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A novel teaching resource for introducing sustainability to chemistry higher education students

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1. **Overview:** A board-game "**Green Chemistry**" has been designed and developed as an alternative means of introducing sustainability concepts to higher education (HE) students in chemical sciences. Small group social interaction and an informal learning style between peers is sought. Concepts in the game relate to sustainable chemical manufacture. These include process change to utilise less harmful raw materials more efficiently, reduction of waste streams, energy efficiency, emissions controls and financial penalties.
   An outline of game-play is given and the positive views of those playing the game, both students and tutors, are presented.
   This game has been used at HE institutions in the U.K., elsewhere in Europe and beyond.

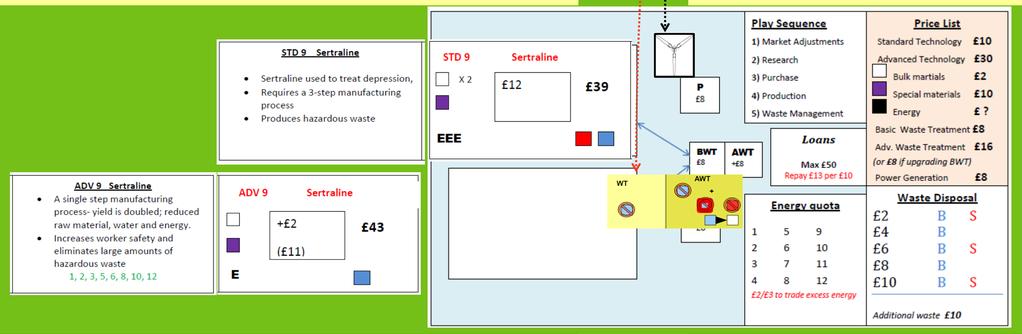
2. Chemical Manufacturing Technologies

Players invest in one or two technologies, depicted on two-sided cards (Sertraline manufacture is shown as an example here):

•One side shows the conventional manufacturing method (STD), the reverse side is the upgraded "**Green Chemistry**" (ADV) alternative.

•Each game-card, with coded symbols, is accompanied by a text-card which describes the chemical manufacturing process depicted.

•Twelve technologies are featured. Players auction for possession of a **Technology Card** (base £10 + variable £12 minimum cost). Technology Cards may later be flipped to the ADV side for £30 cost.



3. Interpreting the Technology Cards

Cards show the units of ***Bulk*** ☐ and ***Special*** ■ ***raw materials*** and ***Energy*** (**E**) units players buy to generate the product.

The product provides ***income*** (£39/£43 here) and also ***Bulk*** ■ and ***Special*** ■ ***waste*** which must be disposed or treated immediately.

All commodities are tracked by using coloured tokens.

Text cards list (in green numbers) which of the "Twelve Principles of Green Chemistry[1]" prominently apply to that technology. A summary of these principles is available to students to consider in the context of the game through improved raw material and energy use and waste reduction by changing from "STD" to "ADV" process.

4. Options for players

Players can invest to improve their game chemical plant.

Energy costs change, tending upwards. Players can buy **on-site power generation (P)**, representing heat exchangers and renewables engineering, to offset energy costs.

Waste is expensive to dispose. On-site **basic waste treatment (BWT)** can eliminate some waste. **Advanced waste treatment** can eliminate special waste and recycle some bulk waste into usable raw material.

Loans are available for investment, at a cost! Loan £10

5. Waste and Energy Markets

Waste tokens not eliminated through on-site treatment must be disposed to a market which escalates cost through use.

The first **Bulk** waste ■ token generated is placed on the top space on the disposal market (£2), the next on the space below (£4), etc.
Special waste ■ treatment costs escalate rapidly.
Players must manage waste carefully through investment or improved (ADV) processes.

Players may use 12 **Energy units (E)** in the game freely, representing an industrial emissions permit. Each energy token used is placed on a free space on the quota. Additional energy use costs money, though players can trade any unused quota with each-other.

How do I get this game?

Free-of-charge from the author as a set of print-and-play files. German language translation is also available.

Just e-mail a request.

6. Using the game in the classroom

The game is designed to be played in small groups (**4-6 players** per game) in an informal setting. Once learned, a game takes about **60 minutes**. After six rounds of play, the **winner** is s/he with the most money.

The game can be implemented into courses in an number of ways[2], but best learning impacts are derived by introducing supplementary research exercises into the technologies or by playing on a couple of occasions to allow students to discuss representations in the game.

7. Introducing Sustainability

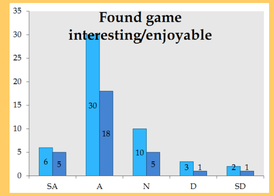
The game centres on Green Chemistry concepts applied to industrial chemical production. The "Twelve Principles"[1] are overtly featured:

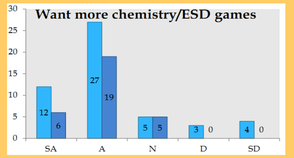
- Improving manufacturing process to use **fewer or less harmful raw** materials.
- Using **energy efficient** synthesis approaches.
- The scope for sites to implement **energy recovery and/or generation**.
- The benefits of **reducing waste streams**, often through investment.
- The existence of **emissions controls** (including CO_2).

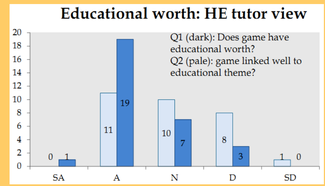
8. Views of those who have played

Data collected from:
- NTU year 2 chemistry undergraduate students (n=51) and;
- Chemistry HE tutors at ViCE (University of York 2011, n=30)

using 5-point Likert-style questions.







[1] **P. Anastas & J. Warner (1998).** Green Chemistry, Theory and Practice. OUP London.
[2] **Mike Coffey (2014).** Green Chemistry: classroom implementation of an educational board-game. In "***Handbook of Research on Pedagogical Innovations for Sustainable Development***", eds. Ken Thomas & Helen Muga, pp. 454 – 474. IGI Global.
Thanks to the **U.K. Higher Education Academy** for support from their Development Fund which allowed this project to proceed.