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## How to Close the Loop of Platinum from Heavy Vehicles Catalytic Converters?

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### 1. Context - Key Figures

- Emission regulations are increasingly strict
- Catalytic converters (CC) are mandatory devices
- Contain a non-negligible amount of Platinum (Pt)
- European dependency on "critical raw materials" such as Pt coming mainly from South Africa [EC, 12]
- No EoL regulations for heavy vehicles in Europe
- Boom of circular economy (CE) practices to explore



**Tremendous Economic Cost: 1 kg of Platinum = 30 k€**

**Environmental Burden (GHG Emissions + Energy): 1 kg of Primary Platinum = 40 tons CO<sub>2</sub> eq. + 200 GJ**

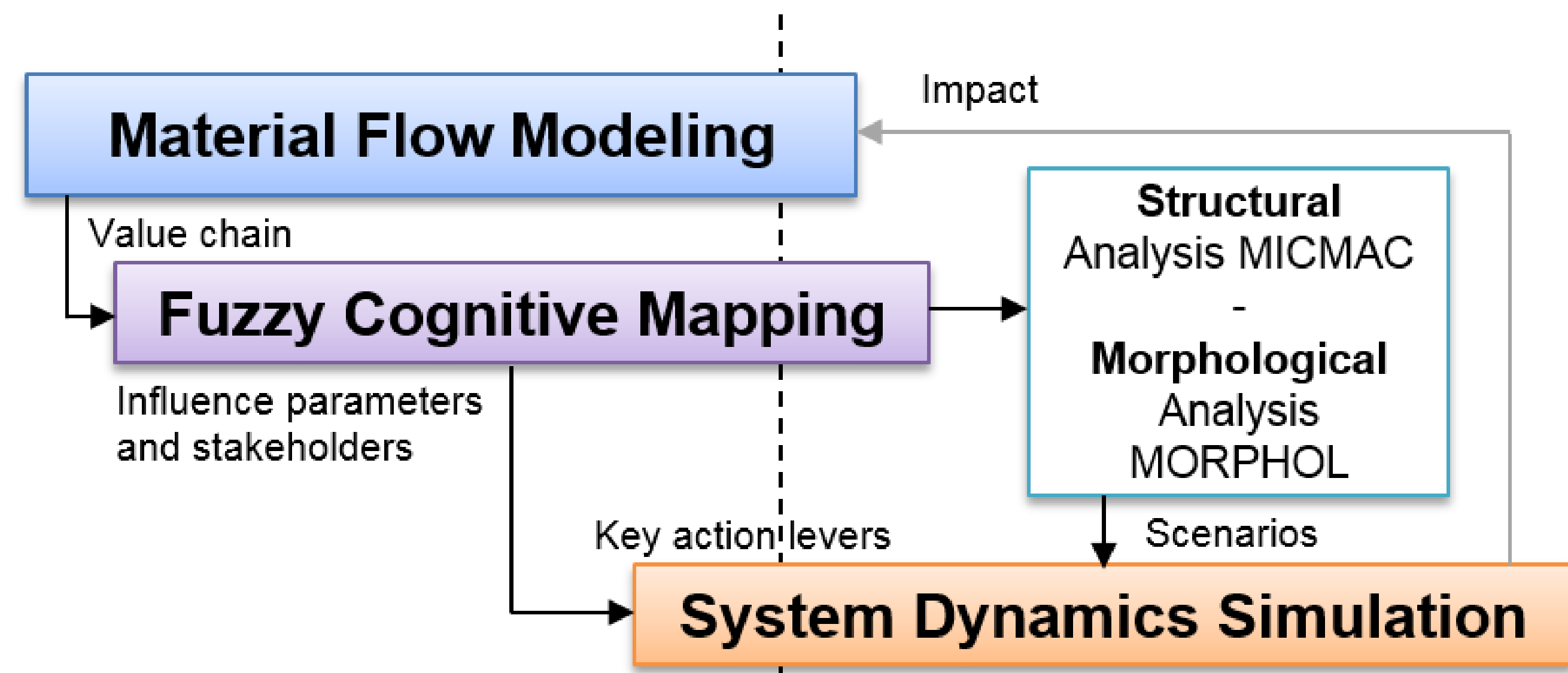
**Technological Feasibility to Recycle Pt from CC > 95 %**

- Interest for European industrialists to recover the Pt of their systems
- Secondary Pt from EoL CC could divide by 20 the environmental cost

### 2. Objectives

- Make an inventory of influence parameters to close-the-loop & link the identified parameters to stakeholders' action levers
- Quantify the impact of key actions levers on the CE performance by considering both environmental & economic parameters
- Propose and test a methodology to do so on an industrial system

### 4. A Multi-Tool Methodology



#### 1. Material Flow Analysis (MFA) with STAN

- To have a comprehensive and quantitative view of the current value chain and its important sub-systems (collection rates, exports, EoL chain efficiency, ...)
- To capture visually the missed opportunities and value buckets
- To identify involved stakeholders on the value chain

#### 2. Fuzzy Cognitive Mapping (FCM) with Mental Modeler

- To map and link both influencing parameters and potential actions levers of a complex system on a semi-quantitative causal graph

#### 3. Structural Analysis with MICMAC

- To select key influence parameters and promising actions levers

#### 4. Scenarios Generation with MORPHOL

- To set up different relevant prospective scenarios

#### 5. System Dynamics (SD) with Vensim

- To simulate and compare the influence of selected actions levers on the CE performance, with stocks & flows, plus feedback loops
- To evaluate the potential environmental and economic impacts

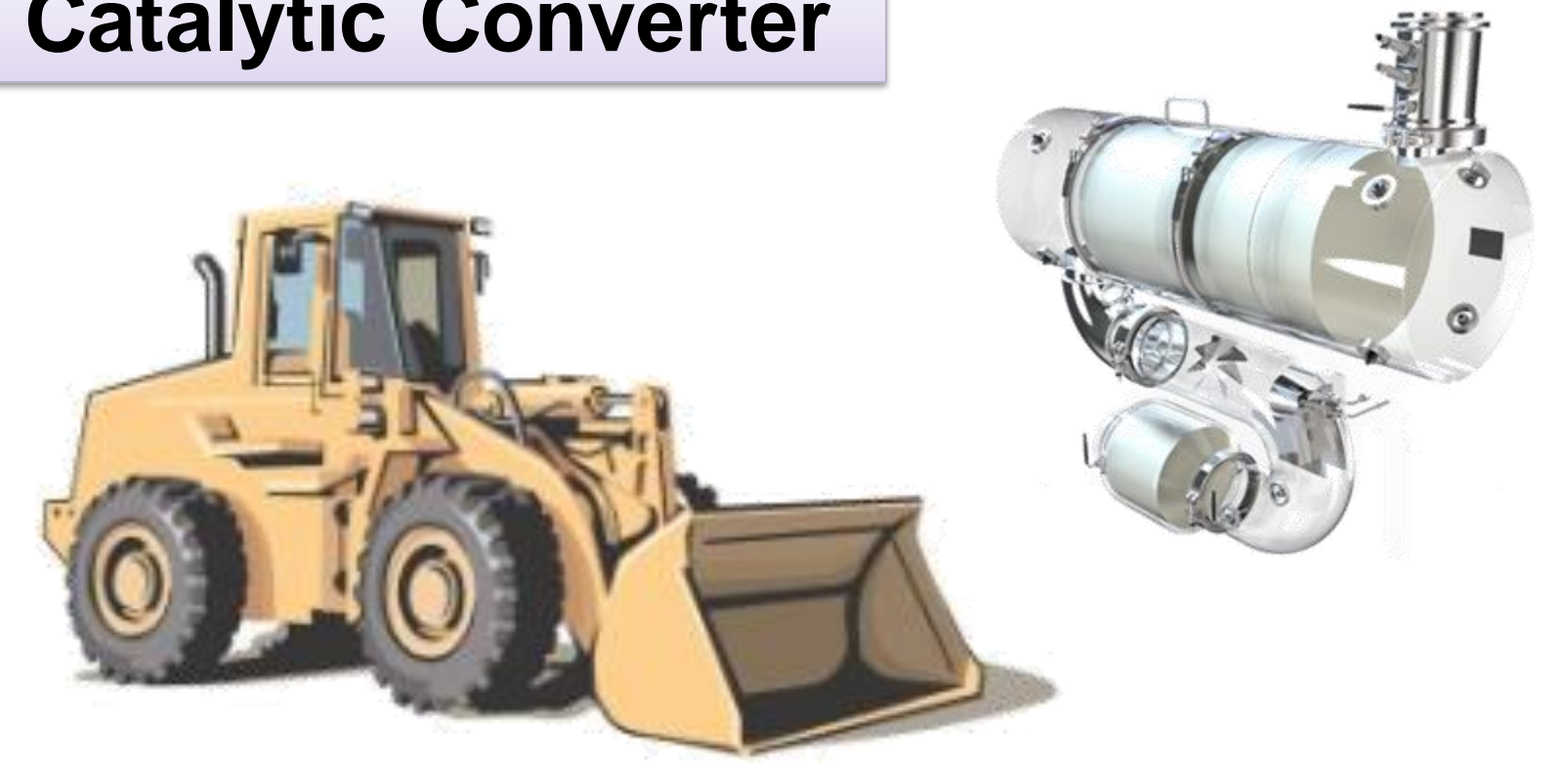
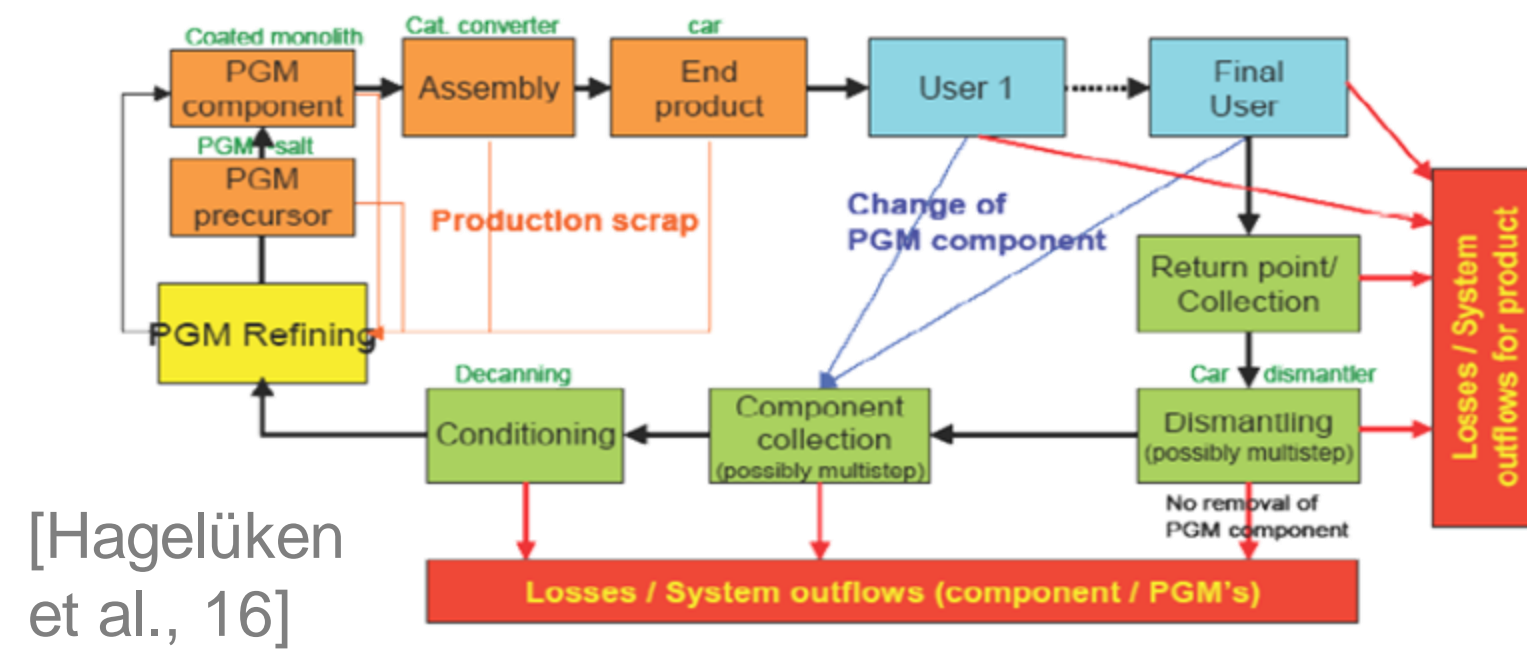
→ Looping to report the impact on the value chain and actors' network

### References

- [EC, 12] Report on Critical Raw Materials for the EU, European Commission, 2012.
- [Farel et al., 13] Farel, R., Yannou, B., Bertoluci, G., Finding Best Practices for Automotive Glazing Recycling: a Network Optimization Model, Journal of Cleaner Production, 2013.
- [Hagelüken et al., 16] Hagelüken, C., et al., The EU Circular Economy and Its Relevance to Metal Recycling, Recycling Volume 1, Issue 2, 2016.
- [Idjis et al., 17] Idjis, H., Da Costa, P., Attias, D., Is Electric Vehicles Battery Recovery a Source of Cost or Profit?, The Automobile Revolution, Springer, 2017.
- [Johnson Matthey, 2017] PGM Market Report May 2017, Summary of Platinum Supply & Demand in 2016 and Forecast for 2017, JM Precious Metals Management, 2017.

### 3. Literature Review - Industrial Diagnosis

#### Current Value Chain of Platinum from Catalytic Converter



- Overall platinum recycling rate from autocatalyst = 50% (less for heavy vehicles) → How to improve the end-of-life recycling rate of Pt & the recovery of CC in Europe?
- Many qualitative recommendations and opportunities are discussed in the literature
- But there is a lack of quantitative studies to evaluate the impact of possible solutions

#### Methods & Tools to Model and Simulate CE Strategies

- Use several tools (from industrial ecology, sustainability, prospective methods, etc) and their complementary strengths to cover the whole complexity of the CE paradigm (e.g. systemic & lifecycle thinking, ...)

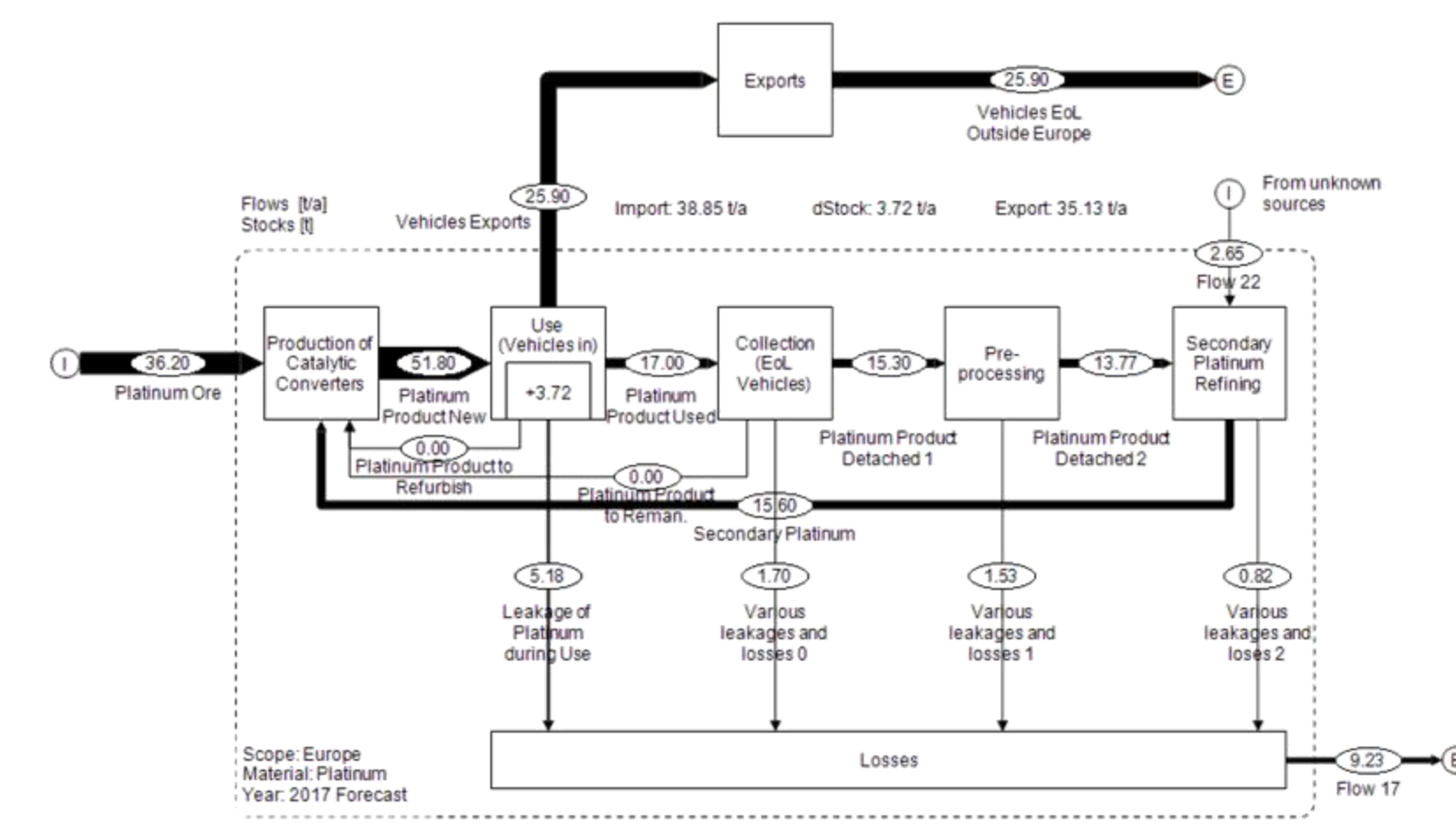
Features Tools	Modeling services	Simulation-based	Feedback loops	Value Network ...
MFA	X		(X)	X
System Dynamics (SD) ...	(X)	X	X	

- Multimethodology (mix of modeling and simulation tools) inspiration from the works of: [Farel et al.,13] SD to design an end-of-life (EoL) value chain of glass from EoL cars [Idjis et al., 17] Cognitive mapping & SD to design a recycling network for lithium-ion batteries

### 5. Application - First Results

#### 1. Material Flow Analysis + Stakeholders Mapping + Value Buckets

- 1 MFA for the Pt value chain from CC, at the European scale, data from [JM, 17]
- 1 MFA for the Pt need, use and recovery from the point of view of an European company manufacturing and selling CC → Quantified information about the existing channels, with stocks and losses for the European Union and for one OEM

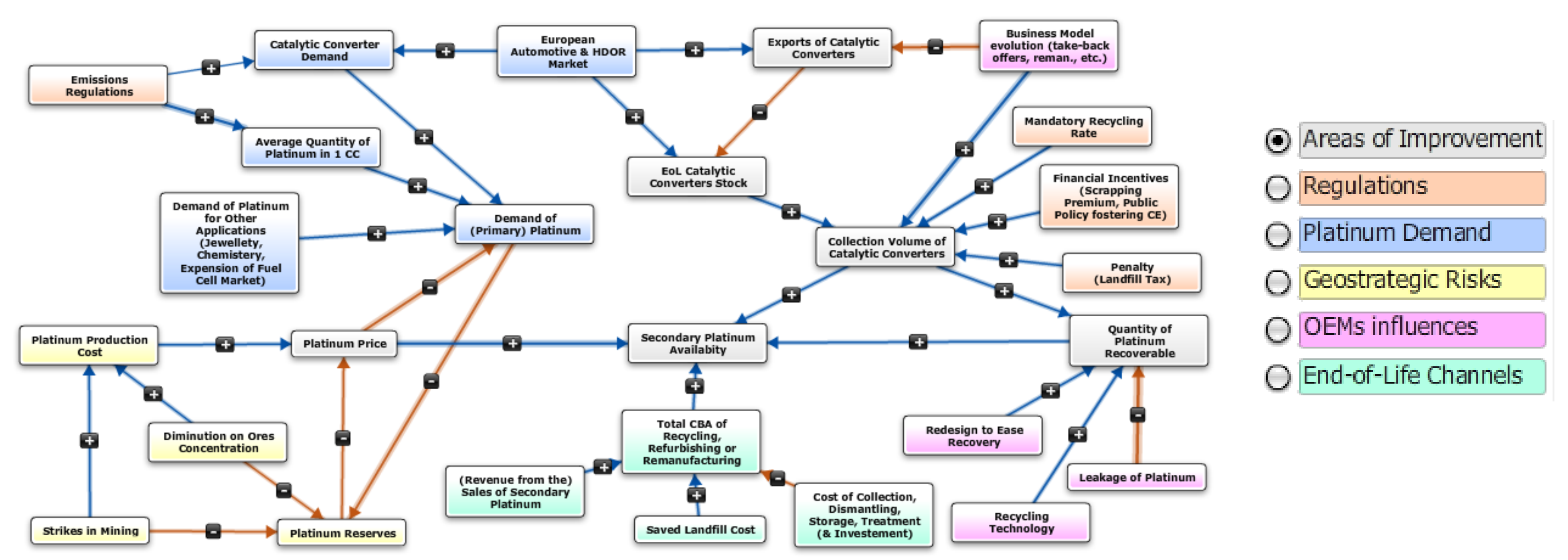


Examples of involved actors: **ANGLO PLATINUM**, **Johnson Matthey** (Precious Metals Management), **LIEBHERR**, **BOUYGUES CONSTRUCTION**, **CIDER Engineering**

**Value Bucket: Stock of CC in use in Europe Annual Import > 36 tons of Primary Platinum**

**Value Bucket: Halve the import of Primary Pt → Savings of: 700 k tons CO<sub>2</sub> eq. & 3 000 TJ**

#### 2. Fuzzy Cognitive Mapping + Clusters of Action Levers



### 6. Perspectives - Next Steps

