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# Supply Chain Modeling: Downstream Risk Assessment Methodology (DRAM) Demonstration of Capability

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April 2015



IDA Document D-5347
Log: H 15-000038

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**About This Publication**

This work was conducted by the Institute for Defense Analyses (IDA) under contract HQ0034-14-D-0001, Project DE-6-3247, "Strategic Material Security Program Reports on National Defense Stockpile Requirements," for the Strategic Materials Office of the Defense Logistics Agency (DLA). The views, opinions, and findings should not be construed as representing the official position of either the Department of Defense or the sponsoring organization.

**About This Publication**

The authors would like to thank the reviewer, Dr. Michael Rigdon.

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D. Sean Barnett
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# Executive Summary

This briefing presents the Institute for Defense Analyses' (IDA) development of the Downstream Risk Assessment Methodology (DRAM). This work was done for Defense Logistics Agency Strategic Materials (DLA SM) to provide the capability to analyze supply chains of strategic and critical materials and the applications or products in which they are used. That capability will allow DLA SM to assess and mitigate risks that may arise from vulnerabilities in the supply chains that would not be revealed by traditional analysis of the supply of and demand for materials at the raw material level.

The analysis of supply chains is an important addition to DLA SM's capabilities because the supply chains for strategic and critical materials and their applications used by the United States have become increasingly global. Thus, the United States relies on offshore material processing capabilities "downstream" from the step of raw material production to obtain many goods important to its economy and to the Department of Defense (DoD). Such reliance on overseas capabilities can create vulnerabilities to the supplies of those goods during a crisis or conflict that might not be revealed by traditional analysis of supply of and demand for materials in their raw forms.

This briefing demonstrates the operation of DRAM using the neodymium-iron-boron (NdFeB) magnet supply chain as a test case. It can also serve as a model for analyzing other materials and supply chains of interest to DLA SM. The NdFeB magnet supply chain has characteristics that make it more challenging and ultimately more useful to model than the simplest possible chain: it contains two materials of interest and nodes in multiple countries for most stages of production. NdFeB magnets are also a product type that is important to DoD.

The approach of the DRAM modeling effort was to represent each important production step in the global supply chain for a material and characterize how it operates in terms of production capacity and material feedstock requirements. The fundamental approach is mass flow analysis, from raw material through each step in production. The model must also be able to estimate supply and demand on a time-phased basis under the conditions of the National Defense Stockpile (NDS) planning scenario and any other scenarios of interest. It must be able to represent material shortfall mitigation measures, and it must be able to reflect longer term changes in technology, the market, and the security environment that may affect the supply chain.

After developing the supply chain model, the study showed how it could be used to assess shortfall risk associated with downstream materials similar to the way that DLA SM and IDA have been assessing shortfall risk associated with raw (upstream) materials. In that approach (i.e., the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM)), risk is taken to be the product of the probability of the shortfall and its consequences. The probability is ordinarily taken to be the probability of the scenario giving rise to the shortfall. Because DRAM looks at downstream supply chains and the goods these chains produce, the consequences of a downstream shortfall may be taken to be the consequences of the shortage of goods produced with the material(s) in question.

IDA used the DRAM model to demonstrate how shortfalls can be assessed and to show the cost effectiveness of mitigation measures that were evaluated under several different scenarios. The scenarios imposed different effects on material supply and demand and on how potential mitigation measures could or could not work. The scenarios considered were (1) peacetime, (2) the cutoff of imports from China, (3) the cutoff of imports from China with increased demand, (4) no imports (closed economy), and (5) no imports and the failure of a sole U.S. source for one material. The scenarios have some elements that may be somewhat similar to those of the NDS "Base Case" planning scenario, but IDA chose them primarily to cover a range of possible circumstances and show how the model responds to them. The mitigation measures considered were (1) government stockpiling, (2) an alternative federal inventory option, (3) spot market purchases, (4) material substitution; and (5) a concerted material production program. The demonstrations for each scenario included an assessment of the product produced by the supply chain, the material flows through the chain, and the shortfalls (if any). The effectiveness of the mitigation measures were shown, with costs estimated, where shortfalls were found. The mitigation measures were also evaluated for and prioritized by cost effectiveness.

Although the cases presented were analyzed to demonstrate the capabilities of DRAM, we can draw a few conclusions from them regarding the nature of strategic and critical material supply chains and their potential vulnerabilities. The loss of sources within a supply chain can create shortfalls, depending on the redundancy of the network and the U.S. market share of potential material imports. Different mitigation measures may not be suitable for some material processing nodes and scenarios (e.g., substitution, spot market purchases). The capacities of material production nodes in domestic supply chains may not be balanced for self-sufficiency. For example, shortfall mitigation at multiple nodes may be required to allow the production of the final product at full domestic capacity.

In conclusion, this briefing demonstrates the supply chain modeling capabilities of DRAM. The capabilities are flexible and can represent a wide variety of supply chains for different materials and products. DRAM can model a wide range of supply and demand conditions that could arise from scenarios of interest to DLA-SM and DoD. DRAM can also model a wide range of possible shortfall risk mitigation measures. Acquiring supply chain data can be difficult because it is frequently considered to be business sensitive and may not be available at all for foreign producers. Nevertheless, the analyses in this demonstration show that DRAM can be useful for gaining an understanding of supply chains important to DoD and potentially uncovering vulnerabilities that are not apparent from analyzing upstream (raw material) supply and demand only.

# Contents



# Appendices

# 1. Introduction

IDA

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# Supply Chain Modeling: Downstream Risk Assessment Methodology (DRAM) Demonstration of Capability

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Dr. Jerry Bracken

August 6, 2013

Institute for Defense Analyses

This briefing presents the Institute for Defense Analyses' (IDA) development of the Downstream Risk Assessment Methodology (DRAM). This work was done for Defense Logistics Agency Strategic Materials (DLA SM) to provide the capability to analyze supply chains of strategic and critical materials and the applications or products in which they are used. That capability will allow DLA SM to assess and mitigate risks that may arise from vulnerabilities in the supply chains that would not be revealed by traditional analysis of the supply of and demand for materials at the raw material level.

The work described was performed in the first half of 2013. Thus, the briefing reflects the status of the DRAM analytical capability at that time. It also notes where recommendations for further development or implementation of DRAM have been followed, particularly in IDA's support of the preparation of the 2015 Report on National Defense Stockpile Requirements.

# Agenda

- Modeling Objectives
- Description of Approach
  - Modeling supply chains
  - Relating downstream shortfalls to risk
- Capability Demonstration Cases
  - Peacetime Supply and Demand
  - China Import Cutoff
  - China Import Cutoff with Increased Demand
  - No Imports
  - No Imports with Sole Source Cutoff
- Modeling Observations
- Illustration of Supply Chain for Additional Material
- Conclusions

1

This briefing presents IDA’s work in developing DRAM and demonstrates the working of the methodology using test cases, as outlined on the slide.

# 2. Objectives

# IDA | Supply Chain Modeling Task

## Task Objectives

- Develop Downstream (supply chain) Risk Assessment Methodology for strategic materials (DRAM) consistent with and building upon Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM)
- Design and conduct tests of DRAM using data from recent IDA material case studies and risk assessments
- Build downstream material supply chain databases for and apply/adapt DRAM for 10 additional materials (possibly more)

## Presentation Objectives

- Present DRAM and demonstrate its operation on neodymium magnet supply chain
  - Prototype test case developed from available data
  - Model for analysis of downstream supply chains for materials of interest to DLA SM

2

The objectives of the IDA subtask from DLA SM and this briefing are shown on the slide. This subtask is part of IDA's broader task supporting DLA SM's strategic materials program. One goal of the broader task is to provide DLA SM an integrated, analytically sound approach to strategic material risk assessments and analyses of risk mitigation. DLA SM will use risk assessments and analyses of risk mitigation to support its planning for and management of the National Defense Stockpile (NDS). To give DLA that risk management capability, IDA previously developed the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM). RAMF-SM allowed DLA SM to move from its traditional shortfall-based planning process for the NDS to a new risk-based process that allows the consideration of the probabilities and consequences of potential material shortages and additional risk mitigation strategies that go beyond stockpiling. DLA SM used RAMF-SM in developing risk mitigation strategies, including stockpile recommendations, for its *Strategic and Critical Materials 2013 Report on Stockpile Requirements*.[1] The goal of this subtask in developing DRAM is to build upon RAMF-SM and allow DLA to perform risk assessments and analyses of risk mitigation for the *supply chains* of strategic and critical materials in addition to the assessments for the materials' raw forms that were conducted using RAMF-SM for DLA SM's 2013 report.

The analysis of supply chains is an important addition to DLA SM's capabilities because the supply chains for strategic and critical materials and their applications used by the United States have become increasingly global. Thus, the United States relies on offshore material processing capabilities "downstream" from the step of raw material production to obtain many goods important to its economy and to the Department of Defense (DoD). Such reliance on overseas capabilities can create vulnerabilities to the supplies of those goods during a crisis or conflict that might not be revealed by traditional analysis of supply of and demand for materials in their raw forms. DRAM gives DLA SM the ability to identify and mitigate such vulnerabilities and, hence, further capability to reduce materials-related risk to the nation. DRAM can also help DLA determine the form of a material to stockpile if the raw material analysis shows that the material would be in shortfall and can help DLA avoid downstream processing gaps or bottlenecks that could render a stockpiled raw material unusable under NDS planning scenario conditions.

This briefing presents DRAM and demonstrates its operation using the neodymium-iron-boron (NdFeB) magnet supply chain as a test case. That demonstration was facilitated by using data that IDA had acquired on that supply chain from past analyses for DLA SM. The test case can serve as a model for analyzing other materials and supply chains of interest to DLA SM.

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[1] Department of Defense, *Strategic and Critical Materials 2013 Report on Stockpile Requirements* (Washington, DC: Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, 2013).

# 3. Supply Chain Modeling

## DRAM (Downstream Risk Assessment Methodology) — Modeling Objectives

- Represent each important production step in global supply chain, from raw materials to finished goods, to include material flows from one step to another
- Estimate supply and demand at each step (node) in each supply chain on a time-phased basis under conditions of National Defense Stockpile planning scenario
  - Increased defense demand, reduced civilian demand, cutoff of material supply from adversaries and unreliable/war damaged sources
- Model response of supply chain nodes to demand for goods, node capacity limits, and quantity of necessary feedstock material available to each node
  - Estimate shortfalls at different nodes under National Defense Stockpile planning scenario conditions
- Model material shortfall mitigation measures applicable at each node of supply chain
- Reflect longer term changes in technology, market, and security environment (alternative futures) in scenario conditions

3

This slide sets out the specific objectives of the DRAM modeling effort. The goal is to represent each important production step in the global supply chain and characterize how it operates in terms of production capacity and material feedstock requirements. The fundamental approach is mass flow analysis—from raw material through each represented step in production. The model must also be able to estimate supply and demand on a time-phased basis under the conditions of the NDS planning scenario and other scenarios of interest. It must be able to represent material shortfall mitigation measures, and it must be able to reflect longer term changes in technology, the market, and the security environment that may affect the supply chain.

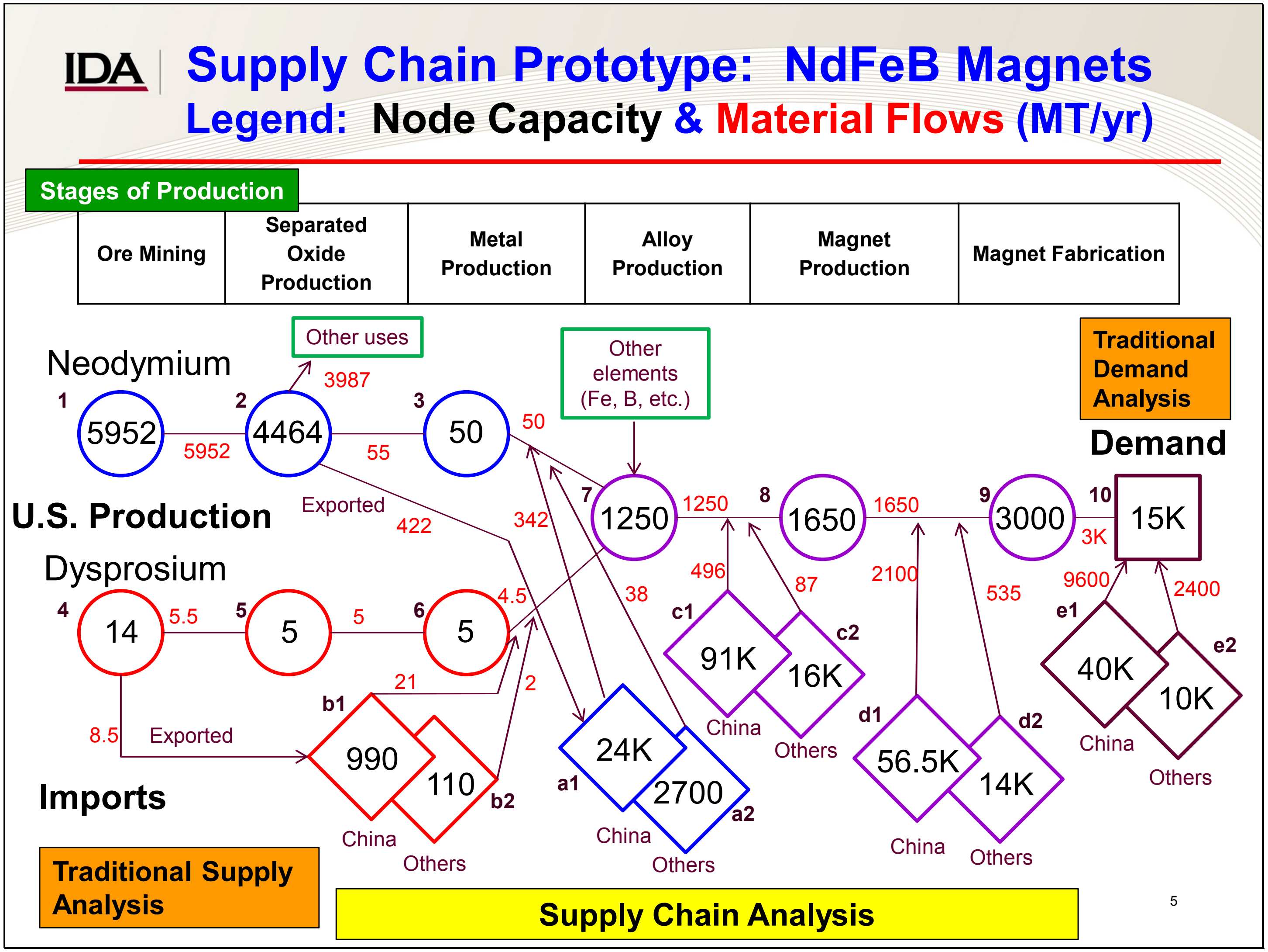
## IDA | DRAM Development — Approach

- **Use neodymium-iron-boron (NdFeB) magnet supply chain as basis for prototype demonstration**
  - **Assessed previously by IDA study team**
  - **Multi-material, multi-strand supply chain**
- **Conduct literature review and canvass experts to identify desirable characteristics of supply chain model, approaches to modeling, and potential challenges**
- **Build model with characteristics to satisfy objectives**
  - **Material flows through nodes and shortfall estimation**
  - **Treatment of shortfall risk mitigation measures**
  - **Refine modeling approach based on results of literature review, expert consultation, and initial tests**
- **Demonstrate prototype DRAM using NdFeB magnets**

4

This slide outlines the specific approach taken to develop the DRAM methodology and build a prototype supply chain model for NdFeB magnets. These magnets were chosen for the prototype because the supply chain has characteristics that make it more challenging and ultimately more useful to model than the simplest possible chain. NdFeB magnet alloy contains two critical materials of interest (neodymium and dysprosium), with nodes in multiple countries in most stages of production. NdFeB magnets are also a product type that is important to DoD (NdFeB magnets are used in many motors and actuators on military platforms and weapon systems), and IDA has information on the supply chain that was collected from past work.

The approach to developing this methodology was to conduct a literature review and canvass experts on supply chain modeling to identify a methodology that would satisfy the analytical needs of DLA SM. The development process was iterative since the approach was tried and refined after initial tests to ensure that it met DLA's needs.


IDA
Supply Chain Prototype: NdFeB Magnets
Legend: Node Capacity & Material Flows (MT/yr)
Stages of Production
Ore Mining
Separated Oxide Production
Metal Production
Alloy Production
Magnet Production
Magnet Fabrication
Neodymium
Other uses
3987
5952
5952
4464
55
50
50
Exported
422
342
Other elements (Fe, B, etc.)
1250
1250
1650
1650
3000
3K
15K
Traditional Demand Analysis
Demand
U.S. Production
Dysprosium
14
5.5
5
5
5
4.5
38
496
87
2100
535
9600
2400
8.5
Exported
21
2
990
110
China
Others
24K
2700
China
Others
91K
16K
China
Others
56.5K
14K
China
Others
40K
10K
China
Others
Imports
Traditional Supply Analysis
Supply Chain Analysis
5

This slide shows a diagram of the NdFeB magnet supply chain that represents the model that IDA developed. The steps of production for NdFeB magnets are set forth at the top of the slide (from Ore Mining through Magnet Fabrication). The nodes of the chain, where the production processes take place, are indicated by large circles for domestic capabilities, and diamonds for foreign capabilities. This diagram focuses on the portion of the supply chain involving the rare earth elements neodymium and dysprosium. Nodes involving the processing of neodymium are indicated in blue, those involving the processing of dysprosium are indicated in red, and those involved in the processing of magnet alloy (formed from neodymium, dysprosium, and other elements) are indicated in purple. The nodes are connected by arcs that correspond to the flow of materials in the magnet production process (from the beginning step on the left through the final step on the right).

The numbers on the slide represent the production capacities of the nodes and the flow of materials in tons per year, from one node to another under the circumstances depicted in this diagram. The large black numbers in each node represent the production capacity of the node in tons per year. (Note that some capacity figures are notional and are used to illustrate the working of the methodology and the supply chain model.) The smaller red numbers between nodes indicate the flow of materials in tons per year, from one production step to the next. The diagram shows that based on the production capacities depicted, material is needed from domestic and foreign sources at several steps to enable the supply chain to meet the U.S. demand for magnets, which is depicted as being 15,000 metric tons (MT) per year. As will be discussed, the model takes into account the amount of feedstock material required at each node to allow the node to produce its output.

Finally, the slide shows how the DRAM methodology expands the analysis beyond the traditional raw materials analysis used in stockpile planning. In the traditional approach, raw material production capacities are compared to demand to determine whether they are sufficient. With the DRAM methodology, one can also look downstream of raw material production to any or all points between raw material and final product production to determine whether the capacities needed along the way are sufficient to meet demand. Thus, the DRAM methodology can enable DLA to uncover potential supply vulnerabilities that would not be revealed by the traditional analysis of raw materials alone.

# Modeling a Supply Chain

- Chains are represented by production nodes and material flows
- Nodes represent places where material/product is altered
- Materials and products flow from upstream, raw state through each step in production process to downstream, finished state
- Demand for product drives production requirements—within limit of production capacity
- Need for material/product feedstock at each node (including process losses) drives upstream production requirements—also within limits of upstream production capacities
- Multiple sources of material/product can be represented
- Shortfalls in final and intermediate products can be estimated
- Mitigation measures alleviate shortfalls by making up for inadequate material/product flows

6

This slide summarizes the working of the supply chain model.

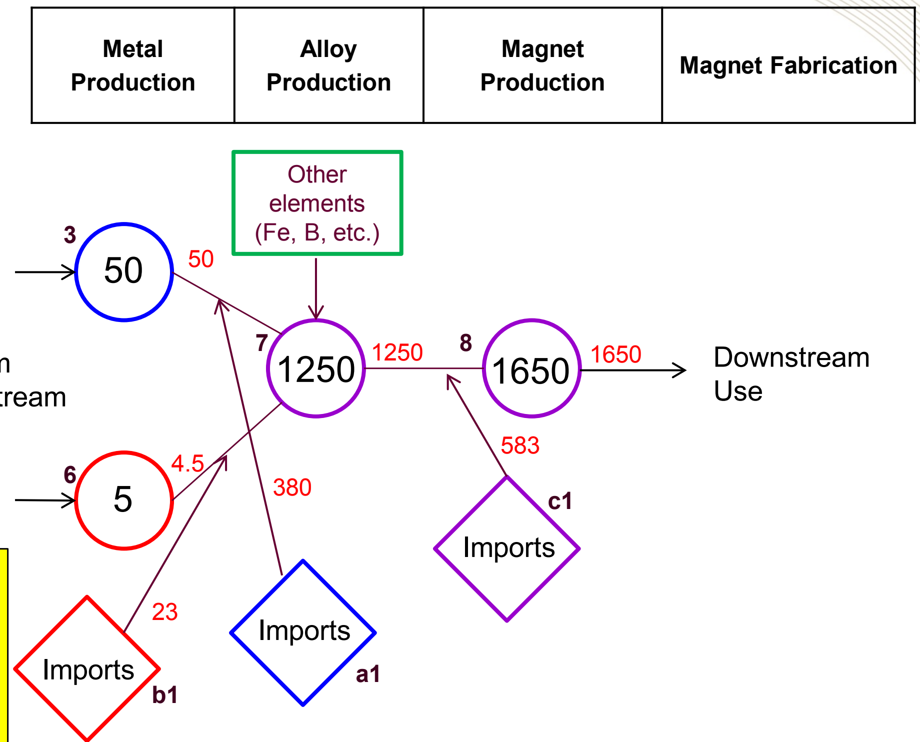
# Production Nodes and Material Flows Illustrated

## Legend: Node Capacity & Material Flows (MT/yr)

**Output of alloy (Node 7) driven by demand for magnet (block) production**

**Output of Node 7 limited by capacity and potentially by Nd and Dy metal feedstock available**

**Where node output is limited, shortfall may be made up by imports or other mitigation measures**




**Flow from Node 7 to Node 8:**

Demand from Node 8 = 1,833 MT

Node 7 capacity = 1,250 MT

Node 7 feedstock required:

- 430 MT Nd metal
- 27.5 MT Dy metal
- 931 MT Fe+B+other materials

7

This slide illustrates the working of a supply chain node where several different materials come together to form one material (NdFeB alloy). Node 7 produces magnet alloy in the United States. It has a capacity of 1,250 tons per year (black number in the circle), and it is producing 1,250 tons per year (red number over arc connecting Node 7 to Node 8.) to meet the demand from Node 8 (which exceeds 1,250 tons per year). To produce 1,250 tons of magnet alloy per year, Node 7 requires 430 MT of neodymium metal (50 domestic plus 380 imported), 27.5 MT of dysprosium metal (4.5 domestic plus 23 imported), and 931 MT of iron, boron, and other materials. Those requirements account for the composition of NdFeB alloy as well as the process losses involved in making the alloy from its components. The flow of materials from the import nodes show how materials from other sources can make up for shortages of supply from U.S. sources.

## Relating Downstream Material Shortfalls to Risk

- RAMF-SM defines risk as possibility of loss or harm:
  - Risk = Probability of material shortfall × Consequences
- Probability of shortfall in DRAM is, to first order, probability of scenario
  - Possibly modified by probability of success of mitigation measures
- Consequences of shortfall in DRAM are consequences of shortage of final product
  - Downstream focus as opposed to RAMF-SM raw material upstream focus
  - Effects of "mid-stream" shortages are assessed by impact on shortfalls of final products
  - Approach to assessing consequences of final product shortfalls is to be developed
    - 2013 Requirements Report used expert judgment; other approaches possible

8

After we have built the supply chain model and used it to identify potential material or product shortfalls, potentially under different scenario conditions, we want to assess the risk created by the potential shortfalls. This approach is consistent with the IDA RAMF-SM approach and DLA SM's goal of moving to risk as a metric for assessing possible material shortfalls and considering mitigation measures that might be adopted to prevent them or eliminate their impact.

In the RAMF-SM approach, risk is taken to be the product of the probability of the shortfall and its consequences. The probability is ordinarily taken to be the probability of the scenario giving rise to the shortfall. However, because DRAM looks at downstream supply chains and the goods these chains produce, the consequences of a downstream shortfall may be taken to be the consequences of the shortage of goods produced with the material(s) in question. One could assess the consequences of a shortage of goods in several ways, including expert judgment, long-term price, the cost of production, and the price elasticity of demand. IDA is exploring the potential for using these approaches to assess the consequences of material shortages for the FY 2015 NDS Requirements Report.

# 4. Demonstration Cases

## IDA | Cases to Demonstrate

- Peacetime supply and demand
- Cutoff of imports from China
- Cutoff of imports from China, with increased demand
- No imports (closed economy)
- No imports and failure of U.S. sole source

Demonstrations include product output, material flows, and shortfalls (if any)

Mitigation measures are demonstrated, with costs estimated, where shortfalls are found

Mitigation measure choices can be optimized for cost effectiveness

9

Now that DRAM has been described and a model of the NdFeB magnet supply chain has been built, the analysis will demonstrate DRAM's capabilities by showing how the model responds to several different scenarios. The scenarios have some elements that may be somewhat similar to those of the NDS "Base Case" planning scenario, but the primary reason for defining them as they are was to cover a range of possible circumstances and show how the model responds to them. In addition to demonstrating the estimation of material shortfalls, this discussion will also demonstrate how the model can be used to evaluate potential shortfall mitigation measures and optimize mitigation measure choices for cost effectiveness.

## IDA | Material Shortfall Mitigation Measures

- *Traditional Government Stockpiling*
- *Other Federal Inventory Options*
- *Extra Buy (Spot Market Purchases)*
- Futures Contracts?
- Reductions in Government "Base Case" Supply Guarantees for Exports
- *Substitution*
- *Concerted Material Production Programs (e.g., Title III)*
- Enhanced Recycling?
- Security of foreign supply arrangements

*Included in Today's Briefing*

10

Once could apply several different shortfall mitigation measures to prevent or mitigate the effects of a material shortfall. These mitigation measures have been assessed or at least considered during the work that IDA has done for DLA SM on managing materials-related risk. The measures in blue are those that will be considered in example scenarios used to demonstrate DRAM.

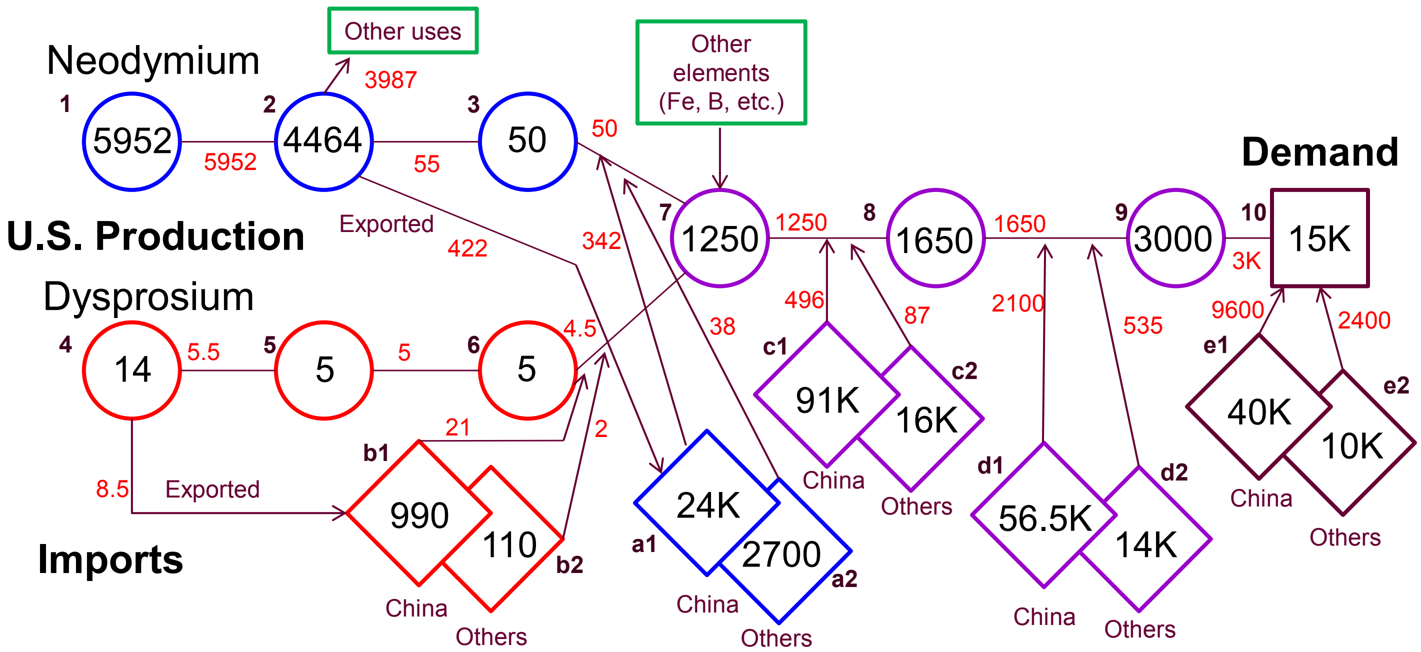
IDA

# Peacetime Supply and Demand Case

## Legend: Node Capacity & Material Flows (MT/yr)

Stages of Production

| Ore Mining | Separated Oxide Production | Metal Production | Alloy Production | Magnet Production | Magnet Fabrication |
|---|---|---|---|---|---|



This slide depicts again the supply chain for NdFeB magnets. It will be used to show how DRAM can model a supply chain and to show its response to different scenarios that affect material supply and demand.

## Peacetime Supply and Demand Observations

- Supply chain depiction shows material/product production and flows under normal conditions
- Demand met by combination of U.S. production and imports
- Material flows driven by demand for finished goods and requirements for producing upstream products, including process losses
- Imports feed U.S. supply chain at several points
- Imports sufficient to meet U.S. demand as long as U.S. market share is at least 24 percent

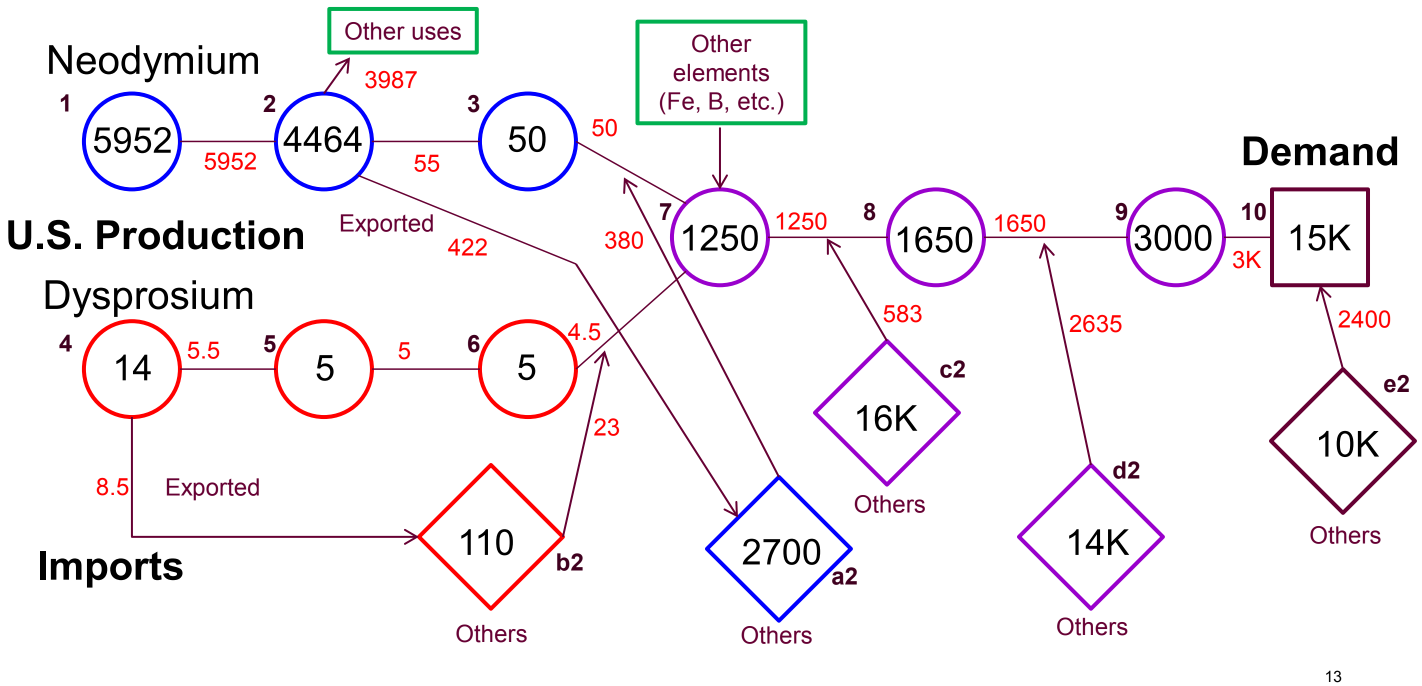
This slide notes how the supply chain for NdFeB magnets meets U.S. demand under peacetime conditions. The U.S. market share of 24 percent of foreign production is necessary to allow the United States to acquire sufficient imports to meet all its demands (in this case, the limiting step requiring that fraction is the importation of finished magnets needed to meet total demand).

# China Imports Cutoff Case

## Legend: Node Capacity & Material Flows (MT/yr)

**Stages of Production**

| Ore Mining | Separated Oxide Production | Metal Production | Alloy Production | Magnet Production | Magnet Fabrication |
|---|---|---|---|---|---|



The next scenario modeled is one in which all imports from China are cut off (the sources (diamonds) marked “China” on slide 11). The supply chain responds to try to meet U.S. demand for magnets under those conditions. Magnet shortfalls must be made up by mitigation measures.

## IDA | China Imports Cutoff Observations

- Imports still available but only at greatly reduced levels
- Sufficient to feed upstream U.S. supply chain so long as U.S. market share is at least 19 percent
- Not sufficient to meet demand for final product.
  If U.S. market share = 24 percent, shortfall = 9,600 MT magnets
- Some mitigation measure(s) required
  - Stockpiling
  - Other Inventory options (e.g., Buffer Stock)
  - Extra Buy
  - Substitution
  - Concerted Program (magnet production and fabrication)

14

When imports from China are cut off, material imports are still sufficient to enable the U.S. portion of the supply chain to operate at full capacity if the U.S. market share is at least 19 percent, which is the share of foreign magnet block production needed to enable the U.S. supply chain (specifically node 9) to operate at capacity. However, that market share is not sufficient to meet U.S. demand for finished magnets (because total U.S. production capacity is simply too low to do so). If U.S. market share is 24 percent (as it was taken to be in the previous (peacetime) scenario), that will still leave us with a shortfall of 9,600 MT of finished magnets.

To make up the shortfall in magnets, one or more shortfall mitigation measures must be applied. This discussion will consider the application of the measures listed here and assess which ones would be most cost effective in this scenario.

## China Imports Cutoff Mitigation Options

**Assumptions:**

- One year shortfall in 4-year scenario
- Planning horizon = 5 years (as in 2013 RR)
- U.S. market share = 24%
- Wartime price multiple = 15
- Probability of war = 0.0037
- Buffer stock rental cost = 15%/yr
- Cost = budget outlays (no recoupment)

| Mitigation Measure | Amount Provided (MT) | Expected Cost (Budget) ($M) |
|---|---|---|
| Stockpiling | 9,600 | 2,515 |
| Inventory | 9,600 | 1,900 |
| Extra Buy | 500* | 7.3 |
| Substitution | 1,500 | 0 |
| Conc. Program (magnets) | 2,560** | 140 |

*Presuming 10% of available capacity previously unused and 50% of that obtained by the United States
**Sufficient to use all available domestic and imported alloy and block feedstock

***Mitigation measures can be similarly assessed for other materials and scenarios***

15

To assess shortfall mitigation measures for cost effectiveness, certain planning assumptions must be made to put the measures in context and, in particular, allow their costs to be estimated. The necessary assumptions for the measures considered here are set out in the slide's bullet points. For the mitigation measures listed here (other than the Concerted Program), these assumptions were also used in the FY 2013 NDS Requirements Report.

The shortfall period is used to calculate the size of the shortfall that must be made up using the mitigation measures. The planning horizon is used to estimate the cost of the Inventory (which is assumed to be held for the government by a private vendor for an annual fee (rental cost)). The U.S. market share determines how much material is available from foreign sources for import into the United States. The wartime price multiple is used to estimate the cost of material or product bought on the spot market during the conflict scenario. The probability of war is used to calculate the expected costs of several mitigation measures that have certain costs that would only be incurred in the event of a conflict. Finally, these assessments consider only budget outlays. Specifically, they ignore any value that that government could recoup from stockpiled material after it is no longer needed to mitigate shortfall risks.

The amounts of material that could be provided by each mitigation measure are shown in the table as are each measure's expected cost. The amount of material that can be obtained through the Extra Buy (or spot market purchase) measure is estimated by presuming that 10 percent of available global capacity is previously unused and that 50 percent of that capacity can be obtained by the United States. The amount of material that can be obtained through the Concerted Program (magnet factory) is based on the assumption that the program would be sized to use all available domestic and imported magnet alloy and magnet block feedstock.

In the DRAM methodology, these and other shortfall mitigation measures can be similarly assessed for other materials and scenarios.

## China Imports Cutoff Optimal Mitigation Solution

- **Shortfall mitigation options can be optimized for cost effectiveness**
- **Optimal measures for the China Imports Cutoff case, under the assumptions stated above**
  - **Mitigation measure priority same as 2013 Requirements Report**

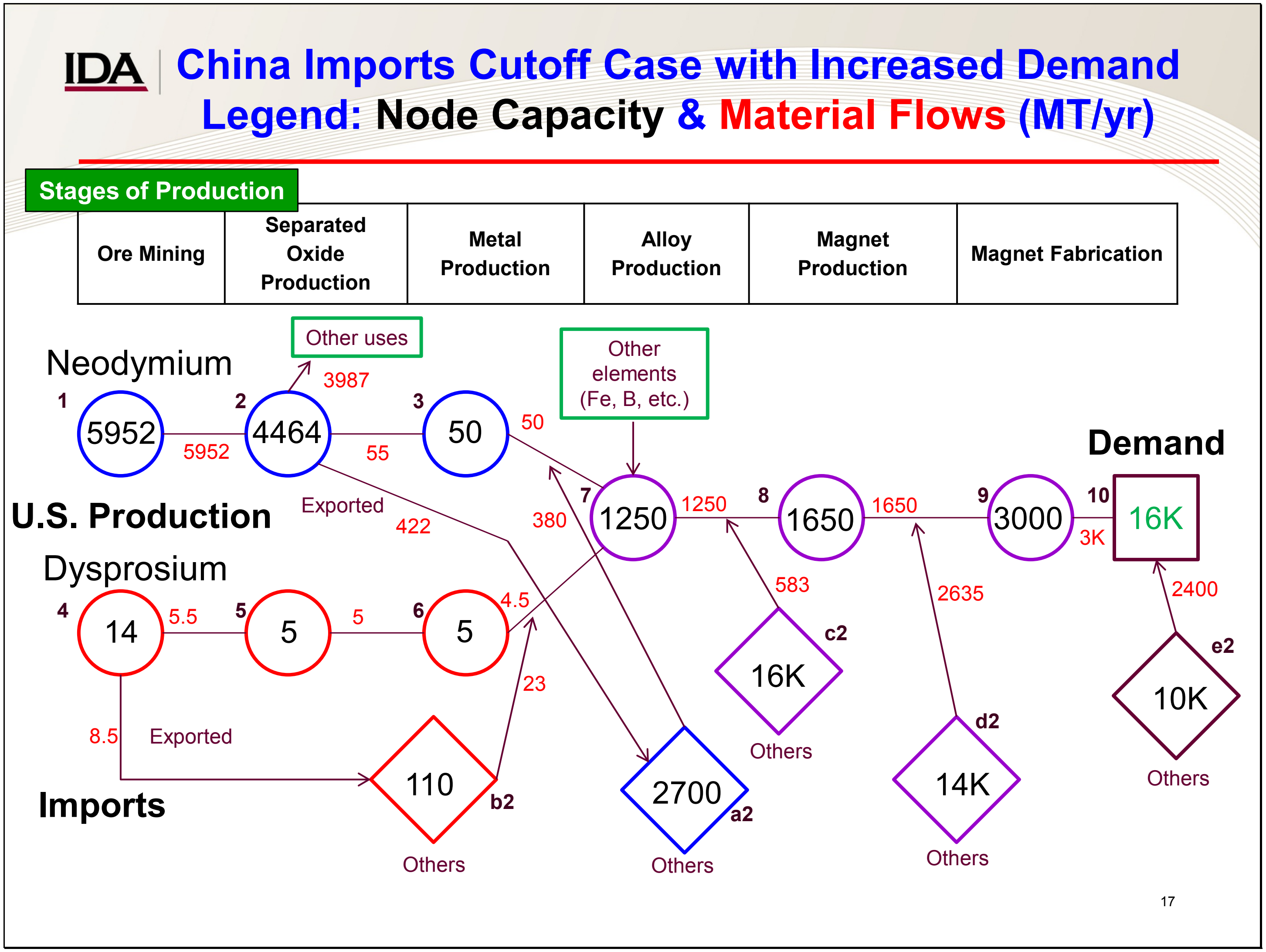
| Mitigation Measure | Amount Provided (MT) | Expected Cost (Budget) ($M) |
|---|---|---|
| Extra Buy | 500* | 7.3 |
| Conc. Program (magnets) | 2,560** | 140 |
| Substitution | 1,500 | 0 |
| Inventory | 5,040 | 995 |
| **Total** | **9,600** | **1,142** |

*Presuming 10% of available capacity previously unused and 50% of that obtained by the United States
**Sufficient to use all available domestic and imported feedstock

***Mitigation measures can be similarly optimized for other materials and scenarios***

16

This slide shows the result when the shortfall mitigation measures on slide 15 are prioritized using the same priorities that were used in the FY 2013 NDS Requirements Report. In this approach, the highest priority measures were applied first, followed by the succeedingly lower priority measures. In this scheme, the Extra Buy and Concerted Program measures were judged to be of the first priority because they provided the goods (magnets) desired by users. (Note that the Concerted Program here is only large enough to use the material feedstock otherwise available under scenario conditions. It does not provide additional feedstock materials.) The Extra Buy measure is applied first because it is less expensive (in dollars per ton) than the Concerted Program. The next priority was assigned to Substitution (because it provides substitute goods rather than the goods in question). The last priority was assigned to Inventory and Stockpiling (because of their relatively high cost), and Inventory was selected (to make up the balance of the shortfall) because it is less expensive (in dollars per ton) than Stockpiling. In this case, the total shortfall could be mitigated for a cost of $1.142 billion.


IDA
China Imports Cutoff Case with Increased Demand
Legend: Node Capacity & Material Flows (MT/yr)
Stages of Production
Ore Mining
Separated Oxide Production
Metal Production
Alloy Production
Magnet Production
Magnet Fabrication
Neodymium
Other uses
3987
1
5952
5952
2
4464
55
3
50
50
Other elements (Fe, B, etc.)
Demand
U.S. Production
Exported
422
380
7
1250
1250
8
1650
1650
9
3000
3K
10
16K
Dysprosium
4
14
5.5
5
5
5
6
5
4.5
583
c2
16K
Others
2635
2400
e2
10K
Others
23
8.5
Exported
110
b2
Others
2700
a2
Others
d2
14K
Others
Imports
17

The next scenario modeled is one in which all imports from China are cut off and U.S. demand is increased (by 6.7 percent) to 16,000 MT of magnets. As with the previous case, the supply chain responds to try to meet U.S. demand for magnets under those conditions. Magnet shortfalls must be made up by mitigation measures.

## China Imports Cutoff with Increased Demand Observations

- Demand increased by 1,000 tons/year (6.7 percent)
- Same imports as in China Imports Cutoff Case
- Imports still sufficient to feed upstream U.S. supply chain so long as U.S. market share is at least 19 percent
- Not sufficient to meet demand for final product.
  If U.S. market share = 24 percent, shortfall = 10,600 MT magnets
- Some mitigation measure(s) required as before but at higher capacity
  - Stockpiling
  - Other Inventory options (e.g., Buffer Stock)
  - Extra Buy
  - Substitution
  - Concerted Program (magnet production and fabrication)

18

When imports from China (raw materials, semi-processed materials, and finished magnets) are cut off and U.S. demand is increased to 16,000 MT of magnets, material imports are still sufficient to enable the U.S. portion of the supply chain to operate at full capacity if U.S. market share is at least 19 percent. However, that market share is not sufficient to meet U.S. demand for finished magnets. If U.S. market share is 24 percent (as it was taken to be in the previous two cases), we are still left with a shortfall of 10,600 MT of finished magnets (shortfall = 16,000 – 3,000 (U.S. produced) – 2,400 (imported)).

To make up the shortfall in magnets, shortfall mitigation measures must be applied, but the demand that must be met is higher. This discussion will similarly consider the application of the measures listed here and assess which ones would be most cost effective in this scenario.

## China Imports Cutoff with Increased Demand Mitigation Options

**Assumptions (same as China Import Cutoff Case):**

- **One year shortfall in 4-year scenario**
- **Planning horizon = 5 years (as in 2013 RR)**
- **U.S. market share = 24%**
- **Wartime price multiple = 15**
- **Probability of war = 0.0037**
- **Buffer stock rental cost = 15%/yr**
- **Cost = budget outlays (no recoupment)**

| Mitigation Measure | Amount Provided (MT) | Expected Cost (Budget) ($M) |
|---|---|---|
| Stockpiling | 10,600 | 2,777 |
| Inventory | 10,600 | 2,093 |
| Extra Buy | 500* | 7.3 |
| Substitution | 1,500 | 0 |
| Conc. Program (magnets) | 2,560** | 140 |

*Presuming 10% of available capacity previously unused and 50% of that obtained by the United States
**Sufficient to use all available domestic and imported alloy and block feedstock

19

This slide shows the planning assumptions associated with this case (which are the same as the last case) along with the results of the analysis of the mitigation measures. In sum, because the capacities of the Extra Buy, Substitution, and Concerted Program options are limited, their output (and cost) does not increase. The output (and cost) of Stockpiling or the privately held Inventory (shown in green) could be increased to meet all of the extra demand in this case. The expected costs of the options are shown with their capacities.

## China Imports Cutoff with Increased Demand Optimal Mitigation Solution

- **Shortfall mitigation options optimized for cost effectiveness**
- **Optimal measures for the China Imports Cutoff with Increased Demand case, under assumptions stated above**
  - **Mitigation measure priority same as 2013 Requirements Report**

| Mitigation Measure | Amount Provided (MT) | Expected Cost (Budget) ($M) |
|---|---|---|
| Extra Buy | 500* | 7.3 |
| Conc. Program (magnets) | 2,560** | 140 |
| Substitution | 1,500 | 0 |
| Inventory | 6,040 | 1,193 |
| **Total** | **10,600** | **1,340** |

*Presuming 10% of available capacity previously unused and 50% of that obtained by the United States
**Sufficient to use all available domestic and imported feedstock

20

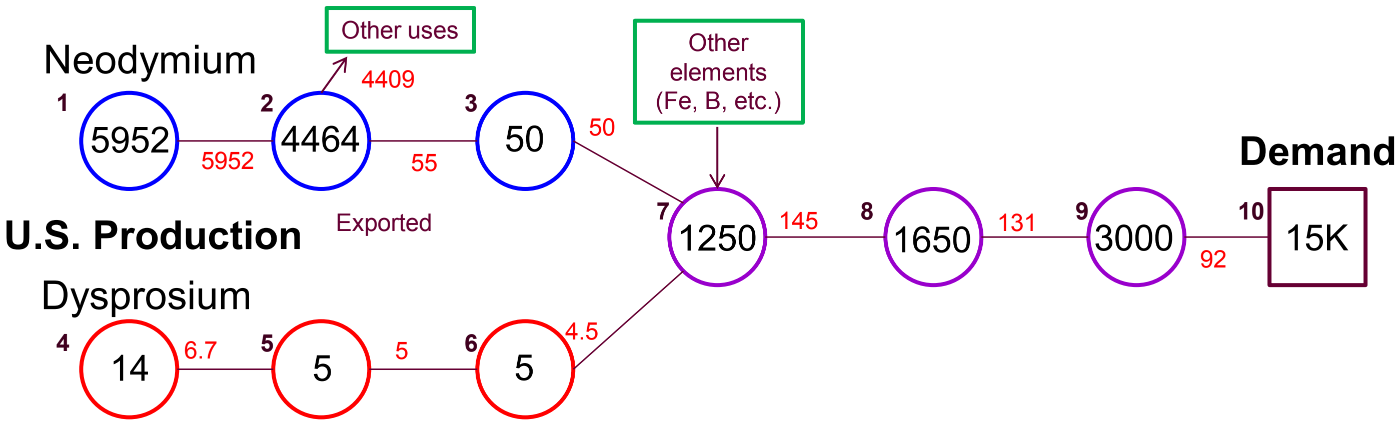
This slide shows the result when the shortfall mitigation measures on slide 19 are prioritized using the same priorities as in the previous case and the FY 2013 NDS Requirements Report. In this approach, the highest priority measures were applied first, followed by the succeedingly lower priority measures. Because the capacities of the Extra Buy, Substitution, and Concerted Program options are limited, their output cannot be increased to meet increased demand. Instead, the output of either Inventory or Stockpiling must be increased. As with the previous case, because Inventory is less expensive (in dollars per ton) than Stockpiling, it is selected, and its size is increased as necessary to meet the increased demand for magnets. This case demonstrates how the analytical method would respond to an increase in scenario demand. In this case, the total shortfall could be mitigated for a cost of $1.340 billion.

# No-Imports Case

## Legend: Node Capacity & Material Flows (MT/yr)

**Stages of Production**

| Ore Mining | Separated Oxide Production | Metal Production | Alloy Production | Magnet Production | Magnet Fabrication |
|---|---|---|---|---|---|




**No Imports**

21

The next scenario modeled is one in which all imports are cut off completely (demand is reset to the previous figure of 15,000 MT of magnets). This case is something of an artificial case, but it shows how the method can address a broad range of possible supply and demand combinations. As with the previous cases, the supply chain responds to try to meet U.S. demand for magnets under those conditions.

## No-Imports Case Observations

- Imports not available at all
- U.S. supply chain output constrained by lack of upstream capacity at several nodes
  - All but Nd ore and oxide production insufficient to meet final demand
  - Tightest bottleneck = Nd metal
- Not sufficient to meet demand for final product; shortfall = 14,900 MT magnets
- Mitigation measure(s) required at one or more nodes
  - Stockpiling
  - Other Inventory options (e.g., Buffer Stock)
  - Extra Buy
  - Substitution
  - Concerted Program (magnet production and fabrication)

22

When imports are totally cut off, the U.S. portion of the supply chain can no longer operate at full capacity. The tightest bottleneck is the supply of neodymium metal, which severely constrains the output of Nodes 7, 8, and 9. It causes a shortfall of 14,900 MT of magnets.

To make up the shortfall in magnets, shortfall mitigation measures must be applied as before, but the shortfall is larger. The discussion will consider the application of the measures listed here and assess which ones would be most cost effective in this scenario.

## IDA No-Imports Case Mitigation Options (1st Approach)

**Assumptions:**

- **One-year shortfall in 4-year scenario**
- **Planning horizon = 5 years (as in 2013 RR)**
- **U.S. market share = 0% (no imports)**
- **Wartime price multiple = 15**
- **Probability of war = 0.0037**
- **Buffer stock rental cost = 15%/yr**
- **Cost = budget outlays (no recoupment)**

**First approach: mitigate shortfall at fabricated magnet supply only**

| Mitigation Measure | Amount Provided (MT) | Expected Cost (Budget) ($M) |
|---|---|---|
| Stockpiling | 14,900 | 3,904 |
| Inventory | 14,900 | 2,943 |
| Extra Buy | 0 (no imports) | 0 |
| Substitution | 1,500 | 0 |
| Concerted Program (magnets) | 0** | 0 |

**No extra feedstock available

23

This slide shows the planning assumptions associated with this case. These assumptions are the same as for the previous cases except for U.S. market share, which goes to zero because all imports are cut off.

It also shows the results of the analysis of the mitigation measures. Two approaches are possible for mitigating the shortfall under these circumstances. One option is mitigation at the fabricated magnet supply, and the other option is mitigating at the fabricated magnet supply and providing materials to enable the U.S. supply chain to operate at capacity. In this case, under the first option, Substitution operates as before (its capacity is limited). The capacity of Extra Buy goes to zero because imports are cut off. The Concerted Program goes to zero because no further feedstock material is available to use to make magnets. That leaves Stockpiling and Inventory to make up the shortfall. The expected costs of the options are shown with their capacities.

## IDA | No-Imports Optimal Mitigation Solution (1st Approach)

- **Shortfall mitigation options optimized for cost effectiveness**
- **Optimal measures under assumptions stated above**
  - **First approach: mitigation at fabricated magnet supply only**
  - **Mitigation measure priority same as 2013 Requirements Report**

| Mitigation Measure | Amount Provided (MT) | Expected Cost (Budget) ($M) |
|---|---|---|
| Substitution | 1,500 | 0 |
| Inventory (magnets) | 13,400 | 2,646 |
| **Total** | **14,900** | **2,646** |

This slide shows the result when the shortfall mitigation measures on slide 23 are prioritized using the first of the two possible approaches for mitigating the shortfall: mitigation at the fabricated magnet supply.

When the mitigation measures are prioritized the same way as in the previous cases and the FY 2013 NDS Requirements Report, Substitution operates as before, but the only other options available to cover the shortfall are Stockpiling and Inventory. Because Inventory is less expensive (in dollars per ton) than Stockpiling, it is selected, and its size is increased as necessary to meet the increased demand for magnets. In this case, with this mitigation approach, the total shortfall could be mitigated for a cost of $2.646 billion.

## No-Imports Case Mitigation Options (2nd Approach)

**Assumptions—same as in first approach**

**Second approach: mitigation with inventory sufficient to enable full use of existing U.S. capacities**

**Amounts:**

- **Nd metal: 380 MT**
- **Dy oxide: 0.5 MT**
- **Dy metal: 22.5 MT**
- **Magnet alloy: 583 MT**
- **Magnet block: 2,635 MT**
- **Fabricated magnets: 12,000 MT**

| Mitigation Measure | Amount Provided (MT) | Expected Cost (Budget) ($M) |
|---|---|---|
| Stockpiling | Amounts above | 3,845 |
| Inventory | Amounts above | 2,898 |
| Extra Buy | 0 (no imports) | 0 |
| Substitution | 1,500 (magnets) | 0 |

25

This slide shows the results of the analysis of the mitigation measures under the second of the two possible approaches for mitigating the shortfall under the following circumstances: mitigating at the fabricated magnet supply *and* providing materials to enable the U.S. supply chain to operate at capacity. In this case, under this approach, Substitution and Extra Buy operate as with the first mitigation option. The Concerted Program remains at zero because no extra feedstock material is available to use to make magnets. That leaves Stockpiling and Inventory to make up the shortfall.

This approach shows how materials needed at several stages of production could be stockpiled or inventoried to allow the U.S. supply chain to operate at capacity, with magnets stockpiled to make up the balance of the shortfall that the U.S. supply chain could not cover. In this case, materials could be held for several succeeding stages of production because the capacity of this chain tends to increase as one moves downstream. The expected costs of the options are shown with their capacities.

IDA

## No-Imports Optimal Mitigation Solution (2nd Approach)

- **Shortfall mitigation options optimized for cost effectiveness**
- **Optimal measures under assumptions stated above**
  - **Second approach: mitigation with inventory sufficient to enable full use of existing U.S. capacities**
  - **Mitigation measure priority same as 2013 Requirements Report**

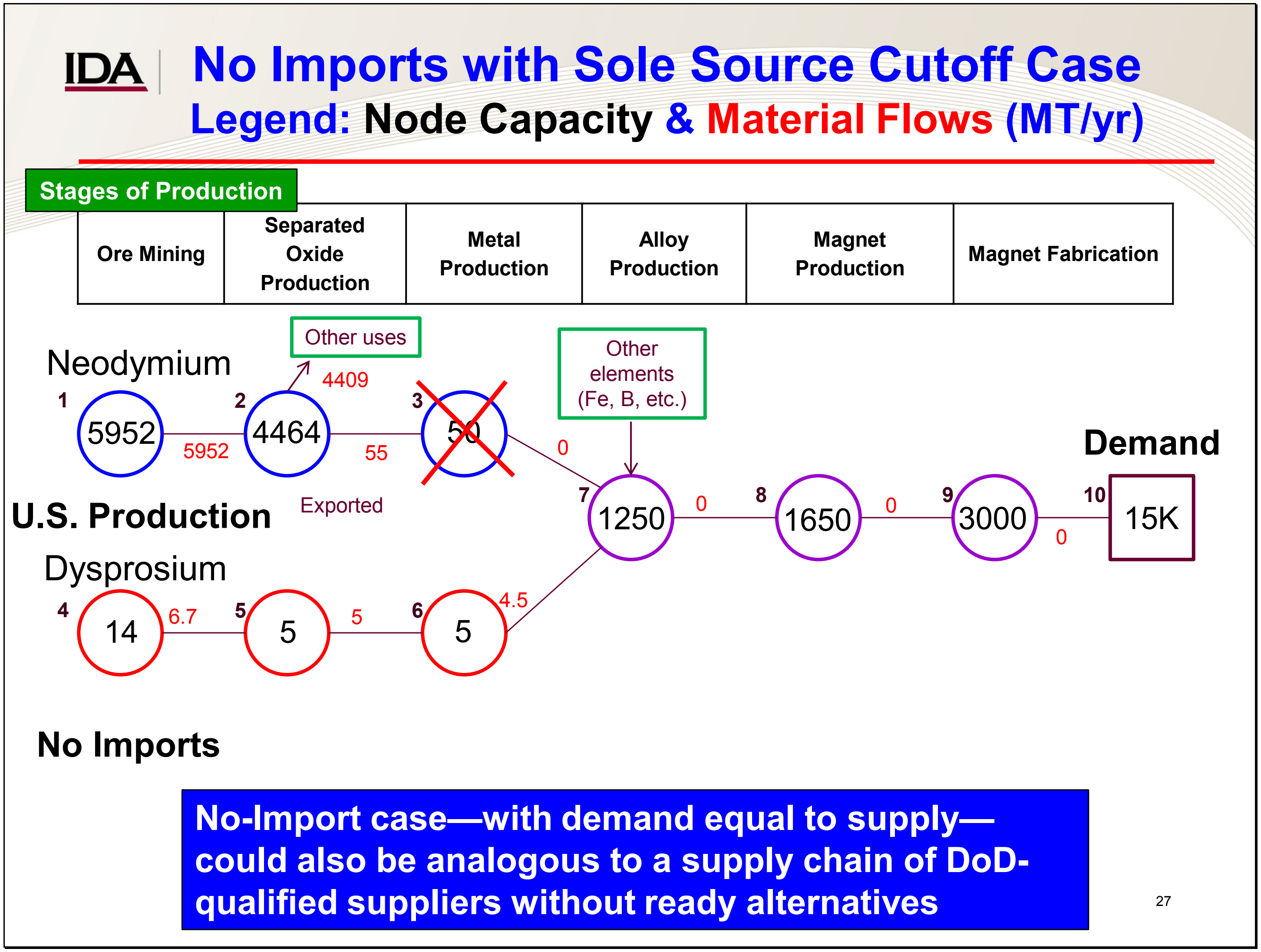
| Mitigation Measure | Amount Provided (MT) | Expected Cost (Budget) ($M) |
|---|---|---|
| Substitution | 1,500 | 0 |
| Inventory (magnets) | 10,500 | 2,074 |
| Inventory (block) | 2,635 | 459 |
| Inventory (alloy) | 583 | 35 |
| Inventory (Dy metal) | 22.5 | 13 |
| Inventory (Dy oxide) | 0.5 | 0.3 |
| Inventory (Nd metal) | 380 | 20 |
| **Total** | **14,900 (magnets)** | **2,601** |

26

This slide shows the result when the shortfall mitigation measures on slide 25 are prioritized using the second of the two possible approaches for mitigating the shortfall: mitigation at the fabricated magnet supply and providing materials to enable the U.S. supply chain to operate at capacity.

The only options available are Substitution and Inventory or Stockpiling. Substitution operates as before. However, Stockpiling and Inventory now include all of the upstream materials needed to enable the U.S. supply chain to operate at capacity plus finished magnets needed to make up the balance of the shortfall. When the costs of acquiring and holding all of the materials indicated are calculated, Inventory remains the less costly approach, and it is selected.

In this case, with this mitigation approach, the total shortfall could be mitigated for a cost of $2.601 billion. That figure is slightly less than the Inventory cost under the first mitigation approach (magnets only). Under this approach, materials are held to enable the U.S. supply chain to operate, which allows the capacity of the domestic manufacturing chain to add value to be used instead of merely stockpiling finished products. While such an approach must make up for material losses incurred at the different upstream stages of the supply chain, it is still less costly. It also preserves the ability of the supply chain to adapt its final product to meet potentially shifting specifications in ways that could be more problematic for an inventory or stockpile of finished goods. This example further shows the ability of DRAM to address the different mitigation approaches that might be developed to address a material shortfall scenario.


IDA
No Imports with Sole Source Cutoff Case
Legend: Node Capacity & Material Flows (MT/yr)
Stages of Production
Ore Mining
Separated Oxide Production
Metal Production
Alloy Production
Magnet Production
Magnet Fabrication
Neodymium
Other uses
4409
Other elements (Fe, B, etc.)
1
5952
5952
2
4464
55
3
50
0
Demand
U.S. Production
Exported
7
1250
0
8
1650
0
9
3000
0
10
15K
Dysprosium
4
14
6.7
5
5
5
6
5
4.5
No Imports
No-Import case—with demand equal to supply—could also be analogous to a supply chain of DoD-qualified suppliers without ready alternatives
27

The next scenario modeled is one in which all imports are cut off completely and one supply chain node that is a sole source of one upstream product (Nd metal in this instance) does not operate. This case is also something of an artificial case, but it could be analogous to a DoD supply chain with no qualified alternative suppliers (where production capacity was just equal to demand) that suffers a failure at one node. As with the previous cases, the supply chain responds to try to meet U.S. demand for magnets under those conditions.

## No Imports with Sole Source Cutoff Case Observations

- Imports not available at all, and sole source node cut off
- U.S. supply chain output constrained by lack of upstream capacity at several nodes
- One node—Nd metal production—is cut off entirely
  - Loss of critical node cuts off all US production of final product
  - All but Nd ore and oxide production insufficient to meet final demand
- Resulting shortfall = 15,000 MT magnets
- Mitigation measure(s) required at one or more nodes
  - Stockpiling
  - Other Inventory options (e.g., Buffer Stock)
  - Extra Buy
  - Substitution
  - Concerted Program (magnet production and fabrication)

28

When imports are totally cut off and U.S. production of Nd metal is totally halted, the U.S. portion of the supply chain can no longer operate at all. This situation causes a complete shortfall of 15,000 MT of magnets. To make up the shortfall in magnets, shortfall mitigation measures must be applied.

IDA

# No Imports with Sole Source Cutoff Case Mitigation Options (1st Approach)

**Assumptions:**

- **One-year shortfall in 4-year scenario**
- **Planning horizon = 5 years (as in 2013 RR)**
- **U.S. market share = 0% (no imports)**
- **Wartime price multiple = 15**
- **Probability of war = 0.0037**
- **Buffer stock rental cost = 15%/yr**
- **Cost = budget outlays (no recoupment)**

**First approach: mitigate shortfall at fabricated magnet supply only**

| Mitigation Measure | Amount Provided (MT) | Expected Cost (Budget) ($M) |
|---|---|---|
| Stockpiling | 15,000 | 3,930 |
| Inventory | 15,000 | 2,962 |
| Extra Buy | 0 (no imports) | 0 |
| Substitution | 1,500 | 0 |
| Concerted Program (magnets) | 0** | 0 |

**No extra feedstock available

29

This slide shows the planning assumptions associated with this case, which are the same as the immediate previous case. It also shows the results of the analysis of the mitigation measures. It considers the first mitigation approach of mitigation at the fabricated magnet supply only. Under this approach, Substitution, Extra Buy, and the Concerted Program operate as in the last case with this approach. That leaves Stockpiling and Inventory to make up the shortfall, which is somewhat larger in this case than in the last. The expected costs of the options are shown with their capacities.

## No Imports with Sole Source Cutoff Optimal Mitigation Solution (1st Approach)

- **Shortfall mitigation options optimized for cost effectiveness**
- **Optimal measures under assumptions stated above**
  - **First approach: mitigation at fabricated magnet supply only**
  - **Mitigation measure priority same as 2013 Requirements Report**

| Mitigation Measure | Amount Provided (MT) | Expected Cost (Budget) ($M) |
|---|---|---|
| Substitution | 1,500 | 0 |
| Inventory (magnets) | 13,500 | 2,666 |
| **Total** | **15,000** | **2,666** |

30

This slide shows the result when the shortfall mitigation measures on slide 29 are prioritized using the first of the two possible approaches to mitigating the shortfall: mitigation at the fabricated magnet supply.

When the mitigation measures are prioritized the same way as in the previous cases and the FY 2013 NDS Requirements Report, Substitution operates as before, but the only other options available to cover the shortfall, which is now slightly larger, are Stockpiling and Inventory. Because Inventory is less expensive (in dollars per ton) than Stockpiling, it is selected, and its size is increased as necessary to meet the increased demand for magnets. In this case, with this mitigation approach, the total shortfall could be mitigated for a cost of $2.666 billion.

## No Imports with Sole Source Cutoff Case Mitigation Options (2nd Approach)

**Assumptions—same as in first approach**

**Second approach: mitigation with inventory sufficient to enable full use of existing U.S. capacities**

**Amounts:**

- **Nd metal: 430 MT**
- **Dy oxide: 0.5 MT**
- **Dy metal: 22.5 MT**
- **Magnet alloy: 583 MT**
- **Magnet block: 2,635 MT**
- **Fabricated magnets: 12,000 MT**

| Mitigation Measure | Amount Provided (MT) | Expected Cost (Budget) ($M) |
|---|---|---|
| Stockpiling | Amounts above | 3,848 |
| Inventory | Amounts above | 2,900 |
| Extra Buy | 0 (no imports) | 0 |
| Substitution | 1,500 (magnets) | 0 |

31

This slide shows the results of the analysis of the mitigation measures under the second of the two possible approaches for mitigating the shortfall under these circumstances: mitigating at the fabricated magnet supply and providing materials to enable the U.S. supply chain to operate at capacity. In this case, under this approach, Substitution and Extra Buy operate as with the first mitigation option. The Concerted Program remains at zero because no extra feedstock material is available to make magnets. That leaves Stockpiling and Inventory to make up the shortfall.

This approach again shows how materials needed at several stages of production could be stockpiled or inventoried to allow the U.S. supply chain to operate at capacity, with magnets stockpiled to make up the balance of the shortfall that the U.S. supply chain could not cover. In this case, as with the preceding case, materials could be held for several succeeding stages of production because the capacity of this chain tends to increase as one moves downstream. The difference in this case is that because the U.S. Nd metal production capacity is presumed not to operate at all, the output of that node must be entirely made up by Stockpiling or Inventory. Thus, the amount of Nd metal that would be stockpiled or inventoried is shown as increasing to 430 MT. The expected costs of the options are shown with their capacities.

## No Imports with Sole Source Cutoff Optimal Mitigation Solution (2nd Approach)

- **Shortfall mitigation options optimized for cost effectiveness**
- **Optimal measures under assumptions stated above**
  - **Second approach: mitigation with inventory sufficient to enable full use of existing U.S. capacities**
  - **Mitigation measure priority same as 2013 Requirements Report**

| **Mitigation Measure** | **Amount Provided (MT)** | **Expected Cost (Budget) ($M)** |
|---|---|---|
| Substitution | 1,500 | 0 |
| Inventory (magnets) | 10,500 | 2,074 |
| Inventory (block) | 2,635 | 459 |
| Inventory (alloy) | 583 | 35 |
| Inventory (Dy metal) | 22.5 | 13 |
| Inventory (Dy oxide) | 0.5 | 0.3 |
| Inventory (Nd metal) | 430 | 23 |
| **Total** | **15,000 (magnets)** | **2,604** |

32

This slide shows the result when the shortfall mitigation measures on slide 31 are prioritized using the second of the two possible approaches to mitigating the shortfall: mitigation at the fabricated magnet supply and providing materials to enable the U.S. supply chain to operate at capacity.

The only options available are Substitution and Inventory or Stockpiling. Substitution operates as before. Stockpiling and Inventory now include all of the upstream materials needed to enable the U.S. supply chain to operate at capacity—including all of the Nd metal needed to make up for the absence of that supply chain node—plus the magnets needed to make up the balance of the shortfall. When the costs of acquiring and holding all of the materials indicated are calculated, Inventory remains the less costly approach, and it is selected.

In this case, with this mitigation approach, the total shortfall could be mitigated for a cost of $2.604 billion. As with the previous case, that cost is slightly less than the cost under the first mitigation approach (magnets only). This case further shows the ability of DRAM to address different material shortfall scenarios—an import cutoff combined with a U.S. supply chain failure.

# 5. Observations

IDA | **Observations**

## Modeling capabilities demonstrated

- Supply chains with material flows for multiple materials and multiple material suppliers
- Multiple scenario conditions
  - Peacetime material flows
  - Increased demand
  - Cutoffs of material supplies from specified sources or all sources, including domestic
- Shortfall risk mitigation measures from 2013 Requirements Report and potentially others
  - Applicable node by node and material by material
  - Effects on individual material flows and mitigation costs calculable
  - Can be optimized using specified priorities or to minimize cost or risk
- Although methodology has been demonstrated, modeling may require large amounts of data

This slide notes that this presentation demonstrates the supply chain modeling capabilities of DRAM. The capabilities are very flexible and can represent a wide variety of supply chains for different materials and products. They can model a wide range of supply and demand conditions that could arise from scenarios of interest to DLA-SM and DoD. They can also model a wide range of possible shortfall risk mitigation measures—those included in the FY 2013 Stockpile Requirements Report and others.

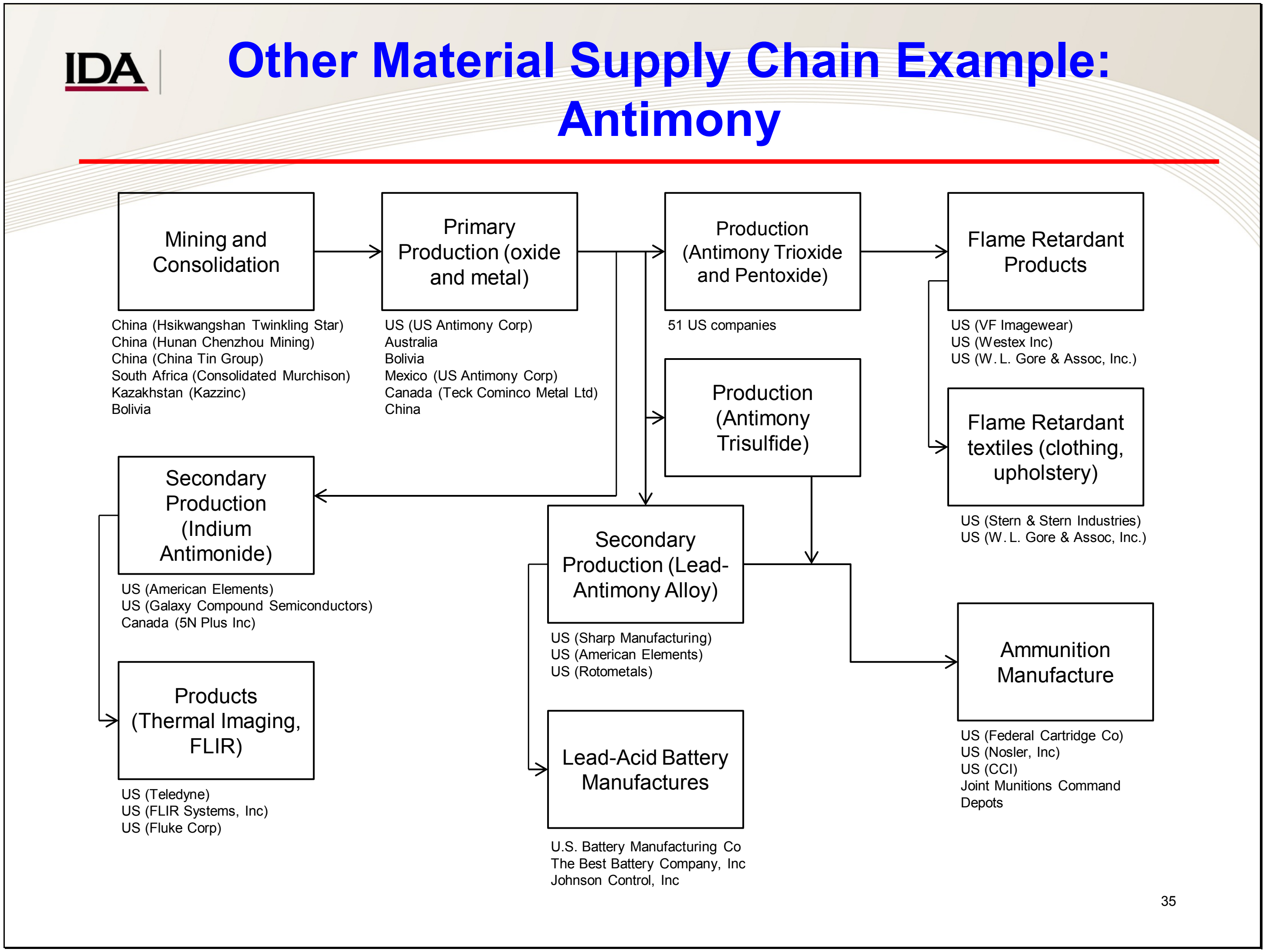
However, while the DRAM modeling capabilities are very flexible and potentially applicable in a wide range of possible shortfall situations, it should be noted that a significant amount of data is required to model and analyze a supply chain this way. It has been IDA's experience that, at times, acquiring supply chain data is difficult. Companies often consider their production capacities to be sensitive information that they do not release publically. Data on foreign producers, particularly those in less well-developed areas of the world or in potentially hostile countries, can also be difficult to obtain. Nevertheless, the analyses demonstrated here show that DRAM can be useful for gaining an understanding of supply chains important to DoD and potentially uncovering vulnerabilities that are not apparent from analyzing upstream (raw material) supply and demand only.

# IDA | Observations (cont.)

## Prototype modeling results

- **Loss of sources within supply chain can create shortfalls depending on redundancy of network and U.S. market share of imports**
  - **Loss of single node could prevent production of final product**
- **Different mitigation measures may not be suitable for some nodes and scenarios (e.g., substitution, extra buy)**
- **Capacities of nodes in domestic supply chains may not be balanced for self-sufficiency**
  - **Shortfall mitigation at multiple nodes may be required to allow production of final product at full domestic capacity**
  - **Options for shortfall mitigation may exist at multiple mid-stream nodes as well as final downstream node**
  - **Relative costs of shortfall mitigation at different nodes (e.g., mid-stream, downstream) may vary depending on material and nature of production process**

Although these cases were analyzed to demonstrate DRAM's capabilities to model supply chains, we can draw some conclusions from them—stated on this slide—regarding the nature of strategic and critical material supply chains and their potential vulnerabilities.


IDA
Other Material Supply Chain Example: Antimony
Mining and Consolidation
China (Hsikwangshan Twinkling Star)
China (Hunan Chenzhou Mining)
China (China Tin Group)
South Africa (Consolidated Murchison)
Kazakhstan (Kazzinc)
Bolivia
Primary Production (oxide and metal)
US (US Antimony Corp)
Australia
Bolivia
Mexico (US Antimony Corp)
Canada (Teck Cominco Metal Ltd)
China
Production (Antimony Trioxide and Pentoxide)
51 US companies
Flame Retardant Products
US (VF Imagewear)
US (Westex Inc)
US (W. L. Gore & Assoc, Inc.)
Production (Antimony Trisulfide)
Flame Retardant textiles (clothing, upholstery)
US (Stern & Stern Industries)
US (W. L. Gore & Assoc, Inc.)
Secondary Production (Indium Antimonide)
US (American Elements)
US (Galaxy Compound Semiconductors)
Canada (5N Plus Inc)
Secondary Production (Lead-Antimony Alloy)
US (Sharp Manufacturing)
US (American Elements)
US (Rotometals)
Ammunition Manufacture
US (Federal Cartridge Co)
US (Nosler, Inc)
US (CCI)
Joint Munitions Command Depots
Products (Thermal Imaging, FLIR)
US (Teledyne)
US (FLIR Systems, Inc)
US (Fluke Corp)
Lead-Acid Battery Manufactures
U.S. Battery Manufacturing Co
The Best Battery Company, Inc
Johnson Control, Inc
35

As noted, DRAM can be used to analyze a wide variety of supply chains for different materials and products. Antimony is another strategic and critical material that has been found to be in shortfall at the raw material level in recent NDS Requirements Reports. DLA-SM has also expressed interest in analyzing the supply chain for certain antimony-containing products like flame-retardant clothing and ammunition (primers). This diagram shows the antimony supply chain at the product type level. Given appropriate data, it or the supply chain of any strategic and critical material could be analyzed for potential vulnerabilities during crisis or conflict scenarios of interest to DoD.

## Issues for Further Investigation

- **Alternative approaches (beyond expert judgment) to assessing consequences of shortfalls of downstream goods**
  - **Motivated by desire for more objective and systematic method that can make use of all data available relevant to supply chains and demand for goods**
- **Approaches to assessing larger supply networks for broader sets of material applications: product types, industries, and the U.S. economy**
  - **Motivated by challenges in collecting supply chain data on firm-by-firm, facility-by-facility, or product-by-product basis**

36

During this work, a few issues were identified for further investigation. One that was noted—somewhat in passing—was finding alternative approaches to assess the consequences of shortfalls of downstream goods. This document focuses on the analysis and mitigation of potential shortfalls arising out of one supply chain (NdFeB magnets). However, if DoD were to evaluate multiple chains, it might discover within one or more scenarios multiple shortfalls that it wished to mitigate. (DoD might conduct such evaluations in preparing the biennial Stockpile Requirements Report.)

In RAMF-SM, risk is used to prioritize shortfall mitigation choices. As noted earlier, risk assessment includes shortfall consequence assessment (risk = shortfall (scenario) probability × consequences). Thus, it is desirable to have a robust method of evaluating the consequences of shortfalls in materials or goods to aid in the risk assessment process. In the 2013 Report on Stockpile Requirements, expert judgment was used to evaluate shortfall consequences. However, developing alternative measures that were more objective and systematic and that could make more use of available data relevant to supply chains and demand for goods was desirable. Further work in this area was pursued during the preparation of the 2015 Report on Stockpile Requirements, and it is discussed in that report and the accompanying IDA Paper (P-5190).

The other issue identified for further investigation was developing approaches to assess larger supply networks for broader sets of material applications: product types, industries, and the U.S. economy. This was motivated by challenges in collecting supply chain data on a firm-by-firm, facility-by-facility, and product-by-product basis. More work on this question was also performed during the preparation of the 2015 Report on Stockpile Requirements. Supply chain analyses using supply and demand data aggregated by country were successfully conducted and are reported in that report and the accompanying IDA Paper (P-5190). Nevertheless, data collection remains a challenge for supply chain analysis. More work on developing data sources and aggregation and estimation techniques will help enhance the future utility of DRAM.

# 6. Conclusions and Recommendations

## Conclusions and Recommendations

- Modeling capability has been developed to represent downstream supply chains for materials of interest to DLA SM under various potential scenarios
  - Capability includes mitigation measures used in 2013 Requirements Report and others
  - Shortfalls can be estimated and mitigation measure cost and effectiveness assessed
- Recommend applying modeling capability to downstream materials of interest to DLA (e.g., one or more of current five materials under study)
  - Build databases for supply chain and shortfall mitigation measures assessment
  - Assess shortfalls and evaluate mitigation measures under 2015 Base Case scenario conditions and other scenarios of interest
- Investigate consequence assessment and modeling of larger networks
- Refine approach based on observations and DLA feedback for use with FY15 Requirements Report and future NDS Requirements Reports

This briefing demonstrates the outcome of this IDA research effort: the development of a modeling capability to analyze downstream supply chains for strategic and critical materials of interest to DLA SM under various potential planning scenarios.

At the end of this capability development effort, we recommended that DRAM be applied to downstream materials of interest to DLA. Such efforts would involve building databases for the supply chains and possible mitigation measures and conducting analyses under scenarios of interest to DLA. This work has been done for several materials for the FY 2015 Report on Stockpile Requirements. Those efforts will be documented in an upcoming IDA Paper (P-5190) prepared in conjunction with IDA's support of the preparation of the FY 2015 Report on Stockpile Requirements.

We also recommended further investigation of shortfall consequences assessment and the modeling of larger supply networks, which was also done to an extent for the FY 2015 Report on Stockpile Requirements. Those efforts will also be documented in IDA Paper P-5190.

Finally, we recommended refining this approach based on observations and DLA feedback for use with the FY 2015 Requirements Report and future NDS Requirements Reports. As noted, this work was also undertaken in conjunction with IDA's support of the preparation of the FY 2015 Report on Stockpile Requirements and will be documented in IDA Paper P-5190.

# 7. Back up Slides

# BACK-UP

38

This slide indicates the beginning of the back-up material in this presentation.

IDA | # Objectives and Schedule

## Objectives

- Develop a Downstream (supply chain) Risk Assessment Methodology for strategic materials (DRAM) that is consistent with and builds upon RAMF-SM
- Design and conduct tests of DRAM using data from recent IDA material case studies and risk assessments
- Build downstream material supply chain databases for and apply/adapt DRAM for 10 additional materials (possibly more)

| Step | Schedule |
|---|---|
| Develop DRAM | Now – June ‘13 |
| Design and Test DRAM | Now – Oct ‘13 |
| Build Databases and Apply DRAM | Now – July ‘14 |
| Brief Sponsor on Progress and Results | Periodic |
| Prepare Supply Chain Work for 2015 RR | Now – Aug ‘14 |
| Deliver IDA P-Paper to Sponsor | Sept ‘14 |

39

This slide summarizes the objectives of and the schedule for IDA’s development of DRAM as of early 2013. While the delivery of this document to the sponsor was deferred, the other schedule milestones were met.

IDA | **Material Prices**

- **The following material prices were used in the calculations in this briefing ($/kg):**

| | |
|---|---|
| **Neodymium Oxide:** | **50** |
| **Dysprosium Oxide:** | **700** |
| **Neodymium Metal:** | **71** |
| **Dysprosium Metal:** | **775** |
| **NdFeB Alloy:** | **79.36** |
| **NdFeB Magnet Block:** | **231.28** |
| **Fabricated NdFeB Magnets:** | **262.02** |

40

These are the material prices used in the mitigation measure cost calculations in this document.

IDA

## Basis for Concerted Program—Magnets

- Potential concerted program: magnet production facility that would produce 2,560 MT/yr for cost of $139 million
- Starting assumption: reported capacity of Hitachi North Carolina magnet production plant of 40 MT/month (480 MT/yr) at cost of $26 million
- Capacity of concerted program taken to be sufficient to use feedstock available in the United States in China Import Cutoff Case
    - Alloy: 1,250 MT/yr domestic + 3,840 MT/yr imported (assuming 24 percent market share) = 5,090 MT/yr total available
    - Block: 3,360 MT/yr imported (24 percent market share)
    - Loss factor is 0.9 for alloy to block and 0.7 for block to magnets
    - Feedstock is sufficient to yield 5,560 MT/yr finished magnets
    - If existing U.S. magnet production capacity is 3,000 MT/yr, concerted program would need capacity of 2,560 MT/yr at cost of $140 million

41

This slide describes the basis for the concerted program for building a U.S. capability to produce fabricated magnets that was considered as a potential shortfall mitigation measure in this document. It was based on the publically reported capacity and cost of the NdFeB magnet plant built by Hitachi in North Carolina. In this document, the concerted program was scaled up to allow it to use all of the feedstock (magnet alloy and magnet block) available domestically and from foreign suppliers in the China Import Cutoff Case.

# Appendix A.
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# Appendix B.
# Abbreviations

| | |
|---|---|
| B | boron |
| DLA SM | Defense Logistics Agency Strategic Materials |
| DoD | Department of Defense |
| DRAM | Downstream Risk Assessment Methodology |
| Dy | dysprosium |
| IDA | Institute for Defense Analyses |
| Fe | iron |
| FY | Fiscal Year |
| MT | metric ton |
| Nd | neodymium |
| NDS | National Defense Stockpile |
| NdFeB | neodymium-iron-boron |
| RAMF-SM | Risk Assessment and Mitigation Framework for Strategic Materials |
| RR | Requirements Report |
| U.S. | United States |

| REPORT DOCUMENTATION PAGE | *Form Approved OMB No. 0704-0188* |
|---|---|



| 1. REPORT DATE (DD-MM-YYYY) | 2. REPORT TYPE | 3. DATES COVERED (From – To) |
|---|---|---|
| XX-04-2015 | Final | Nov 2014 – Apr 2015 |

| | |
|---|---|
| 4. TITLE AND SUBTITLE<br>Supply Chain Modeling: Downstream Risk Assessment Methodology (DRAM) Demonstration of Capability | 5a. CONTRACT NO.<br>HQ0034-14-D-0001<br>5b. GRANT NO.<br>5c. PROGRAM ELEMENT NO(S). |
| 6. AUTHOR(S)<br>Barnett, D. Sean<br>Bracken, Jerome | 5d. PROJECT NO.<br>5e. TASK NO.<br>DE-6-3247<br>5f. WORK UNIT NO. |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>Institute for Defense Analyses<br>4850 Mark Center Drive<br>Alexandria, VA 22311-1882 | 8. PERFORMING ORGANIZATION REPORT NO.<br>IDA Document D-5347<br>H 15-000038 |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)<br>Defense Logistics Agency<br>8725 John J. Kingman Rd., #2545<br>Fort Belvoir, VA 22060 | 10. SPONSOR'S/MONITOR'S ACRONYM(S)<br>DLA<br>11. SPONSOR'S/MONITOR'S REPORT NO(S). |

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Institute for Defense Analyses developed the Downstream Risk Assessment Methodology (DRAM), for the Defense Logistics Agency Strategic Materials (DLA SM), to allow it to analyze supply chains of strategic and critical materials and the applications or products in which they are used. DRAM allows DLA SM to assess and mitigate risks that may arise from vulnerabilities in supply chains that would not be revealed by analysis of the supply of and demand for raw materials alone.

DRAM represents each important production step in the supply chain for a material and characterizes how it operates in terms of production capacity and material feedstock requirements. The fundamental approach is mass flow analysis, from raw material through each step in production. The model can also estimate supply and demand on a time-phased basis under the conditions of the National Defense Stockpile planning scenario and any others of interest. It can represent material shortfall mitigation measures.

The model's operation is demonstrated using the neodymium-iron-boron magnet supply chain as a test case. Several hypothetical scenarios show how it could be used to assess shortfall risk associated with downstream materials similar to the way that DLA SM assesses shortfall risk associated with raw materials.

15. SUBJECT TERMS

materials, supply chain, demand, risk, assessment, mitigation, modeling, methodology, strategic and critical, IDA, Defense Logistics Agency Strategic Materials, National Defense Stockpile, rare earth, neodymium, magnet

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
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