Figure 3
Activity Worksheet: Aluminum barge penny-recycling challenge

Materials/group
4 indirectly vented chemical splash goggles
2 sheets of 30 cm × 30 cm aluminum foil
200–300 (preferably an even distribution) of pre-/post1982 pennies (this activity requires a lot of pennies; if shared between groups, pennies will need to be dried after use by a group)
Tub that will hold 4–5 liters of water requiring 10–15 centimeters depth (may want to provide multiple testing tubs since some companies (groups) like to keep their testing design a secret!)
Volume-measuring device
Scale

Barge company name: ____

Background information
You have recently been asked to design an aluminum barge for the Copper Recycling Corporation (CRC). The purpose of the barge will be to transport pennies down the Mississippi River (without sinking) for copper reclamation. Testing procedures and parameters are explained below. You will have two design opportunities to sell your barge to the CRC. If you succeed, your company may receive a multimillion dollar contract.

Procedure
1. Cut a 30 cm × 30 cm sheet of aluminum foil.
2. Design a barge out of your aluminum foil to hold pennies in a tub of water. *It is important that students spend time with the planning process. Encourage discussion and sketch a design before jumping into the activity.*
3. After your barge has been made, determine the approximate open volume of your barge in mL. (Hint: If you know the density of water, you can get a close approximation of the volume of your barge without actually having to measure it after you complete step 5.) *A few students will realize the mass of the pennies at the point the barge sinks in grams is approximately equal to the volume of the boat in mL because the density of water is roughly 1 g/mL.* The formula for density is density = mass/volume. The point where the barge sinks is very near the ratio of 1 such that numerically the mass amount equals the volume amount when using the metric units grams and milliliters.
4. Add pennies one at a time until your barge sinks.
5. Mass your pennies in grams. *Some students will realize that wet pennies weigh more than dry pennies and decide to dry them off before weighing. Besides not wanting my balance wet, I try to get students to realize the difference in advance of weighing.*
6. Calculate the mass of pennies divided by the volume of the barge. (Hint: If you know the density of water, this answer is simpler than it may seem. See Step 3 again.) Discuss your first barge design. What was its' shape? Did how you place your pennies make a difference? How deep in the water did your barge sit before pennies were added? How does your group plan to change your barge design to increase the number of pennies it will hold?
7. Repeat steps 1–6 for a second barge design. *It is important that students learn from their previous design. Emphasize the importance of discussing ideas and planning in detail.*

8. Retain the pennies held by your second barge design for date examination (pennies prior to 1982 were composed of 95% copper/5% zinc while pennies from 1982 on were composed of only 2.5% copper/97.5% zinc. Prior to 1982, pennies were 95% copper with the remaining 5% composed of zinc and tin.

Barge design 1

Number of pennies held ___________Mass of pennies ________g
Volume of boat _________mL Density = mass/volume __________ g/mL

Boat design 2

Number of pennies held ___________Mass of pennies ________g
Volume of boat _________mL Density = mass/volume __________ g/mL

Compare your barge design with other groups in the classroom. What design increased the number of pennies that could be held?

Locate the value of copper on the precious metals market on the internet. Also, locate the percentage copper in a penny. (Hint: You should examine your pennies closely.) Calculate how much unrecycled copper (using the pennies collected) your barge could have transported without sinking. *Usually some students will remember from the factoid list about Lincoln pennies that the percent copper changes after 1982.*

________ g

Calculate the value of the unrecycled copper within the pennies that your barge held before sinking using commodities market values. You will need to pay special attention to the dates since the percentage of copper composition changed in 198
$ ________

Scaling-up exercise
Based on the best barge design in your class, what would be the approximate dimensions of the barge if it were increased in size by 100? Students will need to measure the dimensions of the best barge design to scale up the dimensions. *While you may not want to tell students that a rectangular-shaped barge is the easiest for scaling up, I have found that using the "best" barge from the class usually comes from the group that made theirs rectangular shaped.*

If you could make the barge 100 times larger, how many pennies could it transport? What would be the mass and value (use commodity market prices) of the copper (remember the difference between pre- and post1982 pennies) if the barge size were increased by a scale of 100?

Additional extensions
If the cost of diesel fuel for a tugboat to push your barge down the Mississippi river is $1/mile unloaded, how much will it cost to transport a full load of pennies (i.e., at least one penny less needed to sink the barge) if each penny increases the fuel cost by 3 cents and the barge is

travelling 150 miles down river? Make your calculations based on a round trip if the return trip is \$1.25/mile going against the current on the return trip.

Which is cheaper—transporting by truck or by barge if it costs 25 cents per penny to transport the pennies by trucks? The fuel mileage of a truck is 8 miles per gallon. The cost of diesel for a truck is \$3 per gallon. Your truck's penny capacity is 50 pennies. The road distance is 75 miles. Again, calculate based on round trips.

Boat cost
If 347-penny boat capacity (This group made accurate calculations using their second barge design when compared to a 50-penny–limit truck. If a group chooses the scaled-up, 100-times-larger barge to make calculations, they will need to scale up the truck carrying capacity to make a fair comparison.)

Cost to the recycling plant = 347 pennies × \$0.03 × \$1 × 150 miles = \$1,562
Return trip cost= \$1.25 × 150 miles = \$187.50

Cost to transport pennies by boat = \$1749

Truck cost
Cost to the recycling plant = 6 trucks × 50 pennies x \$0.25 × 75 miles × \$3/gallons/8 miles/gallon = \$2,109

Cost to the recycling plant= 1 truck × 47 pennies × \$25 × 75 × \$3/gallons/8 miles/gallon = \$441

Return trip cost= 7 trucks × 75 miles × \$3/gallon/8 miles/gallon= \$197

Cost by truck = \$2,747