Bioenergy Ontology for Automatic Pathway Generation

Krishna Sapkota, Pathmeswaran Raju, Craig Chapma, William Byrne, and Lynsey Melville

Abstract—**Bioenergy is a renewable energy and is generated by treating biomass with various technologies. Depending upon the nature of biomass, it is more suitable for one technology than others, and they can further be treated with other technologies. Hence, the biomass follows a pathway of technologies, and the pathway is called bioenergy pathway. Currently, bioenergy pathways are created manually: either by manually sketching or by creating the data manually and generating diagrams from the data. Manually generated pathways are prone to human errors. A solution to this is creating semantic pathways automatically. In this paper, we present the bioenergy ontology to generate semantic pathways automatically. In particular, we have leveraged the Semantic Web technologies to represent the bioenergy knowledge and inferred the pathways. The case study has been carried out in one of the INTERREG Project and found promising results.**

Index Terms—**Bioenergy ontology, pathway, semantic pathway, bioenergy conversion pathways, bioenergy routes, biomass, bioenergy.**

I. Introduction

Bioenergy is the solar energy preserved in biological organisms and their by-products in the form of biomass. The biomass is treated with various technologies in order to utilize the energy in the form of biofuel or heat or electricity. Therefore, the bioenergy is renewable energy and one of the solutions to the depleting fossil fuels. The examples of biomass are plant and animal parts such as root crops, animal slurry and wood parts. Some of the conversation technologies are pyrolysis, anaerobic digestion, fermentation, combustion, gasified and liquefaction [1].

A bioenergy pathway is a conversation route, which contains biomass, conversion technologies, intermediate products and bioenergy. Considering the nature of a biomass, it can be treated with some technologies. The treatment may generate intermediate or final products, which can be directly used in some applications such as heat, electricity and biofuels. Some of the issues in the bioenergy projects are: 1) determining best technologies for a biomass and 2) identifying the opportunity for further treatment of the products. In other words, one of the issues is the identification of the best conversion pathway.

BioenNW [1] and EnAlgae [2] are ongoing North West European projects, which encourage farmers and stakeholders to start a new bioenergy plant in the region. These projects are started with the aim to increase the global share of renewable energy sources by 20% within the EU by 2020. One of the objectives of the projects is to provide the farmers in the region with decision support tools, which will help them in various decision-making processes [2]–[6] such as answers to the following questions:

1) What is the best place to start a new bioenergy plant?
2) What kind and how much amount of biomass are available in the region?
3) What kind of technology is suitable for the plant in that region?
4) How much investment is needed and how long will it take to get the returns?
5) What are the logistic and other related costs involved?

The conversion pathway is one of the decision support tools developed as part of the projects. The conversion pathway will help farmers to see what kind of bioenergy technologies and bioenergy can be produced from a given biomass in a region, thus helping them to make an informed decision on while staring a potential new bioenergy plant.

Current bioenergy conversion pathways are largely manual [7]. The experts usually design the pathway manually with some graphical diagram and explain the diagrams to the farmers. Recently, there has been a surge on developing web-based diagrams using JavaScript frameworks [3]. These frameworks need to be provided with data in a specific format such as JSON in order to display the pathway on the web. However, the data is created manually. Creating data manually could lead to human errors while creating them, since there is no method to check the consistency of the data [8]. Ontology provides a mechanism to check the consistency of the data thus making less prone to errors. The extensibility of the conversion pathway is also a constraint to the current approaches, since the knowledge is confined to the expert who created the pathway. They need either to start from the scratch again or to modify the previous pathway with substantial time consumption.

The limitations and issues can be addressed using the Semantic Web technologies. Ontology can be used to represent the domain knowledge and check the constancy of the pathway data. This approach is extensible since the vocabularies on the ontologies are reusable, and they are explicitly defined. In other words, the ontology not only holds the data but also explicitly defines the concepts used for a particular purpose. Using the existing definition of the ontology, engineers can extend the new concepts, which

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[1] http://bioenergy-nw.eu/about-bioennw/
[2] http:// http://enalgae.eu/
[3] http://www.biobasedeconomy.nl/routekaart/

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conform to the existing knowledge. In this paper, we present an ontology-based conversion pathway generation for bioenergy, which aims to exploit the explicit specification of the conceptualization [9] in order to share and extend the information. This is an extension of our earlier short paper [10]. In the proposed approach, the ontological axioms and rules are used to define the entities such as biomass, intermediate product, final product and application, and technologies such as pyrolysis, anaerobic digestion and combined heat and power engines. The followings are the key benefits of using the proposed approach of ontological pathway generator:

1) Explicit definition of the concepts: It defines the key concepts used in the conversion pathway explicitly, which will make the ontology re-useable and extensible.
2) Consistent data: It provides a mechanism to check the consistency of the data needed for conversion pathway.
3) Automatic generation of conversion pathway: It generates the conversion pathway automatically by means of ontological inference mechanism.

The rest of the paper is organized as follows. Semantic Web technologies and their importance are described in Section II. Section III provides the detailed description of the bioenergy ontology and its role in pathway generation. The finding of this research is concluded in Section IV.

II. Semantic Web Technologies

Ontology is defined as a formal specification of the conceptualization [9], which means the representing the concepts with specific meaning in a succinct way. The ontology is an extension of Resource Description Framework (RDF) and RDF-Schema. The RDF contains triples, which is the combination of subject predicate and object. Ontology contains more vocabulary than RDF and RDF-Schema; in fact, they are built on the vocabularies in RDF and RDF-Schema. The ontology contains T-Box and A-Box [11].

The T-Box or terminological box defines the concepts. The concepts are arranged in a hierarchical manner, and the relationship is called 'is-a" relationship. There exists another kind of relationship between the concepts, which is lateral relation. Besides, the concepts have data properties, which help to specify the nature of the concept. In other words, there are two kinds of properties: object properties and data-type properties. The object properties help to relate the individuals to each other. The data-type properties relate the individuals with data-type values such as string and number. There are asserted and defined classes. The former is explicitly asserted by the user or ontology engineer while creating the ontology while the later will be deduced from the ontology inference engine. The most important component of the defined classes is axioms. The axioms are the constraint defined for a class; if some entity in the ontology fulfills the constraints, it will be inferred that the entity belongs to the class, or this entity is this class.

The A-Box or assertion box contains the instances of the classes defined in the T-Box, their properties and relationships to other instances. The T-Box and A-Box can be compared with database schema and the data respectively.

The Semantic Web Rule Language (SWRL) is used in ontologies to infer/assert additional knowledge in the ontology [12]. For example, it can help deduce the uncle relationship if a person has a male parent, and the parent has a male sibling.

SPARQL query language is used to query the information in the ontology or RDF triples [13]. It is an SQL-like query language, where variables are represented with a question mark and statements are terminated with a dot. One of the important aspects of the SPARQL is the use of the namespace, which distinguishes concepts from different ontologies and different domains.

III. The Bioenergy Ontology for Conversion Pathway

Bioenergy project for North West of Europe, BioenNW aims to facilitate the farmers in the selected region to start a new bioenergy plant. The regions have been selected in five countries: the United Kingdom, the Netherlands, Germany, Belgium and France. It has Business Support Centers (BSC) in each country for the region, where farmers are advised with some bioenergy experts in the area. These regions contain unit of areas called Cell, which is a square of area, for example, 1KM square cell. The project aims to provide the information about the cell such as how much it yields in a year, what kind of biomass is available, what the regulatory guidelines and incentives are applicable. The experts provide various decision support tools to the farmers.

The BioenNW Decision Support Tools (DST) are the Web-based tools, which can be accessed remotely by the farmers, and encourage them to establish a new farm. Some of the DSTs are map-based information tools, while others are dashboards and conversion pathway. Map-based information tools allow the user to click on a map to see whether the location is suitable for a particular bioenergy plant. Dashboards provide all the calculation related cost and economics such as how much investment is needed and how long it will take to earn the investment back.

A conversion pathway is a route through which a biomass is converted into bioenergy; it involves the use of various technologies and production of various intermediate products. It will help farmers to see the viability of a bioenergy plant in the area depending on the biomass type available in the region. Depending upon the nature of the biomass. Hence, they follow different pathways. In this project, there are variations of two pathways that start either from Anaerobic Digestion (AD) or from Intermediate Pyrolysis (IP) [14].

AD is a process or technology of treating biomass with some anaerobic bacteria in the absence of oxygen thus generating biogas and digestate. The biogas can be used in Combined Heat and Power engine (CHP) to generate heat and power. Whereas, the digestate can be treated as a fertilizer in agriculture or can be dried and treated with IP.

IP is a process or technology, which heats biomass in a high temperature in a closed cylinder, and produces intermediate pyrolysis gas, intermediate pyrolysis oil and bio-char. The intermediate pyrolysis gas can be treated with CHP to produce heat and power. Whereas the intermediate pyrolysis oil is blended with biofuel and has two options: sell as it is or treat with Duel Fuel CHP engine (dCHP) in order to produce heat and power. The bio-char can be sold as in the current state in order to generate some income.

Besides, there are some variations in the technologies. The biogas or intermediate pyrolysis gas can be treated with Generator, which only generates power not heat. If the digestate is not sellable, it can be dried and enter the IP route, which produces all the intermediate and final products in the IP. The intermediates in the pathway such as intermediate pyrolysis gas and blended intermediate pyrolysis oil, enter the dCHP, and produce heat and power.

Currently, the pathway diagrams are created manually and displayed in a web application with the use of keywords. In order to relate the keywords to the types of the biomass, a hierarchy of biomass is created in a spreadsheet. This spreadsheet is created by following the biomass categories recommended by the Corine website [4]. The spreadsheet contains an exhaustive list of recommended technologies for each biomass in order to find out whether an individual is suitable for some kind of bioenergy technology. In this paper, the keyword-based manual conversion-pathway is replaced with innovative ontology-based, automatic and semantic conversion-pathway.

In the ontology-based conversion pathway generation, the biomass hierarchy in the Corinne website is represented in an ontology. In this paper, the ontology is referred to as the bioenergy ontology. Representing the data in the ontology makes them semantically consistent, reusable, sharable and extendable. Then, the nature of the biomass is defined with the help of axioms so that the ontology can be run with some inference engines, which will make the implicit knowledge explicit. Besides, SWRL rules are implemented in order to assert new knowledge in the ontology based on the existing knowledge such as relating the biomass with the bioenergy technologies. It will be queried with SPARQL in Java to generate the conversion pathway automatically. The summary of the pathway generation is depicted in Fig. 1.

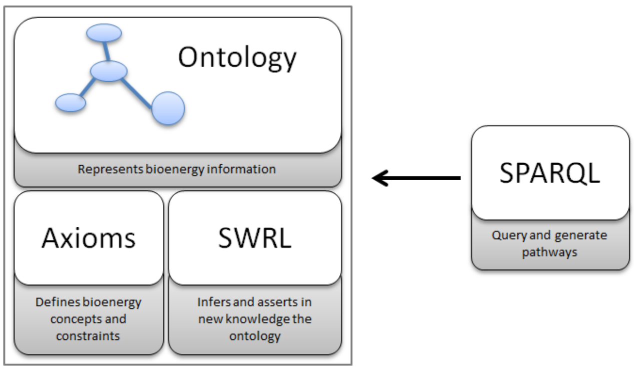


Fig. 1. Semantic Web technologies used for generating the conversion pathways.

A. The Bioenergy Ontology

The bioenergy ontology is based on the OWL 2 DL and created in an ontology editor Protégé. The concepts in the bioenergy ontology are extended from the concepts of the upper ontology Suggested Upper Merged Ontology (SUMO) [11]. SUMO is suitable for our purpose because it has been widely used [15], and it has useful concepts for this project such as AbstractEntity, PhysicalEntity and Attributes (see Fig. 4).

1) Abstract entities

The abstract entities are the entities that only exist in mind, and do not exist physically. In the bioenergy ontology, the abstract entity contains a class Attribute, which subsumes the classes such as Boolean, Composition, Consistency, DryWet, Intensity and State. These classes and their individuals are useful for defining the axioms of the biomass, and eventually inferring their suitable conversion pathways. Boolean enumerates true and false; Composition comprises Mixed or Separated; Consistency has Soft and Hard; DryWet - as it suggests - contains Dry and Wet; Intensity consists of High and Low; and State houses Solid, **Gas** and Liquid. Fig. 2 shows some attributes and their definitions.

Fig. 2. Attributes in the bioenergy ontology.

2) Physical entities: Asserted classes

The asserted classes are borrowed from Corine website [5], which was adapted in our project by adding and removing various entities following several consultations with the experts in the project.

Some of the asserted classes are Application, BioenergyEntity and Process. The class Application represents the entities such as Selling and Fertilizer. The BioenergyEntity can be a raw material, biomass, intermediate product or the final product. The class Biomass is categorized as agricultural, waste and woody biomass, which is further divided and subdivided into several types of biomasses. The class Process can be either Refinement or Technologies. Refinement does not give out a new product, but it will just refine the product and make them suitable for further processing. Technology takes in a bioenergy entity and converts it into a new bioenergy entity.

3) Physical entities: Defined classes

Some classes under physical entity are defined classes; they are defined with some axioms. For example, Product is a defined class, which is defines as a bioenergy entity, which is

[4] http://www.eea.europa.eu/publications/COR0-landcover

[5] http://www.eea.europa.eu/publications/COR0-landcover

output of some processes. This is further divided into intermediate and final product. IntermediateProduct is a product, which is input of some process. This means that it further undergoes some processes and turns into new products. FinalProduct is a product, which does not need further processing, and can be used in some application. Some defined classes are depicted in Fig. 7.

4) Properties

The properties are the important aspect of the bioenergy ontology, which are used to define classes and to relate the individuals with each other. In the bioenergy ontology, we have defined various object properties in order to define the bioenergy classes and assert knowledge to the ontology. Some of them are depicted in Fig. 3.

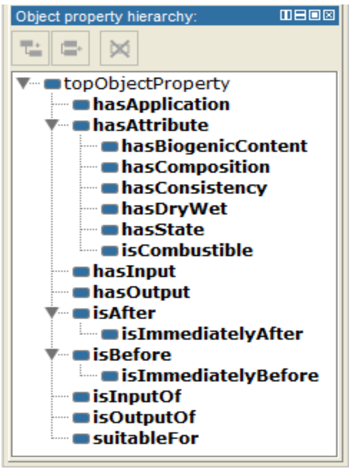


Fig. 3. The object properties in the bioenergy ontology.

The property hasApplication relates the bioenergy entities with their application. The sub-properties of hasAttribute are designed to define the bioenergy entities using range as some abstract attributes such as State, Consistency and Composition. The properties hasInput and hasOutput have their inverse properties isInputOf and isOutputOf respectively. These properties and another object property suitableFor relate bioenergy entities with processes. In order to identify different intermediate stages of the conversion pathway, the temporal object properties – isBefore and isImmidiatelyBefore – are implemented which have their inverse properties isAfter and isImmidiatelyAfter respectfully.

5) Bioenergy axioms

The ontological axioms help in defining the classes explicitly, which makes the information understandable to other users thus making it easy to share and extend. Besides, the axioms help to make the implicit knowledge explicit with the help of some reasoners. In the bioenergy ontology, many classes are provided with their defining axioms. Two of them are described in this paper: EntityForAD and EntityForIntermediatePyrolysis.

The axioms for EntityForAD (see Fig. 5) contain the followings:

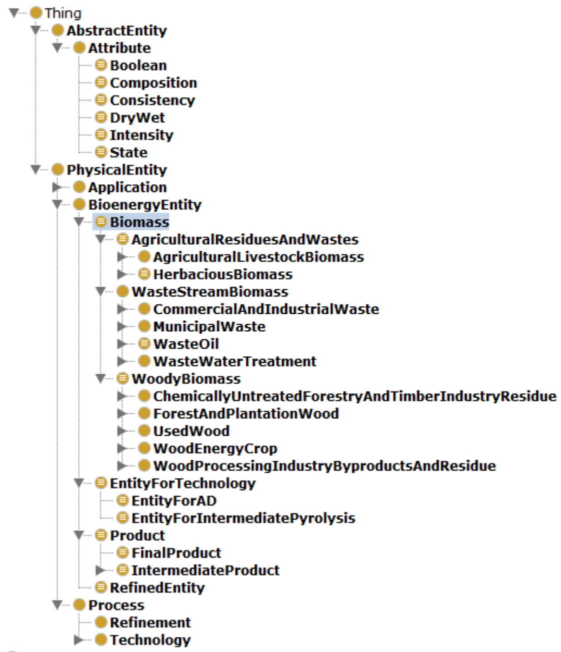
1) It is an EntityForTechnology and
2) Either it has biogenic content high or
3) It is a liquid or
4) It is explicitly defined as a suitable entity for anaerobic digestion or
5) It is a solid, wet and soft.

EntityForTechnology is a BioenergyEntity, which is suitable for some Technology. This axiom helps to identify the bioenergy entities, which are suitable for treating with anaerobic digestion.

The axiom for EntityForIntermediatePyrolysis (see Fig. 6) includes the followings:

1) It is an EntityForTechnology, and either
2) It is explicitly defined as suitable for IntermediatePyrolysis or
3) It is solid hard or
4) It is solid soft and dry.

This axiom helps to determine the bioenergy entities that are suitable for treating with an intermediate pyrolysis.



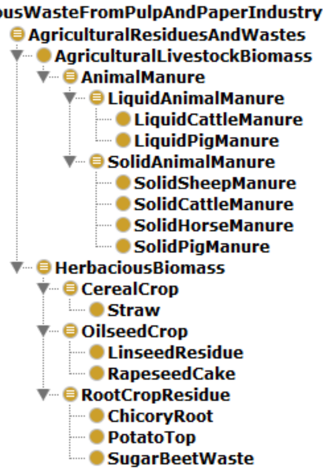


Fig. 4. Important classes in the bioenergy ontology.

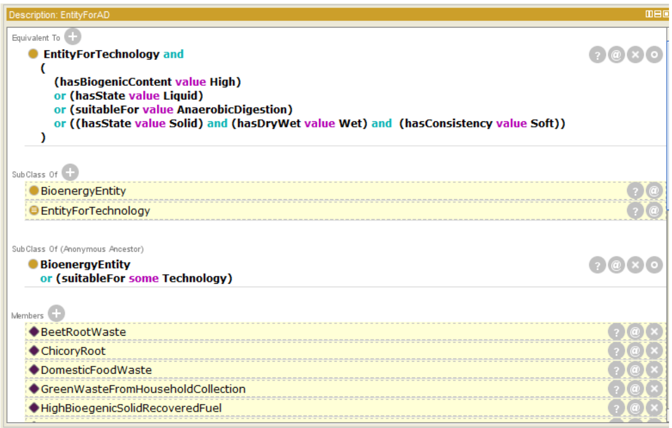


Fig. 5. Axiom defining entity suitable for anaerobic digestion.

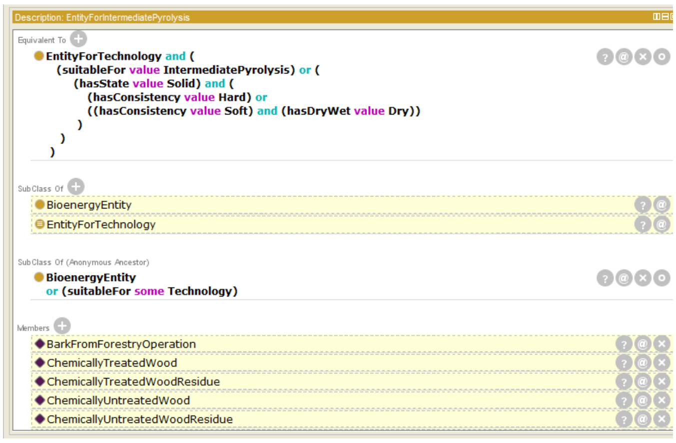


Fig. 6. Axiom defining the entity suitable for intermediate pyrolysis.

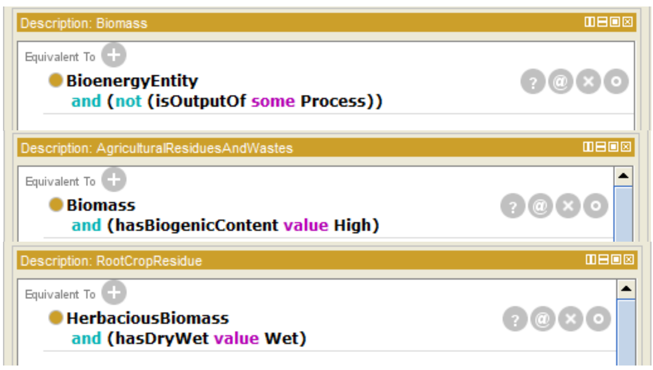


Fig. 7. Some classes and their axiomatic definitions in the bioenergy ontology.

6) *Bioenergy rules*

The semantic rules in the ontology are used to infer new knowledge and assert new knowledge to the ontology. In this paper, we have used some rules to assert new knowledge to the ontology, which helped in relating the bioenergy entities with the technologies and generating appropriate pathways for each bioenergy entity. For example in Fig. 8, the highlighted rules help in relating the bioenergy entities with their suitable technologies. The second rule (highlighted) asserts that all the individuals of EntityForIntermediatePyrolysis are related to the technology IntermediatePyrolysis via an object property isInputOf. Whereas the last rule (highlighted) asserts that all the individuals of the class EntityForAD are related with the technology AnaerobicDigestion via the object property isInputOf. The rest of the rules infer the different stages of the Bioenergy conversion pathway such as intermediate products and technologies

B. Inferred Pathway Generation

The ontology is queried in Java with the help of APIs and libraries such as Jenna and Pellet, and using SPARQL query language. In particular, the queries are about obtaining the bioenergy entities as the input and the output of the technologies and their applications. It needs tracing the relations that starts with a biomass and following until a final product is determined, and finding the application of the products. Fig. 9 shows an example of the SPARQL query, which returns the technology suitable for a biomass ChicoryRoot and the output of the technology. In this case, it will return AnaerobicDigestion as the technology, and Biogas and Digestate as the output.

```
Rules:
Rules
FirstIntermediateProduct(?e1), Technology(?t2),
isInputOf(?e1, ?t2), isOutputOf(?e2, ?t2) ->
SecondIntermediateProduct(?e2),

EntityForIntermediatePyrolysis(?e) -> isInputOf(?e,
IntermediatePyrolysis)

Biomass(?b), Technology(?t1), isInputOf(?b, ?t1),
isOutputOf(?e1, ?t1) -> FirstIntermediateProduct(?e1),
FirstTechnology(?t1)

Technology(?t5), ThirdIntermediateProduct(?e4),
isInputOf(?e4, ?t5), isOutputOf(?e5, ?t5) ->
FifthTechnology(?t5), FourthIntermediateProduct(?e5)

Technology(?t4), ThirdIntermediateProduct(?e3),
isInputOf(?e3, ?t4), isOutputOf(?e4, ?t4) ->
FourthIntermediateProduct(?e4),
FourthTechnology(?t4)

SecondIntermediateProduct(?e2), Technology(?t3),
isInputOf(?e2, ?t3), isOutputOf(?e3, ?t3) ->
ThirdIntermediateProduct(?e3), ThirdTechnology(?t3)

EntityForAD(?e) -> isInputOf(?e, AnaerobicDigestion)
```

Fig. 8. The rules in the bioenergy ontology.

In order to generate the bioenergy pathway, a biomass is given as an input. Based on the input, it tracks its relations with technologies with the help of the two object properties: isInputOf and isOutputOf. In particular, it recursively runs the following pseudo-code to generate the conversion pathway.

```
Method: processNode(Node)
    Get node type: Bioenergy Entity or Process
    Get application of the node (optional)
    Get child nodes: Process nodes (if current node is
    Bioenergy Entity) or Bioenergy entity nodes (if current
    node is Process)
    For each child node, processNode(childNode)
```

The pathway information is represented in JSON format (see Fig. 10), which is displayed in the web page (see Fig. 11) using a JavaScript framework: d3 tree layout[6]. Fig. 10 shows a bioenergy pathway for ChicoryRoot. Firstly, ChicoryRoot undergoes processing with AnaerobicDigestion, which yields Biogas and Digestate. Digestate is used as the final product and has application Fertilizer. The Biogas is a FirstIntermedaiteProduct and is treated in a CombinedHeatAndPowerEngine, which produces Heat and Power as the final products. Heat and Power can be sold to generate income.

```
SPARQL query:
PREFIX kbe: <http://www.bcu.ac.uk/kbe/pathway-ontology.owl#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT DISTINCT  (?t AS ?Technology) (?e as ?Output)
WHERE {
kbe:ChicoryRoot kbe:isInputOf ?t.
?t   rdfs:type  kbe:Technology;
               kbe:hasOutput ?e.
}
```

Technology	Output
AnaerobicDigestion	Digestate
AnaerobicDigestion	BioGas

Fig. 9. A SPARQL query to find out the suitable technology and output for the biomass ChicoryRoot.

```
{
  "name": "ChicoryRoot",
  "type": "Biomass",
  "processes": [
     {
       "name": "AnaerobicDigestion",
       "type": "FirstTechnology",
       "output": [
          {
            "name": "BioGas",
            "type": "FirstIntermediateProduct",
            "processes": [
               {
                 "name": "CombinedHeatAndPowerEngine",
                 "type": "SecondTechnology",
                 "output": [
                    {
                      "name": "Heat",
                      "type": "FinalProduct",
                      "application": ["InternalUse"]
                    },
                    {
                      "name": "Power",
                      "type": "FinalProduct",
                      "application": ["Selling"]
                    }
                 ]
               }
            ]
          },
          {
            "name": "Digestate",
            "type": "FinalProduct",
            "application": ["Fertilizer"]
          }
       ]
     }
  ]
}
```

Fig. 10. A conversion pathway for ChicoryRoot, generated in JSON format.

C. Discussion

Ontology captures the knowledge of the experts in a domain. In this paper, we have used ontology to capture the domain knowledge about different kinds of the biomass, their

[6] http://mbostock.github.io/d3/talk/20111018/tree.html

nature and the bioenergy pathways the biomass follows. It is demonstrated that leveraging Semantic Web technologies help to infer new knowledge from the existing knowledge. We have demonstrated that the use of axioms and SWRL rules have inferred the pathways suitable for a specific type of a biomass.

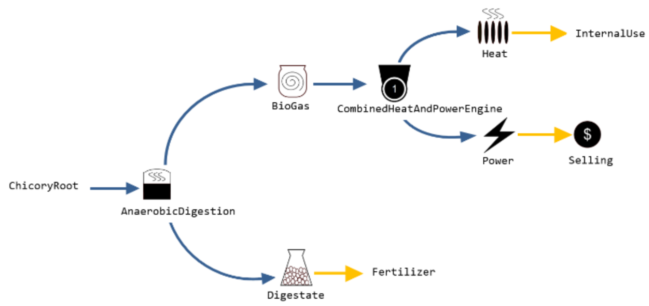


Fig. 11. Snapshot showing the visualization of the pathway.

The bioenergy ontology presented here does not incorporate the all the entities, constraints and the rules. This is a proof of concept; it proves that if a biomass is properly defined with properties and we have experts' knowledge captured in an ontology, we can infer the suitable bioenergy pathway for the biomass.

The benefit of the semantic approach presented in this paper is that this ontology can be extended easily by adding more biomass and defining them with more attributes. Besides, we can add more technologies and more pathways and their characteristics.

Application of the semantic approach of the Bioenergy pathway generation in the real case study has been consulted and discussed with the experts; and, it has been found that the outcomes are consistent with the information they have provided in the spreadsheet and the diagrams.

IV. Conclusion

In this paper, we presented the bioenergy ontology, which is designed to generate conversion pathways automatically. The ontology contains the concepts, which are sufficiently defined with axioms and rules. By inferring the knowledge in the ontology, we generated the conversion pathways automatically. This approach is beneficial for extending the pathways or checking whether the knowledge or rules in the pathway are consistent. Besides, ontological representation of the data and rules or knowledge has been proven reusable.

In future work, we aim to integrate the existing ontologies related to biomass and bioenergy, and create a consistent ontology. The pathways currently contain the information that is available in the BioenNW project. For future research, it is recommended to create an exhaustive list of pathways, which incorporates information about all the biomass, intermediate products, final products and application.

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Dr Sapkota joined Birmingham City University in 2013 as a research associate and has been working on the BioenNW interreg IVB programme, which aims to provide semantic decision support tools to the stakeholders in the region to start new bioenergy and algae plants.

Pathmeswaran Raju is a reader in knowledge modelling and engineering at the Birmingham City University. His current research interests include knowledge engineering for design, engineering and manufacturing disciplines for the development of knowledge-based engineering systems.

His current role involves developing knowledge-based decision support system for the Energetic Algae (EnAlgae) INTERREG IVB NWE programme, and developing requirements and knowledge models for Platform Independent

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Craig Chapman is the director for the Centre for Knowledge Based Engineering and the associate head of School for Research in the School of Engineering, Design and Manufacturing Systems at Birmingham City University (BCU). The main focus of Craig's career has been research, development and the application of design engineering automation and the development of knowledge based engineering solutions, enabling companies to respond rapidly to design engineering changes and explore multiple solutions with consideration to all life cycle phases.

He is currently the principle investigator at BCU for the Platform Independent Knowledge Model (PIKM) project as part of Technology Strategy Board (TSB)/Rolls-Royce funded Strategic Investment in Low-carbon Engine Technology 2 (SILOET2) programme and EU Clean Sky initiative, focusing on modelling product and process knowledge for advanced design automation and Knowledge Based Engineering system development, he is also technical advisor on the Energetic Algae (EnAlgae) INTERREG IVB NWE Programme and the BioenNW INTERREG IVB Programme developing knowledge-based decision support systems and semantic knowledge models.

William Byrne is a research associate in the Centre for Knowledge Based Engineering at Birmingham City University, working on the BioenNW INTERREG IVB programme, developing semantic decision support tools to the stakeholders in the region to start new bioenergy and algae plants. After a few years away from academia after his first degree, Will returned to do his MSc in computer science. Since then he has worked on a range of projects including looking at informal learning via a mobile context-aware museum guide, an automated semantic annotation system for video, and supporting language learning with multi-touch tables.

Lynsey Melville is the director of the Centre for Low Carbon Research and the head of Bioenergy Research. She has previously worked as a process scientist for Severn Trent Water and following her PhD (funded by the Engineering and Physical Sciences Research Council (EPSRC)) established a spin out company from the University of Wolverhampton with two other academics. This company offered consultancy, Research and Development in the water and wastewater industry. She has previously worked as a consultant at Birmingham City University on two EU funded programmes offering support to regional SMEs in the environmental goods and services sector.