Quantifying and Formalizing Product Aspects through Patent Mining

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Abstract
Like most front-end design methodologies, TRIZ is characterized by the need of an abstraction level to apply the methodology. Users of these methodologies rely on intrinsic skills to map a specific situation to an abstracted one, analyze it through the methodology, and, if applicable, map it back to a specific situation. A methodology and algorithm are proposed that eliminate this subjective and difficult to perform mapping by formalizing automatically identified, fine-grained product dimensions or Aspects. These Aspects can be applied in idea generation and problem solving contexts, e.g. building a function database, performing trends analysis and searching for similar products.

Keywords
TRIZ, patent mining, function database, functional basis, product properties

1 INTRODUCTION
The Theory of Inventive Problem Solving (TRIZ) is based on the manual analysis of what TRIZ practitioners estimate to be around 40,000 innovative patents. By deductive reasoning, the applied specific innovative solutions were mapped to a small number of extracted abstract inventive principles. This specific to abstract mapping was the basis for a methodology and a set of tools for generating innovative solutions. The most popular TRIZ tools are [1]:

- the Contradiction Matrix to solve Technical Contradictions;
- the Separations Principles to solve Physical Contradictions;
- Substance-Field (SU-Field) modeling and the Inventive Standards to transform technical systems;
- ARIZ as a list of logical procedures for eliminating contradictions; and
- TRIZ Trends as a system of laws that govern engineering system evolution.

Before using any of these tools, TRIZ users rely on their experience and skills to map a specific problem to a more abstracted problem formulation. After applying the tools, TRIZ users map the obtained abstract solutions back to their specific situation. The black arrows in Figure 1 illustrate this approach.

![Figure 1. Mapping between specific to abstract formulation](image)

The mapping to and from the abstraction level is crucial to using TRIZ, but also difficult to learn and apply. To circumvent this subjective and difficult to perform mapping, a methodology and algorithm are proposed that use fine-grained, automatically identified product dimensions allowing to discover direct links between specific problems and related specific solutions, indicated by the light-grey arrow in Figure 1. In the remainder of this paper, these dimensions will sometimes be called Products Aspects.

These fine-grained Product Aspects encompass product properties, functions and technologies. Even more importantly, the resulting Product Aspects interlink these concepts. These Aspects can therefore be considered as a basic framework for accomplishing, among others, the following semi-, or fully automated tasks:

- problem solving, searching for products implementing specific solutions similar to the unknown abstract solution for your specific problem [2];
- trend analysis based on sequences of product Aspects [3];
- using, proving and updating the contradiction matrix; and
- searching for properties, processes or technologies which can deliver a certain desired function, similar to the TRIZ Function Database.

In this paper, the latter task is chosen as an example of the usefulness of the obtained Product Aspects. It is noteworthy that the proposed methodology and algorithms are meant as a supporting tool for starting TRIZ users, or as a completeness check for advanced TRIZ users. It can, however, not be the aim to replace abstraction as a central problem solving concept from the TRIZ methodology.

The remainder of this paper is organized as follows. Section 2 overviews related research on Product Functions and Product Properties. Section 3 describes the proposed methodology, and Section 4 illustrates, interprets, and compares the obtained results to another functional classification. The conclusions are formulated in the final section.

2 RELATED RESEARCH
2.1 Functions and Properties
Pahl et al. [4] describe the overall function as the intended overall relationship between inputs and outputs of a plant, machine or assembly, which is independent of any practical solution. This definition is similar to the TRIZ concept of Main Useful Function. This overall function can be broken into sub-functions forming a function hierarchy,
which often resembles the component, or modular hierarchy for adaptive designs. From this, it is clear that from a practical point of view, (sub)functions of a system are often closely related to its components or building blocks. These subfunctions can be provided by physical, chemical or biological processes, which in turn are realized by a working interrelationship between physical, chemical or biological effects, and geometric and materials characteristics. In a TRIZ context, this can be interpreted as the function database, e.g. physical effects, and as the properties of the product or artifact.

2.2 Categorization of Functions
Pahl et al. [4] also developed a classification of functions and flows, in which functions are divided into 5 types, Channel, Connect, Vary, Change and Store. The flows are divided into three types, Energy, Material and Signal. This classification was elaborated further by Stone and Wood [5], introducing a consistent classification scheme, the functional basis, which describes each product or artifact function in a verb-object (function-flow) format. Stone also explicitly states that this methodology contributes to several product design areas, including systematic function structure generation, comparison of product functionalities, and creativity in concept generation. These contributions are similar to the task list in the Introduction Section.

Another effort was performed at NIST, which developed a hierarchical taxonomy following the approach by Pahl et al. [4]. The NIST taxonomy provides a set of terms that are atomic, but also generic enough to allow modeling of a wide range of engineering products or artifacts [6]. Later, Hirtz et al [7] reconciled and compared the NIST effort, the Functional Basis, the Systematic Approach of Pahl and Beitz (SAPB), a 6 function classification from Hundal [8], and TRIZ. Another comparison of TRIZ and SAPB can be found in Malmqvist [9], which proposes to restructure the vocabulary of TRIZ using the top level hierarchy of SAPB.

Although classical TRIZ only defines the concept of Main Useful Function (MUF), later additions or variants have included the concept of auxiliary or subfunctions [10]. Although not explicitly, a function categorization can be found within TRIZ as the databases of effects, subdivided in Physical, Chemical, and Geometrical effects.

This database was later reorganized into a matrix format listing, with on the one hand different kinds of functions, and on the other hand a categorization of the object or flow into solid, fluid and gas. This database, the CREAT Function Database [11], was furthermore extended with more effects, and will be used as a reference for the results obtained from the proposed methodology. Therefore, in this remainder of this paper, this database is referred to as the Function Database.

3 PROPOSED METHODOLOGY
The research proposes an algorithm and framework that, through analysis of term occurrences within patents, extracts information concerning product properties and functionalities. The methodology also allows discovering links between properties, between functionalities, and between properties and functions.

3.1 Gathering properties and functions
The EPO Worldwide Patent Statistical Database (PATSTAT) [12] used in this research is aimed at researchers and contains most patent fields such as dates, citations, and abstracts. However, in its original form, the database does not contain full text descriptions. Since other research [13] [14] shows that the inclusion of a certain number of words of the description can be beneficial to text-mining in a patent environment, these descriptions are downloaded from other sources and inserted into the PATSTAT database applied. Currently, the database contains around 150,000 random patents with full text description sections.

In the proposed approach, only the description sections are retained for further processing, although the additional benefit from processing the claims and abstract section too will be analyzed at a later stage.

In order to allow fast querying, the full text description of each patent is pre-processed, which encompasses a filtering step and linking step. The filtering only retains words occurring in Wordnet. Since Wordnet’s vocabulary contains a large number of both technical and non-technical words in different spellings, this has the effect of eliminating only misspelled words.

The filtering furthermore allows retaining only terms with specific Wordnet categories, such as noun, adjective or verb categories. This is beneficial to storage or processing requirements, and also leads to less noisy results since the structure to be extracted from the data is mainly related to adjectives and verbs [2] [3] [10]. The nouns are also stored because these directly relate to products or product families.

To further reduce the noise level, all terms from the Wordnet adjectival and verb categories which do not contribute valuable information about the structure or workings of a product are manually discarded from further processing. This step divides the number of terms to process by three. This step however does not have a high impact on the structure obtained from the results, as it are not the specific terms that matter, only their co-occurrence within the patents. The reasoning was validated by comparing the results with and without the manual filtering, which clearly illustrates the same structure. However, the results obtained with manual filtering are much more interpretable as a large amount of noise was cancelled.

The second pre-processing stage links each retained term to all patents in which it occurs, and stores this information in a table added to the PATSTAT database. This pre-processing allows fast retrieval in response to the queries in subsequent processing steps explained below.

3.2 PCA
The PATSTAT database is queried from MATLAB, and transformed into a standard term-document matrix format, in which each element Aj represents the number of times term i occurs in patent j. This matrix is weighted with a Term Frequency Inverse Document Frequency (tf-idf) scheme [15] and normalized to account for different patent text lengths.

In a next step, certain Wordnet categories closely related to products, such as noun artifact and noun body, are discarded from further processing. This is done to bring out structure related to the properties and functions of products, and not structure related to products themselves.

The resulting term-document matrix is subjected to a Principle Component Analysis (PCA) [16], a technique closely related to Singular Value Decomposition (SVD) [17] [18]. This analysis allows extracting a given number of Principle Components (PCs), of which the first PC is the linear dimension oriented in such a way that it explains the maximum amount of the variance in the data set. Each succeeding PC represents as much of the
remaining variability as possible, taken into account that all PCs are orthogonal to each other.

Before applying PCA, a term is represented as coordinates in the tf-idf weighted term-document matrix, in which each coordinate can loosely be interpreted as the number of times the term occurs in a document. These coordinates are expressed in correlated variables, as the number of times a term occurs in a certain document can be related to the number of times it occurs in other documents.

After PCA, all terms are expressed in a smaller number of uncorrelated variables or PCs, resulting in a term-PC matrix. For testing and analysis the number of resulting PCs is set arbitrarily to 300. In case this number is augmented, the first 300 PCs will remain the same, but more variance will be explained overall. Figure 8 in Annex A depicts terms in a coordinate system formed by two PCs. In this figure different concepts can be discerned, of which “digital data transport” and “molecular biology” are indicated with a dotted oval. It is however difficult to interpret the meaning of the PCs, a goal which can be obtained through the techniques in the next subsection.

3.3 Varimax

Varimax rotation is the most used variant of all techniques aimed at rotating the PC coordinate system to a new coordinate system which is easier interpreted. For Varimax this is done through orthogonal rotation maximizing the sum of the variance of the PCA loading vectors. After rotation each term can be approximately described by a linear combination of few PCs. By comparing the coordinates of term “heat” in a Varimax rotated PC coordinate system in Figure 2 with the same coordinates without rotation in Figure 3, it is easily seen that the Varimax rotation indeed allows terms related to heat to be interpreted in fewer components.

4 RESULTS

4.1 Raw Results

Due to the high dimensionality of the results, it is difficult to illustrate the overall results in one or more figures. For this reason, the figures in this section only describe certain concepts, which are mapped to a low number of dimensions, called Products Aspects, by the Varimax rotation, e.g. the “heat” concept can be illustrated by inspecting only Product Aspect, or rotated dimension, number 18.

Figure 6, of which a larger version can be found in Annex A, shows only the terms with a coordinates higher than the 99.98% percentile on both the second and the third Product Aspect. This is a standard way to display the results of a PCA analysis, which clearly illustrates that Product Aspect, or rotated dimension, number 2 is related to the concept of “linear or volumetric dimension” through terms such as inch, centimeter, millimeter, dimension, length, micron, and milliliter. Product Aspect number 3 is related to “molecular biology” through terms such as bind, binding, fusion, biological, moiety, pierce, regulate, immobilization, helix and transduction.

The 99.98% threshold is chosen arbitrarily, but set high enough not to encumber the figure by the number of terms displayed. Furthermore, a term with a high coordinate on a Product Aspect is said to be highly loaded on that Aspect, and hence is much related to the latent concept captured by that Aspect. Therefore, the approach proposed allows to display terms in order of importance in a table-like format. This format is used in the subsections below.
4.2 Interpretation of the results

Table 1 below illustrates the results of manually interpreting the first 10 Product Aspects through the analysis explained in the previous subsection. A more detailed version with the first 30 Product Aspects including the top loaded terms on each Product Aspect can be found in the Table 3 in Annex B.

Table 1. Manual interpretation of the first 10 Product Aspects

| Number of Product Aspect | Interpretation of Product Aspect                                      |
|-------------------------|---------------------------------------------------------------------|
| 1                       | Linear/volumetric dimension                                         |
| 2                       | Mixing and filtration                                                |
| 3                       | Molecular biological                                                 |
| 4                       | Conical/concentric/groove/lubrify to perform sealing                 |
| 5                       | Stretching and breaking                                               |
| 6                       | Properties of CMOS and bipolar technology                            |
| 7                       | Breaking of light                                                     |
| 8                       | Rotation and impact on friction/grinding/cutting/inertia             |
| 9                       | Capacitance related to electrical circuits                           |
| 10                      | Different types of shapes                                            |

From the analysis of the results, it can be seen that the proposed methodology allows extracting meaningful concepts from the global patent database. The concepts can broadly be subdivided into the following groups:

- general more abstract concepts, e.g. linear/volumetric dimension;
- concepts related to a technology or field, e.g. molecular biology;
- concepts related to general properties, e.g. shapes;
- concepts related to specific properties in a technical field, e.g. capacitance in electrical circuits; and
- concepts related to a certain function, e.g. sealing, and stretching and breaking.

The Product Aspects from the last group not only contain interrelated functions, but also the properties of the artifacts, processes or technologies useful for obtaining these functions.

4.3 Example use of Product Aspects

The methodology explained is illustrated here by semi-automatically searching for properties of the artifacts, processes or technologies which are useful to implement the "heat" function.

First the words containing “heat” are fetched from the collection of indexed words, resulting in the words heating, heat, preheat, overheating, reheat, overheat.

In a second step, the coordinates of these words in all 300 Product Aspects are analyzed to extract the Aspects related to the heat concept. Figure 7 illustrates a graphical approach to extract these Aspects by plotting the result of multiplying the coordinates of all terms in each Aspect. From this it can be seen that only Aspect 18 is central to all heating related terms.

Table 2 shows the 100 terms with the highest loadings on Product Aspect 18 and therefore assumed to be related to the heating concept more than any other extracted terms. This enumeration allows for a fast manual extraction of useful techniques, processes or properties to implement the heating functionality.

Table 2. 100 Terms with the highest loading on the Product Aspect 18 related to heating

| Rank | Term                      |
|------|---------------------------|
| 1    | heat                      |
| 2    | dissipate                 |
| 3    | sink                      |
| 4    | dissipation               |
| 5    | thermal                   |
| 6    | cooling                   |
| 7    | heating                   |
| 8    | convection                |
| 9    | temperature               |
| 10   | overheating               |
| 11   | sinking                   |
| 12   | decay                     |
| 13   | flowing                   |
| 14   | asymptotic                |
| 15   | electronic                |
| 16   | absorption                |
| 17   | radiate                   |
| 18   | overheat                  |
| 19   | condense                  |
| 20   | insulate                  |
| 21   | resistance                |
| 22   | inlet                     |
| 23   | conditioner               |
| 24   | steam                     |
| 25   | redshift                  |
| 26   | solder                    |
| 27   | resistive                 |
| 28   | condense                  |
| 29   | insulate                  |
| 30   | resistance                |
| 31   | vaporization              |
| 32   | soldering                 |
| 33   | electricity               |
| 34   | ruggedization             |
| 35   | refrigeration             |
| 36   | airflow                   |
| 37   | anemometry                |
| 38   | insulation                |
| 39   | evaporative               |
| 40   | warping                   |
| 41   | convect                   |
| 42   | dollop                    |
| 43   | thermoelectrical          |
| 44   | thermoelectricity         |
| 45   | impermeableness           |
| 46   | radiation                 |
| 47   | transferability           |
| 48   | ceramic                   |
| 49   | enfold                    |
| 50   | slipperness               |
| 51   | turbulence                |
| 52   | neutralisation            |
| 53   | bump                      |
| 54   | regulate                  |
| 55   | joule                     |
| 56   | geothermal                |
| 57   | astronomical              |
| 58   | concavity                 |
| 59   | microwave                 |
| 60   | enclose                   |
| 61   | solar                     |
| 62   | optimize                  |
| 63   | standstill                |
| 64   | attrition                 |
| 65   | thermostatic              |
| 66   | seep                      |
| 67   | vaporization              |
| 68   | poise                     |
| 69   | frustum                   |
| 70   | compactness               |
| 71   | deformation               |
| 72   | updraft                   |
| 73   | invariability             |
| 74   | cooking                   |
| 75   | hydrodynamic              |
| 76   | rapidness                 |
| 77   | crosscurrent              |
| 78   | packaging                 |
| 79   | ventilation               |
| 80   | sublimation               |
| 81   | whiteout                  |
82. infeasibility  83. structural  84. dehumidify  
85. melting          86. melt         87. shrinkage  
88. reformation      89. condensing  90. smoothness  
91. dampen           92. seepage     93. loop    
94. airt             95. flatness    96. frictionless  
97. agility          98. convexity   99. flip  
100. desalinate      

| Table 4 in ANNEX B gives an overview of 34 terms selected from the first 100 terms and directly relates them to ways to heat from the Function Database. The value of the matrix elements are: |
|---|
| 0, or empty cell, if there is no apparent direct link between both the term and the concept from the Function Database |
| 1 if the link is clear between the term and the concept from the Function Database, e.g. “liquefying” is a phase change |
| 2 if exactly, or almost exactly, the same words are used, e.g. term “condense” and “condensation” from the Function Database |

The reasons could be that some techniques, such as insulating, are not regarded as actually heating, or that the techniques are straightforward for a domain specialist and therefore can not be considered inventive.

5 FURTHER RESEARCH

Another direction for further research is to map nouns, related to products, into the Product Aspects, and to eliminate those Aspects which are only related to one product, or one product family. The same idea could be implemented through the mapping of the patent classification codes, such as IPC or ECLA codes, to the Product Aspects.

The obtained results can also be compared to other documented classifications of functions, such as the Functional Basis [7], but it is assumed that this mapping is much more open to interpretation as the Functional Basis is more abstract than the results obtained via the proposed methodology.

6 CONCLUSIONS

It was shown that text-mining allows to extract meaningful structure from patents through analyzing the co-occurrences of certain Wordnet categories. The results of this analysis can be interpreted as fine-grained product dimensions, called Product Aspects, and encompassing properties, functions and technologies.

It was shown that these dimensions are consistent with the Function Database, and can be used to validate and check this database for completeness.

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ANNEX A

Figure 8. Terms with high coordinates in non-rotated dimensions (Principle Components) 2 and 3

Figure 9. Terms with high coordinates in rotated dimensions 2 and 3
## Annex B

### Table 3. Manual interpretation of first 30 rotated dimensions

| Number of dimension | Terms from pca | Interpretation                                                                 |
|---------------------|----------------|--------------------------------------------------------------------------------|
| 1                   | inch, centimeter, square, millimeter, micron | dimension, length, cross, polymeric, micrometer, linear dimension               |
| 2                   | compound, stirring, acetic | synthesis, dryness, filtration, aqueous, tetrahedron, temperature, moisture, mixing and filtration |
| 3                   | binding | biological, immobilization, fusion, moisture, fluorescence, immobilizing, pince, biochemical, Biological binding |
| 4                   | axial | radial, seal, sealing, groove, clearance, conical, cross, lapar, deformation | Conical form/concentric/groove/subtly to perform sealing |
| 5                   | tensile | elongation, strength, ductility, break, toughness, blend, impact, secant, stretching | Stretching and breaking |
| 6                   | breakdown | diffusion, conductivity, implantation, depletion, bipolar, voltage, isolation, diffuse, anneal | Properties of CMOS and bipolar technology |
| 7                   | wavelength | optical, refractive, spectral, diffraction, refraction, diffract, collimate, spectrum, chromatic | Breaking of light |
| 8                   | rotation | rotate, rotational, torque, rotary, clutch, angular, meshing, axial, roller | Rotation and impact on friction/grinding/cutting/inertia |
| 9                   | capacitance | inductance, capacitive, impedance, inductive, parasitic, voltage, reactance, resistance, tuning | Capacitance ad related to electrical circuits |
| 10                  | decagon, dodecagon, nonagon, octagon, heptagon, hexagon, octagonal, tetragon, intersect | ruggedness | Different types of shapes |
| 11                  | oiliness | sulfurized, greasiness, overstep, viscosity, rust, viscometric, friction, emulsify, abate | Viscosity/greasiness and friction |
| 12                  | dosage | inflammation, inhibition, congestive, milligram, dysfunction, prevention, homeostasis, toxicity, military | Medical dosage and effects |
| 13                  | transmutation | transmutation | fission, neutron, incase, decay, burnup, subatomic, moderation, irradiation | Nuclear transmutation |
| 14                  | measurement | measuring, measured, accuracy, meter, precision, detecting, inaccuracy, absorbance, deviation | Measurements, monitoring, precision and error |
| 15                  | highlighting | navigate, graphical, textual, highlight, restructure, navigation, visual, numeric, electronic | Organisation and navigation of text |
| 16                  | decompress | decompression | compress, decompressing, compression, compressing, standard, piracy, alphanumerical | Compressing and decompression (mainly of data) |
| 17                  | implode | rarefaction | implication, communicative, metamorphosis, actuation, acoustical, lesson, overpressure, repositioning, implosion / wave / acoustical / overpressure | Implosion / wave / acoustical / overpressure |
| 18                  | heat | dissipate | sink, dissipation, thermal, cooling, heating, convection, temperature, overheating | Heat/Cooling, dissipation, convection |
| 19                  | syntactic | clause | prepositional, semantic, linguistic, canonical, interjection, rummage, textual, lexicalized | Linguistic, semantic, syntactic structures |
| 20                  | sensitization | sensitizing | tabular, graininess, sensitize, photomechanical, photomechanical, spectral, desensitization | Photographical properties and processes |
| 21                  | flame | retardant | flammability, flaming, dripping, burning, combustibility, chip, extinguishing, ignite | Fire, combustion and extinguish |
| 22                  | hardness | toughness, tempering, hardening, quenching, harden, brittleness, annealed, forging, abrasion | Ways to form/harden/modify |
| 23                  | hybridize | hybridization | amplification, amplify, nick, cloning, electrophoresis, fluorescence, polymorphism | Hybrid of hybrid nature |
| 24                  | magnetic | magnetization | ferromagnetic, antiferromagnetic, magnetize, demagnetization, squareness, magnetism, anisotropy, saturation | Magnetic properties and related effects as hysteresis |
| 25                  | meaty | crispness | abstractness, crispy, crinkle, frying, gelatinize, crunch, crisp, gelatinise | Food properties and processes |
| 26                  | color | luminance | brightness, gradation, colorimetric, chromatic, colorimetry, saturation, palette | Luminance and color |
| 27                  | digital | analog | quasistatic, amplitude, filter, multiplier, noise, distortion, sampling, linearity | Properties and functions related to noise, filtering, … |
| 28                  | chopiness | attitudinal | skimming, recreation, skin, dunk, hydrodynamic, slick, smoking, warping | NOISE |
| 29                  | sanitized | sanitation | scald, sanitation, degas, sterilization, smoother, sterility, steam | Sanitizing/washing |
| 30                  | pasteurized | pasteurization | unpasteurized, curdling, acidity, fermenting, homogenization, skim, reticulation | Pasteurization and pasteurizing |
Table 4. Mapping of CREAX Function Database to retrieved concepts

| Phase Changes | Condensation | Convection | Conduction | Radiant Effect | Combustion | Eddy Current | Exothermic Reactions | Strain Heating |
|---------------|--------------|------------|------------|----------------|------------|--------------|---------------------|----------------|
| radiate       | 2            | 1          | 1          | 1              | 1          |              |                     |                |
| radiation     | 2            | 1          | 2          | 1              | 1          |              |                     |                |
| condensation  | 2            | 1          | 1          | 1              | 1          |              |                     |                |
| conduction    | 2            | 1          | 1          | 1              | 1          |              |                     |                |
| radiation     | 2            | 1          | 2          | 1              | 1          |              |                     |                |
| convection    | 1            | 2          | 1          | 1              | 1          |              |                     |                |
| conductive    |              | 1          | 2          | 1              | 1          |              |                     |                |
| induction     |              | 1          | 2          | 1              | 1          |              |                     |                |
| solar         |              | 2          | 1          | 1              | 1          |              |                     |                |
| condense      |              | 2          |            |                |            |              |                     |                |
| vaporize      | 1            | 1          |            |                |            |              |                     |                |
| sublimation   |              | 1          |            |                |            |              |                     |                |
| microwave     |              |            |            |                |            |              |                     |                |
| vaporization  | 1            |            |            |                |            |              |                     |                |
| condensation  |              |            |            |                |            |              |                     |                |
| connect       | 2            |            |            |                |            |              |                     |                |
| condensing    |              |            |            |                |            |              |                     |                |
| evaporate     | 1            |            |            |                |            |              |                     |                |
| vaporisation  |              |            |            |                |            |              |                     |                |
| evaporation   |              |            |            |                |            |              |                     |                |
| vaporise      | 1            |            |            |                |            |              |                     |                |
| melt          |              |            |            |                |            |              |                     |                |
| airflow       | 1            |            |            |                |            |              |                     |                |
| transferability | 1          |            |            |                |            |              |                     |                |
| defrost       |              |            |            |                |            |              |                     |                |
| liquefy       |              |            |            |                |            |              |                     |                |
| sublimated    |              |            |            |                |            |              |                     |                |
| sublimed      |              |            |            |                |            |              |                     |                |
| blowing       | 1            |            |            |                |            |              |                     |                |
| absorption    |              |            |            |                |            |              |                     |                |
| thermoelectric |              |            |            |                |            |              |                     |                |
| gasification  | 1            |            |            |                |            |              |                     |                |
| ventilation   | 1            |            |            |                |            |              |                     |                |