make full size sheets of straw-based particleboard. We do have the material ground and are waiting for available lab time to run this material into particleboard.

4. For hemp sample panels, I have identified several sources of hemp fiber in Canada. These people have been quite helpful in supplying fiber.

5. The flax fiber I used was acquired in western North Dakota. Flax used to be grown for producing linen. This material has fallen from popularity because of its cost. Flax is now being grown for its seed. Linseed as it is known is a source of oil for paint, ink and plastics. Ironically the biggest drawback to using linseed as a basis for these materials is the cost and availability. It is not that the plant can't be grown but that it is now difficult to get rid of the fiber. The material is so tough you can't plow it down and it is becoming illegal, and is certainly improper, to burn it off the field. Farmers who grow flax for the seed in North Dakota have to bail up the flax straw and haul it to a dumpsite at the edge of their fields. It is sometimes being used as snow fence or is being stacked to provide animal shelter, but mostly it is being left to rot. The particleboard I made from this material is very strong. If a market developed for the straw, a parallel market would surly develop for the seed stock at the same time.

6. Importing a pickup truck full of hemp was an experience. Processed hemp is legal to import. Being that it is hemp, however, raised lots of red flags at the border crossing.

The material had to be inspected, tested for THC content and then classified. Determining a classification for the processed material was actually the most difficult part of bringing in the material. I had a combination of bast fiber and hurd fiber. The customs officer finally decided that I was bringing in textiles and charged me a duty accordingly. The entire process at customs took me 4 hours.

Particleboard and MDF Selected Property Requirements

The following information was obtained from the Buyers and Specifiers Guide from the Composite Panel Association. These are the standards used for specifying different grades of particleboard and MDF and reflect the ANSI standards in use presently.

Particleboard Grades

H High Density, generally above 50 lb./ cu. ft.
M Medium Density, generally between 40 and 50 lb./ cu. ft. This is the most common type.
LD Low Density, generally below 40 lb./ cu. ft.
D Manufactured Home Decking
PBU Underlayment

MDF Grades

HD High Density, generally above 50 lb./ cu. ft.
MD Medium Density, generally between 40 and 50 lb./ cu. ft.
LD Low Density, generally less than 40 lb./ cu. ft.

Other Grades

OSB Oriented strand board, a structural material.

Grade	Internal Bond, psi	Modulus of Rupture, psi	Modulus of Elasticity, psi	Screwholding, face	Screwholding, edge	Formaldehyde, ppm
H-1	130	2,393	348,100	405	298	0.3
H-2	130	2,975	348,100	427	348	0.3
H-3	145	3,408	398,900	450	348	0.3
M-1	58	1,595	250,200	NS	NS	0.3
M-S	58	1,813	275,600	202	180	0.3
M-2	65	2,103	326,300	225	202	0.3
M-3	80	2,393	398,900	247	225	0.3
LD-1	15	435	79,800	90	NS	0.3
LD-2	22	725	148,700	124	NS	0.3
PBU	58	1,595	250,200	NS	NS	0.3
D-2	80	2,393	398,900	NS	NS	0.2
D-3	80	2,828	449,600	NS	NS	0.2
HD	110	5,000	500,000	350	300	0.3
MD<21mm	80	3,500	350,000	325	250	0.3
MD>21mm	80	3,500	350,000	300	225	0.3
LD	40	2,000	200,000	175	150	0.03

Allwood Allfiber, Inc.

Trial Panel Test Results

On a blend for blend basis the results of the test panel trials are listed below.
MDI Resin was used on all these samples

Sample Number and Material	Density	Internal Bond, psi	Modulus of Rupture, psi	Modulus of Elasticity, psi	Screwholding, face	Formaldehyde, ppm	Grade
3,4,5,6/ Durum Wheat, standard grind	38,4 to 41.6	47.4 to 51.6	2,375 to 2,972	401,000 to 448,000	NA	Undetectable	Fail
7/ Course ground Flax	39.6	103	1944	320,000	NA	Undetectable	M-1, M-S, PBU
8/ Durum, Flax Mix	42.7	83	BLOW	-->	-->	Undetectable	
W1 through W5 / Winter Wheat, Standard Grind	40.7 to 49.2	87 to 109.6	2,479 to 3,859	382,000 to 597,000	NA	Undetectable	M-1 through M-3/ PBU/ D-2/ D-3
W6 / Winter Wheat, Standard Grind	36.7	63.1	1,992	298,000	NA	Undetectable	M-1, M-S, LD-1,LD-2 PBU
S1 & S2/ Soybean Straw, Decorative (course) Grind	44.9 to 46.7	63.4 to 67.6	NA	NA	NA	Undetectable	
Hemp 1 through Hemp 5/ Very course to course Grind	40.4 to 45.3	100 to 151	2,577 to 3,762	332,000 to 537,000	NA	Undetectable	M-1 through M-3,/ PBU/ D-2, D-3
Hemp 1-1 Through Hemp 1-33/ course Grind low density Hurd Only	25.9 to 28.4	52 to 75.4 65	665 to 1,158 920	112,000 to 190,000 155,600	183	Undetectable	LD-1, LD-2
Hemp 1-4/ Course grind Medium Density, Hurd Only	38.5 to 40.2	83 to 114 99	1,932 to 2,123 2,027	353,000 to 367,000 360,800	292	Undetectable	M-1, M-S, M-2, M-3/ LD-1, LD-2PBU

Sample Number and Material	Density	Internal Bond, psi	Modulus of Rupture, psi	Modulus of Elasticity, psi	Screwholding, face	Formaldehyde, ppm	Grade
3-1/ Low Density Raw Hemp/ course Grind	30.6 to 31.2	27 to 46 36.1	927 to 977 952	215,000 to 222,000 294,400	NA	Undetectable	LD-1, LD-2
3-2/ Very Low Density Raw Hemp/ course Grind	21.4 to 23.7	22 to 25 24	294 to 330 312	70,000 to 81,000 75,300	NA	Undetectable	Fail
AW1-1 through Aw1-7 And AW5-1 through AW5-3 White Wheat	42.8 to 45.2	118 to 143	3278 to 3655	540,000 to 601,000	243	Undetectable	M-1 through M-3, PBU D-2, D-3 MDF MD
Hemp fiber With Urea Formaldehyde resin	Panel crumbled	Catastrophic Failure					Fail
Hemp Fiber with Phenol Formaldehyde Resin	42	<30					Fail

Sample Description

Samples 3,4,5,6: These panels were produced from Durum wheat straw that I purchased in North Dakota. I used the lab press to produce 24" square panels _" and _" thick. I had anticipated that the material would test similar to board that Gerry Hooper from Allfiber Engineering had previously tested. I was disappointed in this material on 2 fronts. Most importantly was that the Internal Bond tests were so low. The second issue is cosmetic only but this material produced a rather dark colored board. This would lead me to consider this a poor choice of material, since much better materials are available and plentiful.

Sample 7: Flax material. Grinding the flax is difficult due to the nature of the fiber. The pith seems to produce a "dust bunny" or cotton ball effect when the material is hammermilled. I had to settle for a course grind, as a finer grind became unmanageable. A second issue with the flax was that it was an extremely dark color. Flax did produce a very hard board with an excellent internal bond. The MOR and MOE tests were somewhat disappointing. I feel that this material would be excellent if the fiber were broken up better. I expect that fiberized flax would be a better material. Because of the material cost this could be a fine base or blended fiber. More experimentation needs to be done with this material.

Sample 8: This sample consisted of a blend of the Durum wheat straw and flax fiber. The Internal bond seemed to come out between the results of the 2 individual fibers. Because we had a blow with this sample we were unable to obtain enough material to test the MOR or MOE. The result does lead me to the conclusion that flax may indeed be a good reinforcing fiber for composite board. Again more testing is needed.

Sample W1 through W5: Winter wheat from North Dakota was tested as a base fiber. This type of fiber is the basis for most of the strawboard presently being produced. All but the 40-pound density board met or exceeded All the tests for medium density particleboard and in some instances even met high-density standards at medium density weights. This is the most likely type of alternate fiberboard that would be produced in the US. Because of the high value placed on straw as a bedding material on Wisconsin, it is not too likely that this material would be used in a plant in this state.

Sample W6: Winter wheat from North Dakota was tested at a density about 20% lighter than standard particleboard. It passed many of the grade standards for medium density board and "blew the socks off" low-density particleboard standards. If I interpolate the results of the sample testing between this test and the previous one, it would appear that a board could be easily produced that meets M-3 standards at 10% less weight than the standard 42 pound density wood based particleboard.

Sample S1 & S2: Soybean straw from Minnesota was used to produce medium density board with a decorative look. The sample was not large enough to test MOR and MOE. The Internal bond was not as high as I would have liked. The material would probably test better if a finer, less decorative grind was used or if more resin was used. Soybean is an important crop in Wisconsin. This material could be used alone or mixed with wood fiber to produce board in a Wisconsin plant. More testing is needed.

Hemp 1 through Hemp 5: Hemp purchased in Ontario was used to produce these samples. The first batch was produced at an average density of 42 pounds per cubic foot. The grind was either course or very course, The very course grind was an as received grind. The material was over 95% hurd fiber. Any bast that was included was very short. The material tested at unbelievably high rates, especially when we hit 45-pound density. This was the material that tested the best. In some instances it met high-density requirements at 20% less weight and was double some of the medium density specifications.

Hemp 1-1 through Hemp 1-3: This board was produced to test the feasibility of a specific specialty market I am working on. It tested much better than standard 32 to 34 pound low-density board at again 20% less weight. This is amazing, as I had added a water inhibitor to reduce water absorption. Cold water soak testing showed the material to swell less than 10%. I am working on an additional process that will reduce this to below 5%. The material will also hold up under a 4-hour boil test.

Hemp 1-4: This was a course ground hemp sample. The material was 95% Bast hurd and 5% short bast fiber. It again used wax to provide additional water resistance. I produced this board to see what affect the wax would have in comparison to the Hemp 1 through hemp 5 sample run previously. At these rates I was still able to meat all the same specifications except for the Decking grade standards. I would expect the MOR would rise to this level if the density were increased above 42 pounds per cubic foot.

Hemp 2-1 through 2-3: Again a course ground hurd with 5% short bast fiber was used. To this mix I added 10% by weight, course chopped Bast fiber. I also introduced wax for water resistance. My expectation was that the addition of the longer fiber would add considerable strength. I was surprised to see that the additional fiber provided little if any extra strength.

Hemp 2-4: This was the same formula as the previous trial. The difference was the higher density. In this instance the material would not have passed any of the tests for composite board. This obviously surprised me.

3-1 Low-density raw hemp course grind: This material was about 30% bast fiber. The difference between this and the last 2 trials was that the fiber was ground, not chopped. The IB results dropped off and the MOR results were about the same but the MOE improved compared to the sample using hurd only.

3-2 Very low-density board, using what was left at the end of the trial. This material had the weight of a ceiling tile, but would not pass any composite board test. It does provide data for alternate use capabilities.

Note: While I expected that the addition of the stronger bast fiber into the board would increase the strength it appears that the opposite is true. This is probably due to the fact that the bast fiber does not hammer-mill well. It tends to fluff rather than separate. I suspect that the bast fiber would have to be refined differently to break it down. The required result of the refining would be to produce long fibers, but the fibers would have to be longitudinally separated so the binder holds the fiber in the board. Inspection and my suspicion would indicate that the fiber is separating from itself at failure. More research is indicated.

Formaldehyde tests: As a point of reference I ran samples of the hemp fiber using more traditional urea formaldehyde and phenol formaldehyde resins. As with other agricultural fibers, these resins did not perform. It is assumed that there isn't enough acid in the fiber to get the resins to react. Because of the health risks, lack of water resistance and expectation that these resins may eventually be rendered illegal, I see no reason to pursue this approach, but provided the test purely for reference.

I also ran 2 other test samples that are not in the accompanying chart. In these samples I ran oat and Durum straw through an extremely course hammer-mill. This left me with fiber that was 1 to 2" long. About 80% were split with the remaining 20% not split. IB tests on this material showed that the unsplit straws did not assume enough binder to hold together in the hollow portion of the straw. Further, the material was not oriented at lay-up but was instead arranged randomly. Finally the tests were done using Durum an oat straw which failed to pass composite board tests also. The material was sufficiently strong to make a reasonable sidewall underlayment, but did not have sufficient strength to make a structural board. Tests done previously by Gerry Hooper showed that when properly split and oriented, wheat straw passes all the structural tests for OSB.

Press Requirements

Depending on the material and the targeted density, the press platen pressure was as low as 300 lb. per square inch and as high as the maximum we could attain on the press which was 1000 pounds per square inch. The higher pressures were used during the closing cycle of the tougher bast fibers, and at higher densities with some other fibers.

It was found that most of the agricultural fibers we tested required press platen pressures that exceeded the pressures normally expected from previous experience with wood fibers. We were able to do some modifying of the press speed to reduce the platen pressure required but this increases the cycle time for each board.

More research is needed in this area, however it seems apparent that to accomplish a wide product mix, the press should be able to produce a platen pressure of 1,000 pounds per square inch or better.

Agricultural fibers can produce excellent particleboard products. As limited, as this project has been, I was able to produce enough material to attract interest from multiple end users that have expressed interest in agricultural composite board product.

Strawboard, though some of the pioneers got off to a rough start, is starting to come into its own. Consumer interest in “green” products is strong and growing. Being able to purchase “wood” based products that come from sustainable resources is appealing to many people. Being able to help reduce greenhouse gas emissions is going to be an additional selling point for board manufactured in this way.

The Strawboard, Flax and Hemp based particleboard that I developed with the help of this grant, will also help some of America’s farmers and farm communities survive. Each plant will provide from 1.2 million to 3 million dollars in revenue to the area farmers for the straw or fiber. In many areas this straw can be produced for less than the cost of tilling the residue back into the soil, and if done properly will benefit the environment in the process. These plants will also have a projected payroll of 1 to 1.5 million dollars per year. In many of the communities we have been speaking with, this would be the largest employer around. In much of rural America, including many small towns in Wisconsin, additional jobs and income of this magnitude could help reverse the deterioration of the economic base in the area.

I will be using the products I was able to produce to show both potential customers for the product and investors for these plants, what exactly the capabilities of these plants will be. I anticipate that we will be installing a couple of plants in the next year. I am working with NSP at the moment on a project here. We are trying to locate enough material to build a plant in Wisconsin that would use scrap wood and possibly some agricultural residue. Preliminary investigation has shown that there is more than enough available scrap wood in Wisconsin for 4 or more of these plants. If we include scrap wood that is collected as trash from construction sites, used pallets, shipping dunnage and the like this number will increase. We are presently investigating a plant for Wisconsin and we are hoping to find funding to start this plant in the next 2 years.

In Conclusion

The use of agricultural products and wood scrap to produce particleboard and other composite boards is viable, lucrative and cost effective. As shown in this project, higher-grade board can be produced for lower cost using this alternative technology. This project also showed the ability that these smaller plants will have to produce "designer particleboard", that can be made to a customers specific requirements. As an added benefit the final consumer will receive moisture resistant boards that will not make him sick or encounter long term illness problems because of exposure to formaldehyde or other noxious fumes.

The rest of the planet will benefit environmentally because forests will be left standing and carbon dioxide will be pulled from the air and sequestered in these board products.

In Wisconsin, not only can these plants utilize wood waste from our many sawmills and secondary wood producers, but soybean straw, flax, and eventually it is hoped, hemp. These agricultural fibers can provide additional income from existing farms, and may also provide low maintenance crops that can be produced on abandoned farmland to supplement the income of the landowner.

Finally the local community and the investors in these plants will benefit from the revenue source, the wages, the tax base and the profits that these plants will provide.

Of Special Note

Industrial hemp is a fiber that is being legalized in many areas of the world including Canada and portions of Europe and South America. In the Middle East, Asia and Eastern Europe, it has always been an important crop. Because of the mistaken comparison between Industrial Hemp and its notorious cousin Marijuana, it is not presently legal in the USA, though it was a major cash crop in the states until the mid forties. Indeed when hemp was a cash crop, Wisconsin was the largest producer of the fiber. It is said to grow best within 200 miles of the 45^{th} parallel.

I would hope that the US will eventually allow the growing of this fiber. It has been estimated that if 10% of the land in the US was switched to alternate crops, the price of corn, soybeans and other grains would increase by as much as a dollar a bushel as their would be less supply. Also, the use of this material as a source of fiber for composite boards, automotive components, and paper is inevitable. The fiber has a high bulk to weight ratio and is expensive to ship in its raw form. It would be a shame to see all the manufacturing of products like these forced out of the US with the resulting loss of tens of thousands of potential jobs.