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**RECONSTRUCTION OF A GENOME-SCALE METABOLIC  
MODEL OF MAIZE METABOLISM**

A Thesis in

Chemical Engineering

by

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## ABSTRACT

The scope and breadth of genome-scale metabolic reconstructions has continued to expand over the last decade. However, only a limited number of efforts exist on plant metabolism reconstruction focused on a single model plant system (i.e., *Arabidopsis thaliana*). Herein, we present the development of a genome-scale model for a plant with direct applications to food and bioenergy production (i.e., maize). Unlike *A. thaliana*, maize annotation is still underway which introduces significant challenges in the association of metabolic functions to genes. The developed model is designed to meet rigorous standards on gene-protein-reaction (GPR) associations, elementally and charged balanced reactions and a biomass reaction abstracting the relative contribution of all biomass constituents. The metabolic network contains 1,563 genes and 1,825 metabolites involved in 1,985 reactions from primary and secondary maize metabolism. For approximately 42% of the reactions direct evidence for the participation of the reaction in maize was found. As many as 445 reactions and 369 metabolites are unique to maize compared to *A. thaliana*. All reactions are elementally and charged balanced and localized into six different compartments (i.e., cytoplasm, mitochondrion, plastid, peroxisome, vacuole and extracellular). GPR associations are also established based on the functional annotation information and homology prediction accounting for monofunctional, multifunctional and multimeric proteins, isozymes and protein complexes. We describe results from performing flux balance analysis under different physiological conditions, (i.e., photosynthesis, photorespiration and respiration) of a C4 plant and also explore model predictions against experimental observations for two naturally occurring mutants (i.e., *bm1* and *bm3*). The developed model corresponds to the largest and more complete to-date effort at cataloguing metabolism for a plant species.

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# Chapter 1: Introduction

## 1.1 Maize and its importance

*Zea mays*, commonly known as maize or corn, is a plant organism of paramount importance as a food crop, biofuels production platform and a model for studying plant genetics [1]. Maize account for 31% of the world production of cereals occupying almost one-fifth of the worldwide land dedicated for cereal production [2]. Maize cultivation led to 12 billion bushels of grain in the USA alone in 2008 worth \$47 billion [3]. Maize is the second largest, after soybean crop [2]. In addition to its importance as a food crop, 3.4 billion gallons of ethanol was produced from maize in 2004 [3]. Maize derived ethanol accounts for 99% of all biofuels produced in the United States [3]. However, currently nearly all of this bioethanol is produced from corn seed [4]. Ongoing efforts are focused on developing and commercializing technologies that will allow for the efficient utilization of plant fiber or cellulosic materials (e.g. maize stover and cereal straws) for biofuels production. Maize is the most studied species among all grasses with respect to cell wall lignification and digestibility, which are critical for the efficient production of cellulosic biofuels [5]. A thorough evaluation of the metabolic capabilities of maize would be an important resource to address challenges associated with its dual role as a food (e.g., starch storage) and biofuel crop (e.g., cell wall deconstruction).

## 1.2 Genome-scale metabolic reconstruction

This decade we witnessed significant advancements towards mapping plant genes to metabolic functions culminating with the complete genome sequencing and partial annotation



of a number of plant species, namely, *Arabidopsis thaliana* [6], *Oryza Sativa* [7, 8], *Sorghum bicolor* [9], *Zea mays* [10] and *Theobroma cacao* [11]. Nevertheless, attempts to engineer plant metabolism for desired overproductions have been met with only limited success [12]. Genetic modifications seldom bring about the expected/desired effect in plant metabolism primarily due to the built-in metabolic redundancy circumventing the imposed genetic changes [13, 14]. This necessitates the development of genome-wide comprehensive metabolic reconstructions capable of taking account of the complete inventory of metabolic transformations of a given plant organism.

Genome-scale metabolic reconstructions are available for an increasing number of organisms [15, 16]. At least 40 bacterial, 2 archaeal and 15 eukaryotic reconstructions are available to-date [12, 15, 17, 18] while many others are under development. Recently Poolman et al (2009) and Dal'Molin et al (2010) independently constructed the first two genome-scale metabolic reconstructions for a plant organism (i.e., *Arabidopsis thaliana*). The model by Dal'Molin *et al* identifies the set of essential reactions, accounts for the classical photorespiratory cycle and highlights the significant differences between photosynthetic and non-photosynthetic metabolism. The model by Poolman *et al* includes ATP demand constraints for biomass production and maintenance and suggests strategies for the construction of metabolic modules as a consequence of variation in ATP requirement. Both models make a significant step forward towards assessing the metabolic capabilities of plants establishing production routes for key biomass precursors and major pathways of *Arabidopsis* primary metabolism.

### 1.3 Flux balance analysis

Flux balance analysis (FBA) is widely used mathematical approach for studying biochemical reaction networks especially the genome-scale metabolic network reconstructions. In a word, FBA analyzes the flow of metabolites through a metabolic network thus predicting the growth rate of an organism or the rate of production of important metabolite [19]. With the growing number of genome-scale metabolic reconstructions, FBA can be used for extracting the knowledge encoded in the model. For performing FBA a genome-scale metabolic reconstruction needs to be represented in the form of tabulation of stoichiometric coefficients where each row represents a single metabolite whereas each column signifies a specific reaction and these stoichiometries impose constraints for metabolic flow through the network [19]. There are two different ways to represent constraints: as equations balancing reaction inputs to reaction outputs and as inequalities imposing bounds in the system such as uptake or secretion of specific metabolites and upper and lower bounds for maximum and minimum allowable fluxes for a specific reactions. All these balances and bounds determine the solution space i.e. allowable flux distributions of a system.

The next step is to define a potential phenotype in the form of biological objective pertinent to the system under study [19]. The objective can be biomass production (i.e. the rate at which metabolites are converted to biomass precursors such as amino acids, nucleic acids and lipids) or production of desirable compounds. Therefore, FBA involves a system of linear equations that can be solved using available linear programming tools. Since the fundamentals of FBA are simple, it can further be used to analyze and restore network connectivity (GapFind and GapFill [20]) or predicting gene knockouts that allow a species to

produce desirable products (OptKnock [21]). The details of FBA based algorithms used in this work are explained in Appendix A.

#### **1.4 Summary of the work done**

In this work, we describe the construction of a genome-scale *in silico* model of maize metabolism (i.e., *Zea mays* iRS1563). This is, to the best of our knowledge, the first attempt of globally characterizing the metabolic capabilities using a compartmentalized photosynthetic model of an important crop and energy plant species. The development of a genome-scale model for maize is a significant challenge due to its genome size which is 14 times larger [10] than that of *Arabidopsis thaliana* (157 million base pairs) [22]. The constructed model contains 1,563 genes and 1,825 metabolites participating in 1,985 reactions from both primary and secondary metabolism of maize. For 42% of the reaction entries direct literature evidence in addition to homology criteria for their inclusion to the model was identified. We found that as many as 676 reactions and 441 metabolites are unique to *Zea mays* iRS1563 in comparison to the AraGEM model by Dal’Molin *et al.* In order to deduce the genuine differences between maize and Arabidopsis irrespective of annotation chronology we also reconstructed an up-to-date model of Arabidopsis, *A. thaliana* iRS1597. *A. thaliana* iRS1597 contains 1597 genes, 1798 reactions and 1820 metabolites. In comparison to *A. thaliana* iRS1597, *Zea mays* iRS1563 has 445 unique reactions and 369 unique metabolites.

All reactions present in *Zea mays* iRS1563 are elementally and charged balanced and localized into six compartments including cytoplasm, mitochondrion, plastid, peroxisome, vacuole and extracellular space. Provisions for accounting that photosynthesis in maize (i.e.,

a C4 plant) occurs in two separate cell types (i.e., mesophyll cell and bundle sheath cell) are included in the model. GPR associations are delineated from the available functional annotation information and homology prediction accounting for monofunctional, multifunctional and multimeric proteins, isozymes and protein complexes. A biomass equation is established that quantifies the relative abundance of different constituents of dry plant cell biomass. Biomass production under three different physiological states (i.e., photosynthesis, photorespiration and respiration) is demonstrated and the model is tested against experimental data for two naturally occurring maize mutants (i.e., *bm1* and *bm3*).

## Chapter 2: Reconstructing the maize model

The metabolic model reconstruction process follows three major steps: (1) Reconstruction of draft model via automated homology searches for the identification of native biotransformations; (2) Generation of a computations-ready model after defining biomass equation and system boundary and establishing GPR; (3) Model refinement via GapFind and GapFill [23] to unblock biomass precursors as well as reconnect unreachable metabolites. Upon construction of the model, key features such as physiological constraints, network connectivity, uniqueness compared to Arabidopsis metabolism and secondary metabolism are described. In addition, model predictions are contrasted against experimental observations.

### 2.1 Construction of ‘Auto’ and ‘Draft’ models

The B73 maize genome [10] has 32,540 genes and 53,764 transcripts in the Filtered Gene Set (FGS). Out of 32,540 genes, 30,599 (93%) are evidence-based [24], while the remaining 2,141 (7%) are predicted by the Fgenesh program [25]. 13,726 genes (42% of total) do not have any functional annotation information or are identified as proteins with no or hypothetical/putative functions. Of the remainder, 1,361 (7%) genes encode proteins that do not participate in specific metabolic transformations but rather are involved in transcription, signal transduction, DNA repair, DNA binding, DNA/RNA polymerization, protein folding and adhesion. Because the B73 maize genome is not completely annotated we first established Gene-Protein-Reaction (GPR) mappings for the genome-scale model of *A. thaliana*, AraGEM [12] to be used as a proxy. Using these

**Table 2-1:** Model size after each reconstruction step

	<b>Auto model</b>	<b>Draft model</b>	<b>Functional model</b>	<b>Final model</b>
Included genes	946	1,485	1,552	1,563
Proteins	472	714	774	876
Single functional proteins	178	322	381	463
Multifunctional proteins	92	150	153	170
Protein complexes	0	4	4	4
Isozymes	21	36	36	36
Multimeric proteins	87	140	148	148
Others <sup>a</sup>	94	62	62	55
Reactions	1,186	1,667	1,821	1,985
Metabolic reactions	1,154	1,635	1,739	1,900
Transport reactions	32	32	67	70
GPR associations				
Gene associated (metabolic/transport)	1,100	1,581	1,635	1,668
Nonenzyme associated (metabolic/transport)	86	86	86	86
Spontaneous <sup>b</sup>	0	0	7	41
Nongene associated (metabolic/transport)	0	0	78	175
Exchange reactions	0	0	15	15
Metabolites <sup>c</sup>	1,365	1,703	1,769	1,825
Cytoplasmic	1,309	1,643	1,689	1,744
Plastidic	91	102	114	115
Peroxisomic	67	69	92	93
Mitochondrial	60	82	86	86
Vacuolic	5	5	5	5
Extracellular	0	0	15	15

<sup>a</sup>Others include proteins involve in complex relationships, e.g. multiple proteins act as protein complex which is one of the isozymes for any specific reaction.

<sup>b</sup>Spontaneous reactions are those without any enzyme as well as gene association.

<sup>c</sup>Unique metabolites irrespective of their compartmental location.

GPRs as a point of comparison we next identified Arabidopsis gene orthologs in maize and transferred the corresponding GPRs via the AUTOGRAPH method [26]. This step was followed by annotation of the remainder maize genes by bidirectional protein BLAST (i.e.,

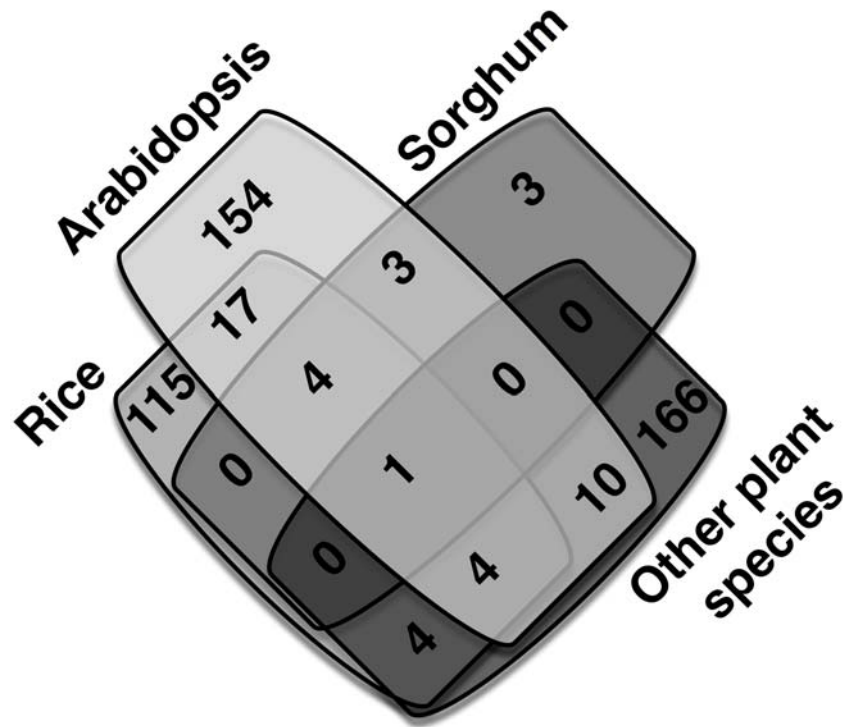
BLASTp) searches against the NCBI non-redundant (nr) database. Out of a total of 1,567 metabolic or transport reactions of AraGEM, GPRs were established for 1,254 reactions via 1,467 genes and 653 enzymes by making use of information from several online databases such as AraCyc, KEGG, Uniprot and Brenda. Bidirectional BLASTp searches for each one of the 1,467 genes included in AraGEM model were carried out against the B73 maize genome using a stringent cutoff value of  $10^{-30}$ . This fully automated process generated an initial model, termed as 'Automodel', containing 946 genes and 1,365 unique metabolites participating in 1,186 reactions (see Table 2-1) exclusively derived from AraGEM. Out of 1,186 reactions, 32 are inter-organelle transport reactions for which homologs were found in maize.

**Table 2-2:** Maize gene annotation via bidirectional BLASTp homology searches against NCBI non-redundant protein database

Species	Number of orthologs	Number of associated reactions	Number of newly added reactions in draft model
<i>Oryza Sativa</i> (Rice)	4,109	312	145
Other plant species	833	214	185
<i>Arabidopsis Thaliana</i> ( <i>Arabidopsis</i> )	802	258	193
<i>Sorghum Bicolor</i> (sorghum)	47	20	11

Genes not included in the automodel were examined further by comparing them against the NCBI non-redundant protein database using the same BLASTp cut-off. This increased the model size to 1,485 genes and 1,703 unique metabolites involved in 1,667 reactions by pulling functionalities absent in AraGEM. This is referred to as the 'Draft model' (see Table 2-1). As described in Table 2-2, orthologous genes were found in *Oryza Sativa* (Rice),

*Arabidopsis thaliana* (Arabidopsis), *Sorghum bicolor* (Sorghum) and less frequently in other plant species such as wheat, tobacco, spinach, soya bean, etc. Notably, 802 orthologous genes from *A. thaliana* were added in the model *Zea mays* iRS1563 that were absent from AraGEM primarily due to recent annotation updates. Reactions associated with these genes were subsequently extracted from on-line databases such as KEGG and BRENDA. Table 2-2 shows the total number of reactions as well as the number of new reactions included in the draft model. Seven reactions having KEGG reaction IDs R00379, R00381, R06023, R06049, R06082, R06138 and R06209 were excluded since they involve generic groups and were not elementally fully defined. Figure 2-1 shows the distribution of the newly added reactions in the draft model based on their orthologous gene of origin.



**Figure 2-1:** Species origin of newly added reactions in the Draft model.



## 2.2 Generation of computations-ready model

A computations-ready model requires a fully characterized biomass equation, assignment of metabolites to reactions, establishment of GPR associations, localization of reactions in compartment(s), and inclusion of intra- and extracellular transport reactions [27].

(i) *Establishing a fully characterized biomass equation:* A biomass equation that drains all necessary precursors present in maize was derived (see Table 2-3). We used the biomass composition of young and vegetative maize plants as measured by Penningd et al (1974) and expressed on a dry weight basis [28]. The amino acid and lignin composition were derived based on the data from [29, 30]. The composition of hemicellulose was approximated using data for Orchard Grass [31], another monocot grass species, as no corresponding information was found for maize. Based on these compositions we also defined aggregate reactions such as ‘Amino acid synthesis’, ‘Protein synthesis’, ‘Carbohydrate synthesis’, ‘Hemicellulose synthesis’, ‘Lignin synthesis’, ‘Lipid synthesis’, ‘Material synthesis’, ‘Nitrogenous compound synthesis’, ‘Nucleic acid synthesis’ and ‘Organic acid synthesis’ to produce necessary biomass precursors (i.e., amino acids, protein, carbohydrates, hemicellulose, lignin, lipids, materials, nitrogenous compounds, nucleic acids and organic acids respectively). The biomass equation also contains a non-growth associated ATP maintenance as in the latest Arabidopsis model AraGEM [12].

**Table 2-3:** Biomass component list in *iRS1563*

<b>Major components</b>	<b>Protein</b>	<b>Carbohydrates</b>	<b>Lipids</b>	<b>Ions</b>
<b>Nitrogenous compounds</b>	L-alanine	ribose	glyceroltripalmitate	potassium chloride
<b>Carbohydrates</b>	L-arginine	glucose	gliceroltristearate	
<b>Lipids</b>	L-aspartic acid	fructose	glyceroltrioleate	
<b>Lignin</b>	L-cystine	mannose	glyceroltrilinolate	<b>RNA</b>
<b>Organic acids</b>	L-glutamic acid	galactose	glyceroltrilinoleate	ATP
<b>Ions</b>	L-glycine	sucrose		GTP
	L-histidine	cellulose	<b>Lignin</b>	CTP
	L-isoleucine	hemicellulose	4-coumaryl alcohol	UTP
<b>Nitrogenous compounds</b>	L-leucine	pectin	coniferyl alcohol	
amino acids	L-lysine		sinapyl alcohol	<b>DNA</b>
protein	L-methionine			dATP
nucleic acids	L-phenylalanine	<b>Hemicellulose</b>	<b>Organic acids</b>	dGTP
	L-proline	arabinose	oxalic acid	dCTP
	L-serine	xylose	glyoxalic acid	dUTP
	L-threonine	mannose	Oxalo-acetic acid	
	L-tryptophan	galactose	Malic acid	
	L-tyrosine	glucose	Citric acid	
	L-valine	uronic acids	aconitic acid	

(ii) *Assignments of genes, reactions, metabolites and compartments.* All metabolic and inter-organelle transport reactions in the draft model have full gene associations. During this step all reactions were elementally balanced and metabolites were assigned appropriate protonation states corresponding to a physiological pH of 7.2. We included an additional 86 reactions to the model without enzyme association information based on direct literature evidence [12]. For example, reactions with KEGG IDs R08053, R08054 and R08055 involved in chlorophyll metabolism are included in the model. Because only limited reaction localization information exists for maize, we adopted the compartment or organelle reaction location of the corresponding orthologous gene/enzyme in Arabidopsis using the Arabidopsis

Subcellular Database, SUBA [32]. Reactions for which no such information is available we assumed that they are present only in the cytoplasm.

(iii) *Identification of system boundary.* The entire reaction network (i.e., system boundary) was distributed across five different intracellular organelles enveloped by the cytoplasmic membrane. Exchange reactions were added in the model to ensure that gaseous metabolites (i.e., carbon dioxide and oxygen), inorganic nutrient metabolites (i.e., nitrate, ammonia, hydrogen sulfide, sulfate, phosphate, potassium and chloride), sugar metabolites (i.e., glucose, fructose, maltose and sucrose), water and photons could enter and leave the system whenever necessary depending on the physiological state. As shown in Table 2-4, constraints on these exchange reactions as well as reactions involved with enzyme RuBisCO (Ribulose-1, 5-bisphosphate carboxylase oxygenase) were established to define three different physiological states (i.e., photosynthesis, photorespiration and respiration) by allowing the selective uptake/release of certain metabolites.

**Table 2-4:** Definition of three different physiological states

<b>Constraints</b>	<b>Photosynthesis (PS)</b>	<b>Photorespiration (PR)</b>	<b>Respiration (R)</b>
CO <sub>2</sub> transport	Uptake	Uptake	Release
Sucrose transport	Disabled	Disabled	Uptake
Photon transport	Uptake	Uptake	Disabled
H <sub>2</sub> O transport	Uptake	Uptake	Uptake
Inorganic nutrient transport	Uptake	Uptake	Uptake
O <sub>2</sub> transport	Release	Unconstrained	Uptake
RUBISCO: EC 4.1.1.39	Carboxylation	Carboxylation: Oxygenation = 3:1	Both disabled

The stoichiometric matrix of the draft model (see Table 2-1) contains 1,901 rows (i.e., total metabolites after taking account of their compartmental appearance) and 1,682 columns (i.e., metabolic reactions, inter-organelle transport reactions and exchange reactions). 970 reactions have one-to-one GPR associations whereas 712 map to more than one gene. 532 reactions map to both isozymes and protein complexes while 4 of them map to only protein complexes, 36 to only isozymes, and 140 to only multimeric proteins.

### **2.3 Network connectivity analysis and restoration**

The draft metabolic model inherently contained gaps, unreachable metabolites, omitted transport mechanisms and missing biomass components. We used the procedures termed GapFind and GapFill [20] to correct for these pathologies. We first concentrated on resolving problems with the participation of components in the biomass equation followed by network connectivity.

We found that 723 out of the 1,683 reactions in the draft model could not carry any flux (i.e., blocked reactions) under any of the relevant three physiological states (e.g. photosynthesis (PS), photorespiration (PR) and respiration (R)). As a result, these blocked reactions prevented the formation of some of biomass precursors. GapFind [20] revealed that only 21 out of 64 biomass components could be synthesized using the draft model. GapFill [20] was applied for bridging the gaps through the addition of metabolic and inter-organelle transport reactions and the relaxing of irreversible of existing reactions in the model. GapFill suggested the addition of 94 metabolic and 35 inter-organelle transport reactions in the model to unblock the production of all 64 biomass components. These putative additions to the

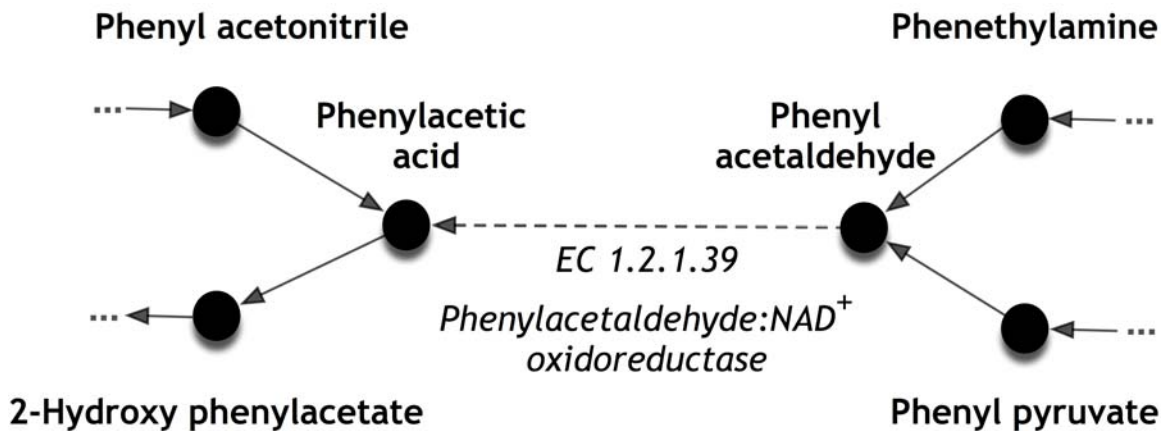
model were tested by performing an additional round of BLASTp searches for the corresponding genes against the maize genome. We found that 54 (out of 93) metabolic reactions could be assigned to maize gene(s) if the expectation value cut-off for BLASTp was lowered to  $10^{-5}$ . In light of the critical need of restoring biomass formation the less stringent cut-off for inclusion was accepted for these genes. Addition of these reactions ensured the production of biomass under all relevant physiological states validating the use of the term ‘*Functional*’ for the updated model (see Table 2-1).

**Table 2-5:** Restoration of network connectivity using GapFill [29]

<b>Number of metabolites</b>	<b>Number of blocked metabolites: before applying GapFill</b>	<b>Number of blocked metabolites: after applying GapFill</b>
Cytosolic (1744)	680	382
Plastidic (115)	28	11
Peroxisomic (93)	5	0
Mitochondrial (86)	2	0

Upon ensuring biomass formation GapFind was also applied to assess network connectivity and 715 blocked metabolites were found in the functional model. By applying GapFill connectivity of 322 (45%) blocked metabolites was restored through the addition of 159 metabolic and 3 inter-organelle transport reactions. Table 2-5 shows the distribution of blocked metabolites into four intracellular organelles before and after applying GapFill. BLASTp searches allowed us to assign 31 (20% of GapFill suggestions) metabolic reactions with specific maize genes. Biological evidence of the occurrence of such additional reactions in maize or other plant species was sought whenever possible. For example, as shown in

Figure 2-2 phenylacetaldehyde appears to be a ‘no-consumption’[20] metabolite in the functional model as no reaction can consume it. Using GapFill we found a homologue in maize (i.e., BLASTp score of  $10^{-24}$ ) and also literature evidence [33] that *Arabidopsis thaliana* has a aldehyde dehydrogenase activity that catalyzes the conversion of phenylacetaldehyde to phenylacetic acid. Hence, by adding this chemical transformation to *Zea mays* iRS1563 a consumption pathway for phenylacetaldehyde is established. After adding these reactions to the functional model and following charge and elemental balancing and GPR association checking the ‘Final’ *Zea mays* iRS1563 model (see Table 2-1) is derived.



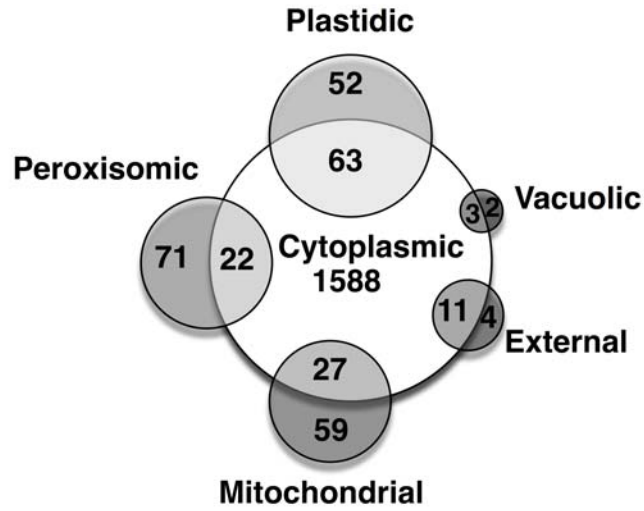
**Figure 2-2:** Example of connectivity restoration for phenylacetaldehyde.

#### 2.4 *Zea mays* iRS1563 model

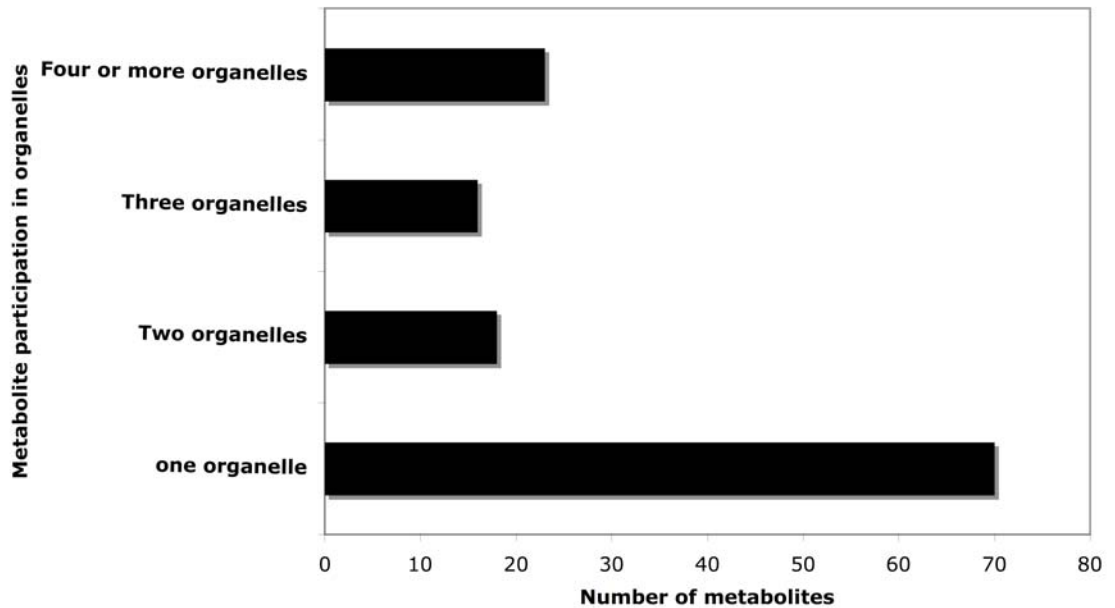
The *Zea mays* iRS1563 metabolic reconstruction contains 1,825 unique metabolites and 1,985 reactions associated with 1,563 genes and 876 proteins. Of these reactions 1,898 are metabolic reactions, 70 are inter-organelle transport reactions and 15 are exchange reactions

between intra- and extracellular environments. GPR associations are established for all entries (see Table 2-1). Notably, we identified that the fraction of multifunctional proteins (19% of the total number of proteins) in *Zea mays* iRS1563 is similar to the ratio found in *E. coli* [34]. *Zea mays* iRS1563 accounts for the metabolic functions for all three physiological states. Photosynthetic as well as photorespiration metabolism was modelled by including light mediated ATP and NADPH production via separate charged balanced reactions in the electron transfer system of the thylakoid membrane [35]. Furthermore, the ratio of fluxes for the carboxylation and oxidation reactions associated with enzyme RuBisCO was kept at 1:0 thus ensuring complete carbon fixation during photosynthesis. This ratio was shifted to 3:1 during photorespiration to model simultaneous carbon fixation and oxidation [36]. Because sucrose is the main growth substrate during respiration for higher plants [37], the aforementioned reactions were inactivated and the exchange reaction for sucrose uptake was activated. Under all these three conditions, inorganic nutrients required for plant growth, e.g. sulfate, nitrate, ammonia, hydrogen sulfide, phosphate, potassium and chloride, were allowed to be freely taken up from the environment via extracellular exchange reactions.

(a)



(b)



**Figure 2-3:** Distribution of metabolites based on their number of appearance in different organelles: (a) cytoplasmic *Zea mays* iRS1563 metabolites in cytoplasm and other organelles, and, (b) *Zea mays* iRS1563 metabolite organelle participation.

The participation of *Zea mays* iRS1563 metabolites across different compartments is shown in Figure 2-3. The five intracellular organelles differ notably in terms of mutual connectivity, metabolite uniqueness and number of metabolites. As shown in Figure 2-3a, approximately

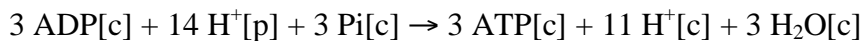
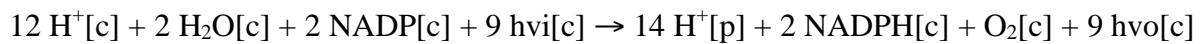


90% of these metabolites are unique to cytoplasm. In addition, cytoplasm contains all metabolites shared between any two organelles because any metabolite needs to be transported through cytoplasm in order to be exchanged between organelles. Among the remaining metabolites, cytoplasm shares the highest number with the plastid (i.e., 63) where photosynthesis and photorespiration occur. It also shares a significant number of metabolites with mitochondrion (i.e., 27) and peroxisome (i.e., 22) that are involved in energy production and fatty acid biosynthesis, respectively. Figure 2-3b shows the distribution of other *Zea mays* iRS1563 metabolites in terms of how many organelles they participate.

## Chapter 3: Analyzing the model *Zea mays* iRS 1563

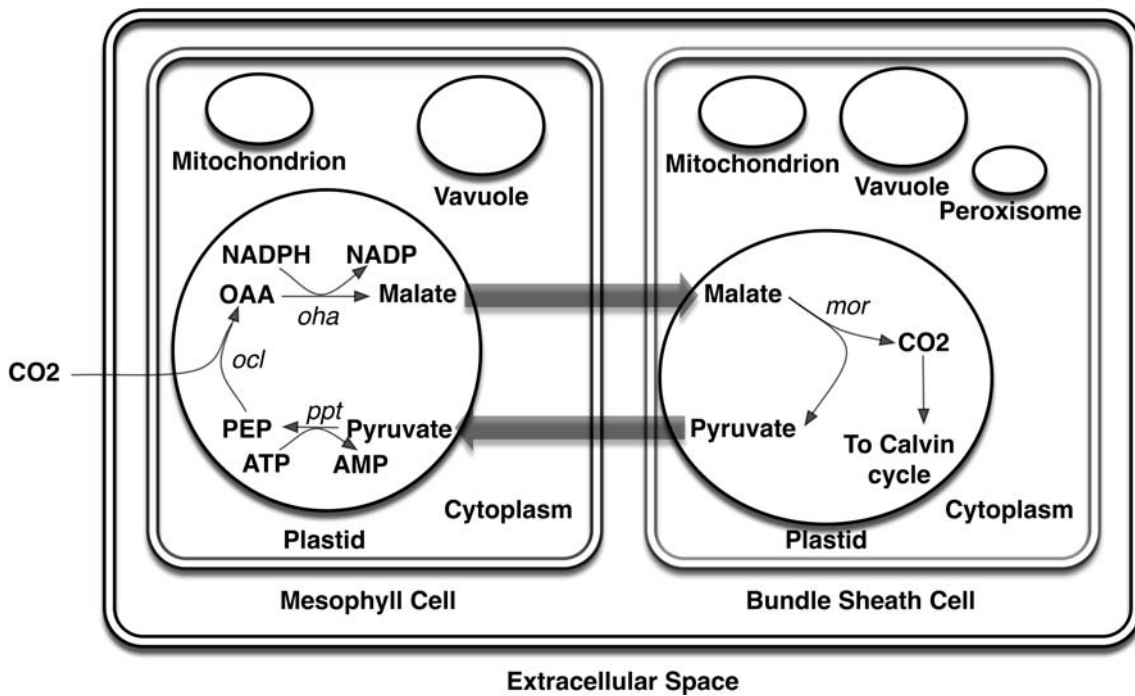
### 3.1 Light reactions, carbon fixation and secondary metabolism

In plants photosynthesis reactions include light dependent and light independent or carbon fixation reactions [38]. *Zea mays* iRS1563 includes charged balanced light reactions culled from a number of literature sources [35, 39-41]. The overall photosynthesis reaction cascade produces two NADPH, three ATP and one O<sub>2</sub> whenever nine photons are absorbed and fourteen H<sup>+</sup> are transferred via the electron-transport system. This defines the following overall balance equations:



Here, [c] and [p] represent cytoplasm and plastid and hvi and hvo signify input and output photons respectively. Carbon fixation in maize (C<sub>4</sub> plant) is more complex compared to Arabidopsis or other C<sub>3</sub> plants [38]. *Zea mays* iRS1563 captures these differences by accounting for (i) direct carboxylation of phosphoenol pyruvate and CO<sub>2</sub> fixation to form C<sub>4</sub> acids such as oxaloacetic acid [ATP: oxaloacetate carboxy-lyase (*ocl*)] and malic acid [Oxaloacetate: NADPH hydrogenase (*oha*)] in mesophyll cells, (ii) transport of malic acid from mesophyll cell to bundle-sheath cells, (iii) decarboxylation of malic acid [Malate:NADP<sup>+</sup> oxidoreductase (*mor*)] in bundle-sheath cells to produce pyruvic acid and CO<sub>2</sub>, which enters the Calvin cycle, (iv) transport of pyruvic acid from bundle-sheath cells to mesophyll cells, and (v) production of phosphoenol pyruvic (i.e., C<sub>3</sub>) acid [ATP:pyruvate,phosphate phosphotransferase (*ppt*)] from pyruvic acid [38]. Figure 3-1, pictorially shows the localization of reactions and organelles between mesophyll and bundle

sheath cells. In addition to differences in carbon fixation reactions, the peroxisome activity is primarily present in bundle-sheath cells and largely absent from mesophyll cells [42]. Because RuBisCO that operates in the Calvin cycle cannot come in direct contact with atmospheric oxygen during day time (see Figure 3-1), photorespiration is restricted providing an advantage for survival in hot and arid environments for maize and other C<sub>4</sub> plants. This comes at the expense of higher (ATP) requirements as C<sub>4</sub> carbon fixation involves additional steps [38].



**Figure 3-1:** Compartment and localization information for *Zea Mays iRS 1563*. Mitochondrion and vacuole compartments are present in both cell types whereas peroxisome is only present in bundle-sheath cell [40]. Plastidic reactions are distributed between mesophyll and bundle-sheath cells.

In addition to photosynthesis, secondary metabolism plays a key role in the physiology of maize. For example, phenylpropanoid metabolism produces monolignols (i.e., *p*-coumaroyl alcohol, coniferyl alcohol and sinapyl alcohol) that are used in the generation of three major lignin subunits H-lignin, G-lignin and S-lignin, respectively [43]. Many of these enzymes such as hydroxycinnamoyl transferase (HCT), ferulate 5-hydroxylase (F5H) and caffeic acid 3-*O*-methyltransferase (COMT) along with their associated reactions are unique to C<sub>4</sub> plants and are not present in the lignin biosynthesis pathways of *A. thaliana* [43]. HCT is involved in the early stages of lignin biosynthesis by controlling the flux from *p*-coumaroyl-CoA towards caffeoyl-CoA while F5H and COMT regulate fluxes from coniferaldehyde and coniferyl alcohol to sinapaldehyde and sinapyl alcohol, respectively [43]. *Zea mays* iRS1563 contains all these enzymes and associated reactions thus providing a comprehensive lignin biosynthesis pathway for a C<sub>4</sub> plant.

In addition to phenylpropanoid metabolism, *Zea mays* iRS1563 provides a detailed description of flavonoid biosynthesis pathways. Flavonoids are pigments occurring in plant as secondary metabolites and mostly function in the recruitment of pollinators and/or seed dispersers [44]. For example, maize is known to produce 3-deoxyanthocyanins which are a specialized class of flavonoids [45, 46]. *Zea mays* iRS1563 contains the dihydroflavonol 4-reductase (DFR) enzyme that catalyzes the reaction for flavan-4-ols biosynthesis that channels flux towards 3-deoxyanthocyanins production [46]. The model also accounts for isoflavone 7-*O*-glucosyltransferase (IF7GT) and associated reactions that are involved in the production of necessary intermediates for pterocarpin phytoalexin conjugates such as

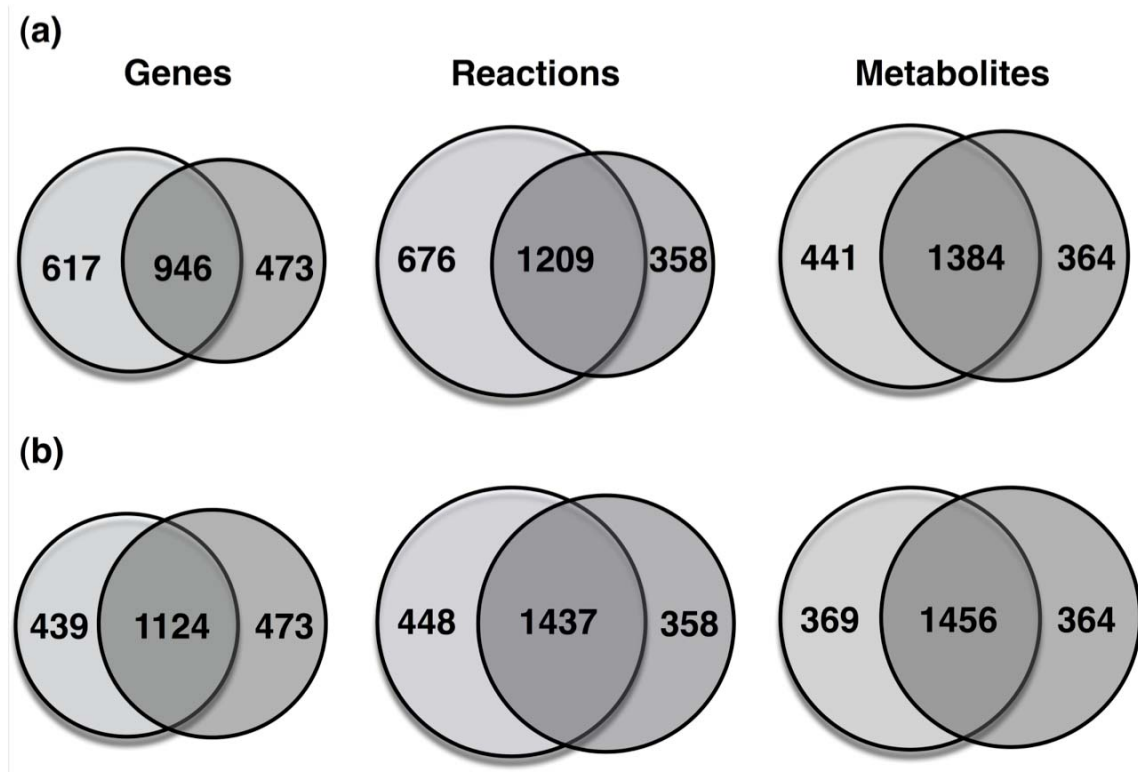
medicarpin 3-O-glucoside-6'-O-malonate (MeGM) and maackain 3-O-glucoside-6'-O-malonate (MaGM) involved in plant defense against fungal elicitation [47].

### 3.2 Comparison between *Zea mays* and *Arabidopsis thaliana* genome scale models

Figure 3-2a compares the total number of genes, reactions and metabolites between *Zea mays* iRS1563 and the *A. thaliana* AraGEM genome-scale-models [12]. Approximately, only 61% of genes in *Zea mays* iRS1563 are present in AraGEM. This yields a surprisingly low degree of matching between these two models of 64% and 76%, respectively in terms of reactions and metabolites. In the interest of elucidating the true differences between maize and *Arabidopsis* irrespective of annotation chronology we constructed a more up-to-date genome-scale model for *Arabidopsis* by appending onto AraGEM newly annotated genes as well as full GPR annotations. We refer to this updated model containing 1,597 genes, 1,798 reactions and 1,820 metabolites as *A. thaliana* iRS1597. The newly added 228 reactions (absent from AraGEM) are involved in various pathways in primary (i.e., glycolysis, TCA, fatty acid and amino acid biosynthesis, starch and sucrose metabolism) and secondary (i.e., biosynthesis of steroid, ubiquinone, streptomycin, thiamin, riboflavin, terpenoid, brassinosteroid, phenylpropanoid, etc.) metabolism of *Arabidopsis*.

A direct comparison of *Zea mays* iRS1563 with *A. thaliana* iRS1597 reveals, as expected, an increased degree of matching of 72%, 76% and 80% in terms of genes, reactions and metabolites, respectively (see Figure 3-2b). We find that 445 reactions are unique to maize with no counterpart in *A. thaliana*. Secondary plant metabolism including flavonoid, mono- and diterpenoid, brassinosteroid, phenylpropanoid, anthocyanin, zeatin biosynthesis,

riboflavin and caffeine metabolism account for 185 of the maize-specific reactions. In addition, a variety of primary metabolism reactions dispersed throughout central metabolism, photosynthesis, amino acid and fatty acid biosynthesis account for the remaining 260 reactions. This comparison implies that about one third of the differences between *Zea mays* iRS1563 and AraGEM are caused by more recent annotation updates while the remaining two third reflect genuine differences between C<sub>3</sub> (i.e., Arabidopsis) and C<sub>4</sub> (i.e., maize) plant metabolism.



**Figure 3-2:** Venn diagram for genes, reactions and metabolites: (a) between *Zea mays* iRS1563 and AraGEM, and (b) between *Zea mays* iRS1563 and *Arabidopsis thaliana* iRS1597.

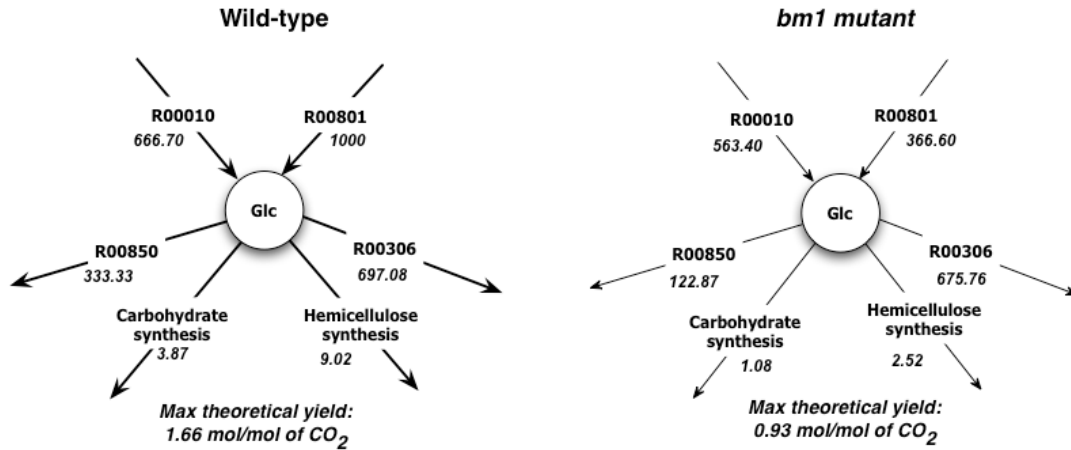
### 3.3 *Zea mays* iRS 1563 model testing

*Zea mays* iRS1563 allows for the production of biomass under all three different physiological states. We investigated the model's ability to predict the effect of suppressing genes in the lignin biosynthesis pathway observed in naturally occurring *brown midrib* (*bm*) maize mutants (i.e., *bm1*, *bm2*, *bm3* and *bm4*) [43, 48-50]. These maize mutants are Mendelian recessives that are characterized by brown vascular tissue in leaves and stems due to a changed lignin content and/or composition [51]. The specific genetic background for two of these mutants (*bm1* and *bm3*) was elucidated based on the analysis of cell wall composition [50]. Mutants *bm1* and *bm3* were found to have disrupted enzymatic activity for cinnamyl alcohol dehydrogenase (CAD) and caffeic acid 3-*O*-methyltransferase (COMT). Both of these enzymes are involved in the last stages of the monolignol pathway [50] that controls lignin synthesis and composition (i.e., the ratio of three major subunits, H-lignin, G-lignin and S-lignin) [52].

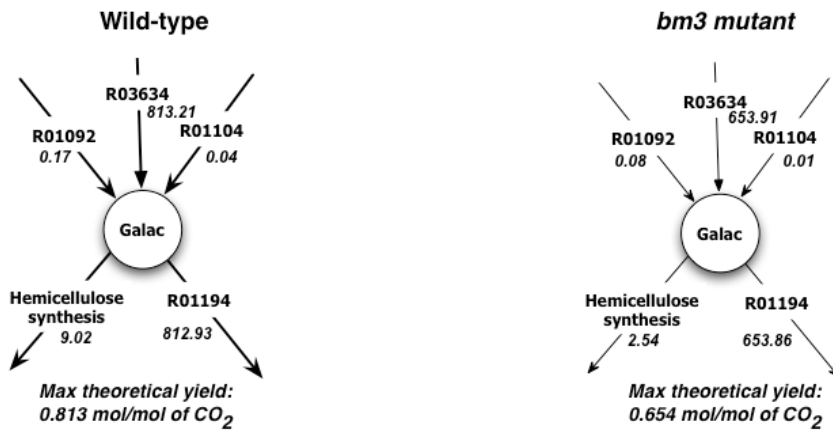
We simulated mutants *bm1* and *bm3* using *Zea mays* iRS1563 under photosynthetic conditions by restricting the flux of the reactions catalyzed by enzymes CAD and COMT to 10% of the wild-type values. It is expected that the disruption of the activity for these genes will directly affect lignin content and composition. We were interested to see whether the *Zea mays* iRS1563 metabolic model will be able to correctly propagate this disruption across the metabolic pathways and correctly predict the effect on other key metabolites. Table 3-1 contrasts experimental results by (Marita et al (2003), Vanholme et al (2008) and Sattler et al (2010)) with *in silico* predictions for the maximum theoretical yield of lignins, sugars and crude protein in terms of whether they increased, decreased, or remained the same in the

mutant strains. Out of 21 compared components *Zea mays* iRS1563 correctly predicted the direction (or absence) of change for 17 cases.

(a)



(b)



**Figure 3-3:** Maximum theoretical yields of (a) glucose and (b) galactose for wild-type vs *bm1* mutant and wild-type vs *bm3* mutant, respectively.



**Table 3-1:** Change in content of cell wall components in *bm1* and *bm3* maize mutants. Cell wall components include lignin subunits, total lignin, S/G ratio, sugars, starch and protein. List of used symbols include ‘↓’: decrease in quantity; ‘↑’: increase in quantity; ‘=’: no change in quantity, with respect to wild Maize plant; ‘/’: comparison of model findings with actual observations, and ‘-’: no experimental observation found.

<b>Model findings vs Experimental observations</b>		
	<b><i>Bm1</i> mutant</b>	<b><i>bm3</i> mutant</b>
H-lignin	↓ / =	↓ / ↓
G-lignin	↓ / ↓	↓ / ↓
S-lignin	↓ / ↓	↓ / ↓
Total lignin	↓ / ↓	↓ / ↓
S/G ratio	= / =	= / =
Glucose	↓ / ↓	↓ / ↑
Mannose	↓ / ↓	↓ / ↓
Arabinose	↓ / ↓	↓ / ↓
Galactose	↓ / ↓	↓ / ↓
Xylose	↓ / ↑	↓ / ↑
Crude protein	-	↓ / ↓

In Figure 3-3 we highlight two cases that describe the availability of glucose and galactose to cell wall for mutants *bm1* and *bm3*, respectively. ‘Carbohydrate synthesis’ and ‘Hemicellulose synthesis’ are aggregate reactions that describe the utilization ratios of sugar molecules such as arabinose, fructose, galactose, glucose ribose, mannose, sucrose, and xylose for the production of carbohydrate and hemicellulose present in the plant cell wall. In Figure 3-3a, wild-type and *bm1* mutant flux values for reactions involving glucose as reactant including ‘Carbohydrate synthesis’, ‘Hemicellulose synthesis’, ‘Alpha,alpha-trehalose glucohydrolase’ [R00010], ‘Sucrose glucohydrolase’ [R00801], ‘Sn-Glycerol-3-phosphate: D-glucose 6-phosphotransferase’ [R00850] and ‘Cellobiose glucohydrolase’ [R00306], are highlighted. For the wild-type case, the maximum theoretical yield of glucose is predicted to be 1.66 moles/mole of CO<sub>2</sub> but it is reduced to 0.93 moles/moles of CO<sub>2</sub> for the *bm1* mutant.

The reduced capability of the *bm1* mutant to direct flux towards ‘Carbohydrate synthesis’ and ‘Hemicellulose synthesis’ implies that less glucose is available for the formation of cell wall components which is consistent with the experimental finding of Table 3-1.

Figure 3-3b contrasts the wild-type and *bm3* mutant maximum theoretical yields for all reactions involving galactose including ‘Hemicellulose synthesis’, ‘ATP: D-galactose 1-phosphotransferase’ [R01092] and ‘Galactosylglycerol galactohydrolase’ [R01104], ‘3-O-alpha-D-Galactosyl-1D-myo-inositol galactohydrolase’ [R01194] and ‘alpha-galactosidase’ [R03634]. A reduction of the maximum theoretical yield of galactose from 0.81 to 0.65 moles/mole of CO<sub>2</sub> for the *bm3* mutant is observed. In addition, the maximum theoretical yield for reaction ‘Hemicellulose synthesis’ decreases by 4-fold compared to wild-type in line with the experimental finding. However, the experimentally observed increase of glucose availability in mutant *bm3* and xylose availability for both *bm1* and *bm3* mutants are in contrast with the model predictions (see Table 3-1). As reported by Guillaumie et al (2007) several gene expression levels were changed during *bm1* and *bm3* mutations implying that additional regulatory constraints may be needed to capture these changes.

## Chapter 4: Conclusions and Future Perspectives

In this work, we introduced the first genome-scale metabolic model *Zea mays* iRS1563 for maize. The model meets the quality and completeness criteria set out [53, 54] for genome-scale reconstructions. 185 of unique maize reactions accounting for a significant fraction of secondary metabolism were delineated. As a by product of this effort a more up-to-date version of AraGEM [12] was constructed including GPR associations. Model predictions of *Zea mays* iRS1563 for two widely occurring maize Mendelian mutants were tested against experimental observations with very good agreement in the direction of changes.

Maize, apart from its central role a food crop, is also a promising plant biomass target for cellulosic biofuels production. Plant cell wall cellulose, hemicellulose and lignin polymers are major contributors of plant biomass [43, 55]. Therefore, controlling the amount and composition of cell wall polymers is important in developing cellulosic maize for biofuel production. In cell wall, lignin provides rigidity by forming a matrix where cellulose and hemicellulose are imbedded via cross-linking bonds [48, 56]. This makes digestion of cellulose and hemicellulose by microbial enzymes (i.e., cellulases) difficult during delignification, one of the critical steps in cellulosic biofuel production [57]. Many genetic modification strategies have been explored to improve maize food crop and/or biofuel characteristics. For example, cellulosic biomass yield improvements have been pursued before by altering the lignin content and composition [58, 59], genetically manipulating the cellulose biosynthetic pathway [60] and over-expressing the gene encoding phosphoenolpyruvate carboxylase (PEPC) to improve CO<sub>2</sub> fixation rate [61]. At the same time, grain yield enhancements have been attempted by up-regulating ADP-glucose

pyrophosphorylase (AGP) that catalyzes the rate limiting step in starch synthesis [62].

Unfortunately, existing genetic engineering strategies to reduce lignin content are problematic as lignin reductions are usually achieved at the expense of plant viability and fitness [57]. It is becoming widely accepted that focusing on a single pathway at a time without quantitatively assessing the system-wide implications of the genetic disruptions may be responsible for not preserving the agronomic properties of the plant. By accounting for both primary and some secondary metabolism pathways of maize, *Zea mays* iRS1563 can be used to explore *in silico* the effect of genetic modifications aimed at plant cell wall modification and/or starch storage on the overall metabolic state of the plant (e.g., biomass precursor availability, cofactor balancing, redox state, etc.). Moving a step further, the use of computational strain optimization techniques [63, 64] can be customized for engineering plant metabolism. By taking full inventory of plant metabolism optimal gene modifications could be pursued for a variety of targets in coordination with experimental techniques. These may include (i) increase cellulose and hemicellulose production, (ii) starch yield, (iii) tolerance against biotic stress (e.g., fungal elicitation), or (iv) disruption of the production of lignin subunits (H/G/S) while enhancing the production of easily digestible lignin precursor (e.g., rosmarinic acid, conferyl ferulate, tyramine conjugates, etc). By making use of high throughput enzymatic assays, proteomic and transcriptomic data across different parts of the maize plant, *Zea mays* iRS1563 could serve as the starting point for the development of tissue-specific maize models [65, 66]. Furthermore, *Zea mays* iRS1563 could also serve as the stepping-stone for the development of genome-scale models for other important C<sub>4</sub> plants such as Sorghum and switch grass.

## Appendix A: Materials and Methods

A number of recent publications [15, 27, 53] have outlined the general steps necessary for the metabolic reconstruction process. In the following section, we highlight the specific methods used in the reconstruction of *Zea mays* iRS1563 and subsequent model simulations in more detail.

### Model reconstruction

The maizesequence database [10] provided the filtered gene set (FGS) which has been generated from the working gene set upon removing pseudogenes and low confidence hypothetical models. The FGS of B73 maize genome (release 4a.53) was downloaded from maizesequence database on Dec 17, 2009. Once maize genes were obtained, we used sequence comparison tools [67] such as stand-alone BLAST (version 2.2.22, NIH) and BLAST+ (version 2.2.22, NIH) for performing homology comparisons. Marvin (version 5.3.3, ChemAxon Kft) was used to calculate the average micro-species charge to determine the net charge of individual metabolites at pH 7.2 assumed for all organelles. In the final step of the model reconstruction, we implemented GapFind and GapFill [20] for analyzing and subsequently restoring metabolic network connectivity.

### Model simulations

Flux balance analysis (FBA) [68] was employed both in model validation and model testing phases. *Zea mays* iRS1563 was evaluated in terms of biomass production under three standard physiological scenarios: photosynthesis, photorespiration, and respiration. Flux distributions for each one of these states were approximated using FBA:

Maximize  $v_{Biomass}$

Subject to

$$\sum_{j=1}^m S_{ij} v_j = 0 \quad \forall i \in 1, \dots, n \quad (1)$$

$$v_{j,min} \leq v_j \leq v_{j,max} \quad \forall j \in 1, \dots, m \quad (2)$$

Here,  $S_{ij}$  is the stoichiometric coefficient of metabolite  $i$  in reaction  $j$  and  $v_j$  is the flux value of reaction  $j$ . Parameters  $v_{j,min}$  and  $v_{j,max}$  denote the minimum and maximum allowable fluxes for reaction  $j$ , respectively. As mentioned in Table 2-4, the three physiological states were represented via modifying the relevant minimum or maximum allowable fluxes and the following constraints:

$$v_{oxi} = 0 \quad (3)$$

$$v_{carboxi} \geq 3v_{oxi} \quad (4)$$

$$v_{carboxi} = 0 \quad (5)$$

where  $v_{Biomass}$  is the flux of biomass reaction and  $v_{oxi}$  and  $v_{carboxi}$  are the fluxes of carboxylation and oxidation reactions associated with enzyme RUBISCO. For photosynthesis and photorespiration, constraints (3) and (4) were respectively included in the linear model, whereas for respiration both constraints (3) and (5) were included.

Once the model was validated, it was further tested for two maize mutants (i.e., *bm1* and *bm3*) under the photosynthetic condition. The following two constraints were included individually in the linear model to represent the mutants:

$$v_{bm1} \leq w \times WF_{bm1} \quad (6)$$

$$v_{bm3} \leq w \times WF_{bm3} \quad (7)$$

Here,  $w$  represents the percent of residual activity of 10%.  $v_{bm1}$  and  $v_{bm3}$  are the fluxes of reactions catalyzed by CAD and COMT, respectively and  $WF_{bm1}$  and  $WF_{bm3}$  are the corresponding wild-type flux values under the photosynthetic condition.

CPLEX solver (version 12.1, IBM ILOG) was used in the GAMS (version 23.3.3, GAMS Development Corporation) environment for implementing GapFind and GapFill [20] and solving the aforementioned optimization models. All computations were carried out on Intel Xeon E5450 Quad-Core 3.0 GH and Intel Xeon E5472 Quad-Core 3.0 GH processors that are the part of the lionxj cluster (Intel Xeon E type processors and 96 GB memory) of High Performance Computing Group of The Pennsylvania State University.

## Appendix B: List of reactions of *Zea mays* iRS 1563

### Reaction ID Reaction Description

R00004[c]	[c]: Pyrophosphate + H <sub>2</sub> O --> 2 Orthophosphate
R00006[c]	[c]: 2 Pyruvate --> 2-Acetolactate + CO <sub>2</sub>
R00009[x]	[x]: 2 H <sub>2</sub> O <sub>2</sub> --> Oxygen + 2 H <sub>2</sub> O
R00010[c]	[c]: alpha,alpha-Trehalose + H <sub>2</sub> O --> 2 D-Glucose
R00014[c]	[c]: Thiamin diphosphate + Pyruvate --> 2-(alpha-Hydroxyethyl)thiamine diphosphate + CO <sub>2</sub>
R00021[p]	[p]: 10 L-Glutamine + 10 2-Oxoglutarate + 7 2 Reduced ferredoxin --> 20 L-Glutamate + 7 Oxidized ferredoxin
R00022[c]	[c]: Chitobiose + H <sub>2</sub> O --> 2 N-Acetyl-D-glucosamine
R00024[p]	[p]: D-Ribulose 1,5-bisphosphate + CO <sub>2</sub> + H <sub>2</sub> O --> 2 3-Phospho-D-glycerate
R00026[c]	[c]: Cellobiose + H <sub>2</sub> O --> 2 beta-D-Glucose
R00028[c]	[c]: Maltose + H <sub>2</sub> O --> 2 alpha-D-Glucose
R00028[p]	[p]: Maltose + H <sub>2</sub> O --> 2 alpha-D-Glucose
R00036[c]	[c]: 2 5-Aminolevulinate --> Porphobilinogen + 2 H <sub>2</sub> O
R00047[c]	[c]: Oxygen + 2 6-Hydroxynicotinate --> 2 2,5-Dihydroxypyridine + 2 CO <sub>2</sub>
R00066[c]	[c]: 2 6,7-Dimethyl-8-(1-D-ribityl)lumazine --> Riboflavin + 5-Amino-6-(1-D-ribitylamino)uracil
R00068[c]	[c]: Oxygen + 2 Ascorbate --> 2 L-Dehydroascorbate + 2 H <sub>2</sub> O
R00084[c]	[c]: 4 Porphobilinogen + H <sub>2</sub> O --> Hydroxymethylbilane + 4 NH <sub>3</sub>
R00086[c]	[c]: ATP + H <sub>2</sub> O <=> ADP + Orthophosphate
R00095[c]	[c]: NAD <sup>+</sup> + 2 Ascorbate <=> NADH + 2 Monodehydroascorbate + H <sup>+</sup>
R00100[c]	[c]: NADH + 2 Ferricytochrome b <sub>5</sub> + H <sup>+</sup> --> NAD <sup>+</sup> + 2 Ferrocyclochrome b <sub>5</sub>
R00115[c]	[c]: NADP <sup>+</sup> + 2 Glutathione <=> Oxidized glutathione + NADPH + H <sup>+</sup>
R00122[c]	[c]: ADP + H <sub>2</sub> O --> AMP + Orthophosphate
R00124[c]	[c]: ATP + ADP <=> ADP + ATP
R00124[p]	[p]: ATP + ADP <=> ADP + ATP
R00127[c]	[c]: ATP + AMP <=> 2 ADP
R00127[p]	[p]: ATP + AMP <=> 2 ADP
R00130[c]	[c]: ATP + Dephospho-CoA --> ADP + CoA
R00131[c]	[c]: 2 Urea + 2 H <sub>2</sub> O --> 2 CO <sub>2</sub> + 3 NH <sub>3</sub>
R00132[c]	[c]: H <sub>2</sub> O + CO <sub>2</sub> --> H <sup>+</sup> + HCO <sub>3</sub> <sup>-</sup>
R00132[m]	[m]: H <sub>2</sub> O + CO <sub>2</sub> --> H <sup>+</sup> + HCO <sub>3</sub> <sup>-</sup>
R00132[p]	[p]: H <sub>2</sub> O + CO <sub>2</sub> --> H <sup>+</sup> + HCO <sub>3</sub> <sup>-</sup>
R00149[c]	[c]: 2 ATP + NH <sub>3</sub> + CO <sub>2</sub> + H <sub>2</sub> O <=> 2 ADP + Orthophosphate + Carbamoyl phosphate
R00149[p]	[p]: 2 ATP + NH <sub>3</sub> + CO <sub>2</sub> + H <sub>2</sub> O <=> 2 ADP + Orthophosphate + Carbamoyl phosphate
R00156[c]	[c]: ATP + UDP <=> ADP + UTP
R00156[p]	[p]: ATP + UDP <=> ADP + UTP
R00158[c]	[c]: ATP + UMP <=> ADP + UDP
R00174[c]	[c]: ATP + Pyridoxal --> ADP + Pyridoxal phosphate
R00177[c]	[c]: ATP + L-Methionine + H <sub>2</sub> O --> Orthophosphate + Pyrophosphate + S-Adenosyl-L-methionine
R00178[c]	[c]: S-Adenosyl-L-methionine --> S-Adosylmethioninamine + CO <sub>2</sub>
R00179[c]	[c]: S-Adenosyl-L-methionine --> 1-Aminocyclopropane-1-carboxylate + 5'-Methylthioadenosine
R00183[c]	[c]: AMP + H <sub>2</sub> O --> Adenosine + Orthophosphate
R00187[c]	[c]: P <sub>1</sub> ,P <sub>3</sub> -Bis(5'-adenosyl) triphosphate + H <sub>2</sub> O --> ADP + AMP



R00190[c] [c]:AMP + Pyrophosphate <=> Adenine + 5-Phospho-alpha-D-ribose 1-diphosphate  
R00192[c] [c]: S-Adenosyl-L-homocysteine + H2O --> Adenosine + L-Homocysteine  
R00200[c] [c]: ADP + Phosphoenolpyruvate --> ATP + Pyruvate  
R00200[p] [p]: ADP + Phosphoenolpyruvate --> ATP + Pyruvate  
R00206[p] [p]: ATP + Pyruvate + Orthophosphate --> AMP + Phosphoenolpyruvate + Pyrophosphate  
R00209[m] [m]: Pyruvate + CoA + NAD+ --> Acetyl-CoA + CO2 + NADH  
R00209[p] [p]: Pyruvate + CoA + NAD+ --> Acetyl-CoA + CO2 + NADH  
R00216[c] [c]: (S)-Malate + NADP+ --> Pyruvate + CO2 + NADPH  
R00216[p] [p]: (S)-Malate + NADP+ --> Pyruvate + CO2 + NADPH  
R00219[c] [c]: 2-Hydroxyethylenedicarboxylate --> Pyruvate + CO2  
R00236[c] [c]:Acetyl adenylate + CoA <=> AMP + Acetyl-CoA  
R00236[m] [m]:Acetyl adenylate + CoA <=> AMP + Acetyl-CoA  
R00238[c] [c]: 2 Acetyl-CoA <=> CoA + Acetoacetyl-CoA  
R00238[m] [m]: 2 Acetyl-CoA <=> CoA + Acetoacetyl-CoA  
R00238[p] [p]: 2 Acetyl-CoA <=> CoA + Acetoacetyl-CoA  
R00238[x] [x]: 2 Acetyl-CoA <=> CoA + Acetoacetyl-CoA  
R00239[c] [c]: ATP + L-Glutamate --> ADP + L-Glutamyl 5-phosphate  
R00239[p] [p]: ATP + L-Glutamate --> ADP + L-Glutamyl 5-phosphate  
R00243[c] [c]:L-Glutamate + NAD+ + H2O <=> 2-Oxoglutarate + NH3 + NADH + H+  
R00243[m] [m]:L-Glutamate + NAD+ + H2O <=> 2-Oxoglutarate + NH3 + NADH + H+  
R00245[c] [c]:L-Glutamate 5-semialdehyde + NAD+ + H2O <=> L-Glutamate + NADH + H+  
R00251[c] [c]: ATP + 5-Oxoproline + 2 H2O --> ADP + Orthophosphate + L-Glutamate  
R00253[c] [c]:ATP + L-Glutamate + NH3 <=> ADP + Orthophosphate + L-Glutamine  
R00253[m] [m]:ATP + L-Glutamate + NH3 <=> ADP + Orthophosphate + L-Glutamine  
R00253[p] [p]:ATP + L-Glutamate + NH3 <=> ADP + Orthophosphate + L-Glutamine  
R00257[c] [c]: ATP + Deamino-NAD+ + L-Glutamine + H2O --> AMP + Pyrophosphate + NAD+ + L-Glutamate  
R00258[c] [c]:L-Alanine + 2-Oxoglutarate <=> Pyruvate + L-Glutamate  
R00258[p] [p]:L-Alanine + 2-Oxoglutarate <=> Pyruvate + L-Glutamate  
R00259[c] [c]: Acetyl-CoA + L-Glutamate --> CoA + N-Acetyl-L-glutamate  
R00261[c] [c]: L-Glutamate --> 4-Aminobutanoate + CO2  
R00267[c] [c]:Isocitrate + NADP+ <=> 2-Oxoglutarate + CO2 + NADPH + H+  
R00267[m] [m]:Isocitrate + NADP+ <=> 2-Oxoglutarate + CO2 + NADPH + H+  
R00267[x] [x]:Isocitrate + NADP+ <=> 2-Oxoglutarate + CO2 + NADPH + H+  
R00286[c] [c]: UDP-glucose + H2O + 2 NAD+ --> UDP-glucuronate + 2 NADH + H+  
R00289[c] [c]: UTP + D-Glucose 1-phosphate --> Pyrophosphate + UDP-glucose  
R00291[c] [c]:UDP-glucose <=> UDP-D-galactose  
R00308[c] [c]: 1,3-beta-D-Glucan + H2O --> D-Glucose + 1,3-beta-D-Glucan  
R00310[c] [c]: Protoporphyrin + Fe2+ --> Heme + 2 H+  
R00316[m] [m]:ATP + Acetate <=> Pyrophosphate + Acetyl adenylate  
R00328[c] [c]: GDP + H2O --> GMP + Orthophosphate  
R00330[c] [c]:ATP + GDP <=> ADP + GTP  
R00335[c] [c]: GTP + H2O --> GDP + Orthophosphate  
R00341[c] [c]: ATP + Oxaloacetate --> ADP + Phosphoenolpyruvate + CO2  
R00342[c] [c]:(S)-Malate + NAD+ <=> Oxaloacetate + NADH + H+  
R00342[m] [m]:(S)-Malate + NAD+ <=> Oxaloacetate + NADH + H+  
R00342[p] [p]:(S)-Malate + NAD+ <=> Oxaloacetate + NADH + H+  
R00342[x] [x]:(S)-Malate + NAD+ <=> Oxaloacetate + NADH + H+  
R00345[c] [c]:Orthophosphate + Oxaloacetate <=> H2O + Phosphoenolpyruvate + CO2  
R00352[c] [c]: ATP + Citrate + CoA --> ADP + Orthophosphate + Acetyl-CoA + Oxaloacetate  
R00355[c] [c]:L-Aspartate + 2-Oxoglutarate <=> Oxaloacetate + L-Glutamate  
R00355[m] [m]:L-Aspartate + 2-Oxoglutarate <=> Oxaloacetate + L-Glutamate  
R00355[p] [p]:L-Aspartate + 2-Oxoglutarate <=> Oxaloacetate + L-Glutamate  
R00369[c] [c]:L-Alanine + Glyoxylate <=> Pyruvate + Glycine  
R00405[m] [m]:ATP + Succinate + CoA <=> ADP + Orthophosphate + Succinyl-CoA  
R00415[c] [c]:UTP + N-Acetyl-D-glucosamine 1-phosphate <=> Pyrophosphate + UDP-N-acetyl-D-

glucosamine  
R00416[c] [c]:UTP + N-Acetyl-alpha-D-glucosamine 1-phosphate <=> Pyrophosphate + UDP-N-acetyl-D-glucosamine  
R00425[c] [c]: GTP + 3 H2O --> Formate + 2,5-Diamino-6-hydroxy-4-(5'-phosphoribosylamino)pyrimidine + Pyrophosphate  
R00426[c] [c]: GTP + H2O --> GMP + Pyrophosphate  
R00428[c] [c]: GTP + H2O --> Formamidopyrimidine nucleoside triphosphate  
R00430[c] [c]:GTP + Pyruvate <=> GDP + Phosphoenolpyruvate  
R00451[c] [c]: meso-2,6-Diaminoheptanedioate --> L-Lysine + CO2  
R00472[x] [x]:Acetyl-CoA + H2O + Glyoxylate <=> (S)-Malate + CoA  
R00475[x] [x]: Glycolate + Oxygen --> Glyoxylate + H2O2  
R00479[x] [x]: Isocitrate --> Succinate + Glyoxylate  
R00480[c] [c]:ATP + L-Aspartate <=> ADP + 4-Phospho-L-aspartate  
R00481[c] [c]: L-Aspartate + Oxygen --> Iminoaspartate + H2O2  
R00494[c] [c]: Glutathione + H2O --> Cys-Gly + L-Glutamate  
R00497[c] [c]: ATP + gamma-L-Glutamyl-L-cysteine + Glycine --> ADP + Orthophosphate + Glutathione  
R00502[c] [c]:UTP + alpha-D-Galactose 1-phosphate <=> Pyrophosphate + UDP-D-galactose  
R00508[c] [c]: 3'-Phosphoadenylyl sulfate + H2O --> Adenylyl sulfate + Orthophosphate  
R00509[c] [c]:ATP + Adenylyl sulfate <=> ADP + 3'-Phosphoadenylyl sulfate  
R00511[c] [c]: CMP + H2O --> Cytidine + Orthophosphate  
R00512[c] [c]:ATP + CMP <=> ADP + CDP  
R00519[x] [x]:Formate + NAD+ <=> H+ + CO2 + NADH  
R00529[c] [c]: ATP + Sulfate --> Pyrophosphate + Adenylyl sulfate  
R00548[c] [c]: FMN + H2O --> Riboflavin + Orthophosphate  
R00549[c] [c]: ATP + Riboflavin --> ADP + FMN  
R00551[c] [c]:L-Arginine + H2O <=> L-Ornithine + Urea  
R00566[c] [c]: L-Arginine --> Agmatine + CO2  
R00570[c] [c]:ATP + CDP <=> ADP + CTP  
R00571[c] [c]: ATP + UTP + NH3 --> ADP + Orthophosphate + CTP  
R00573[c] [c]: ATP + UTP + L-Glutamine + H2O --> ADP + Orthophosphate + CTP + L-Glutamate  
R00575[c] [c]:2 ATP + L-Glutamine + HCO3- + H2O --> 2 ADP + Orthophosphate + L-Glutamate + Carbamoyl phosphate  
R00575[m] [m]:2 ATP + L-Glutamine + HCO3- + H2O --> 2 ADP + Orthophosphate + L-Glutamate + Carbamoyl phosphate  
R00578[c] [c]: ATP + L-Aspartate + L-Glutamine + H2O --> AMP + Pyrophosphate + L-Asparagine + L-Glutamate  
R00582[c] [c]: O-Phospho-L-serine + H2O --> L-Serine + Orthophosphate  
R00586[c] [c]: L-Serine + Acetyl-CoA --> O-Acetyl-L-serine + CoA  
R00588[x] [x]: L-Serine + Glyoxylate --> Hydroxypyruvate + Glycine  
R00602[c] [c]: Methanol + H2O2 --> Formaldehyde + 2 H2O  
R00610[c] [c]: Sarcosine + H2O + Oxygen --> Glycine + Formaldehyde + H2O2  
R00615[c] [c]: Thiamin diphosphate + H2O --> Thiamin monophosphate + Orthophosphate  
R00621[m] [m]: 2-Oxoglutarate + Thiamin diphosphate --> 3-Carboxy-1-hydroxypropyl-ThPP + CO2  
R00631[c] [c]: Fatty acid + NADH --> Aldehyde + NAD+ + H2O  
R00640[c] [c]: L-Galactono-1,4-lactone + 2 Ferricytochrome c --> Ascorbate + 2 Ferrocycytochrome c  
R00645[c] [c]:Ascorbate <=> Monodehydroascorbate + H+  
R00650[c] [c]: S-Adenosyl-L-methionine + L-Homocysteine --> S-Adenosyl-L-homocysteine + L-Methionine  
R00658[c] [c]:2-Phospho-D-glycerate <=> Phosphoenolpyruvate + H2O  
R00658[p] [p]:2-Phospho-D-glycerate <=> Phosphoenolpyruvate + H2O  
R00662[c] [c]: UTP + H2O --> UMP + Pyrophosphate  
R00669[c] [c]: N-Acetylornithine + H2O --> Acetate + L-Ornithine  
R00694[c] [c]:L-Phenylalanine + 2-Oxoglutarate <=> Phenylpyruvate + L-Glutamate  
R00697[c] [c]:L-Phenylalanine <=> trans-Cinnamate + NH3  
R00698[c] [c]: L-Phenylalanine --> 2-Phenylacetamide

R00702[c] [c]:2 trans,trans-Farnesyl diphosphate --> Pyrophosphate + Presqualene diphosphate + H+  
R00703[c] [c]:(S)-Lactate + NAD+ <==> Pyruvate + NADH + H+  
R00714[c] [c]:Succinate semialdehyde + NADP+ + H2O <==> Succinate + NADPH + H+  
R00715[c] [c]:N6-(L-1,3-Dicarboxypropyl)-L-lysine + NAD+ + H2O <==> L-Lysine + 2-Oxoglutarate + NADH + H+  
R00716[c] [c]:N6-(L-1,3-Dicarboxypropyl)-L-lysine + NADP+ + H2O <==> L-Lysine + 2-Oxoglutarate + NADPH + H+  
R00719[c] [c]:ITP + H2O --> IDP + Orthophosphate  
R00720[c] [c]:ITP + H2O --> IMP + Pyrophosphate  
R00722[c] [c]:ATP + IDP <==> ADP + ITP  
R00742[c] [c]:ATP + Acetyl-CoA + HCO3- --> ADP + Orthophosphate + Malonyl-CoA  
R00742[p] [p]:ATP + Acetyl-CoA + HCO3- --> ADP + Orthophosphate + Malonyl-CoA  
R00755[c] [c]: 2-(alpha-Hydroxyethyl)thiamine diphosphate --> Acetaldehyde + Thiamin diphosphate  
R00762[c] [c]: D-Fructose 1,6-bisphosphate + H2O --> D-Fructose 6-phosphate + Orthophosphate  
R00762[p] [p]: D-Fructose 1,6-bisphosphate + H2O --> D-Fructose 6-phosphate + Orthophosphate  
R00766[c] [c]: UDP-glucose + beta-D-Fructose 6-phosphate --> UDP + Sucrose 6-phosphate  
R00790[c] [c]: Nitrite + 6 Reduced ferredoxin + 7 H+ --> NH3 + 2 H2O + 6 Oxidized ferredoxin  
R00790[p] [p]: Nitrite + 6 Reduced ferredoxin + 7 H+ --> NH3 + 2 H2O + 6 Oxidized ferredoxin  
R00801[c] [c]: Sucrose + H2O --> D-Fructose + D-Glucose  
R00806[c] [c]:UDP-glucose + D-Fructose <==> UDP + Sucrose  
R00840[c] [c]:Inositol 1-phosphate <==> D-Glucose 6-phosphate  
R00847[c] [c]: ATP + Glycerol --> ADP + sn-Glycerol 3-phosphate  
R00848[c] [c]:sn-Glycerol 3-phosphate + FAD <==> Glycerone phosphate + FADH2  
R00859[c] [c]: Sulfite + 3 Reduced ferredoxin --> Hydrogen sulfide + 3 Oxidized ferredoxin + 3 H2O  
R00867[c] [c]: ATP + D-Fructose --> ADP + beta-D-Fructose 6-phosphate  
R00878[c] [c]:alpha-D-Glucose <==> D-Fructose  
R00883[c] [c]:GDP + D-Mannose 1-phosphate <==> Orthophosphate + GDP-mannose  
R00887[c] [c]: GDP-mannose --> GDP + Mannan  
R00888[c] [c]: GDP-mannose --> GDP-4-dehydro-6-deoxy-D-mannose + H2O  
R00889[c] [c]:GDP-mannose <==> GDP-L-galactose  
R00890[c] [c]: GDP-mannose + 1,4-beta-D-Mannan --> GDP + 1,4-beta-D-Mannan  
R00896[c] [c]: Mercaptopyruvate + Glutamate --> L-Cysteine + 2-Oxoglutarate  
R00899[c] [c]: Cys-Gly + H2O --> L-Cysteine + Glycine  
R00904[c] [c]: beta-Aminopropion aldehyde + NAD+ + H2O --> beta-Alanine + NADH  
R00905[c] [c]:3-Ureidopropionate + H2O <==> beta-Alanine + CO2 + NH3  
R00919[c] [c]:Propanoyl-CoA + NADP+ <==> Propenoyl-CoA + NADPH  
R00924[c] [c]:Propanoyl-CoA + FAD <==> FADH2 + Propenoyl-CoA  
R00927[c] [c]: CoA + 2-Methylacetoacetyl-CoA --> Propanoyl-CoA + Acetyl-CoA  
R00935[c] [c]: (S)-Methylmalonate semialdehyde + CoA + NAD+ --> Propanoyl-CoA + CO2 + NADH + H+  
R00936[c] [c]: Dihydrofolate + NADH + H+ --> Tetrahydrofolate + NAD+  
R00937[c] [c]: Folate + NADH --> Tetrahydrofolate + NAD+  
R00939[c] [c]:Tetrahydrofolate + NADP+ <==> Dihydrofolate + NADPH + H+  
R00940[c] [c]: Folate + NADPH --> Tetrahydrofolate + NADP+  
R00943[c] [c]:Tetrahydrofolate + Formate + ATP <==> ADP + Orthophosphate + 10-Formyltetrahydrofolate  
R00944[c] [c]: 10-Formyltetrahydrofolate + H2O --> Formate + Tetrahydrofolate  
R00945[c] [c]:5,10-Methylenetetrahydrofolate + Glycine + H2O <==> Tetrahydrofolate + L-Serine  
R00945[m] [m]:5,10-Methylenetetrahydrofolate + Glycine + H2O <==> Tetrahydrofolate + L-Serine  
R00948[c] [c]:ATP + D-Glucose 1-phosphate <==> Pyrophosphate + ADP-glucose  
R00948[p] [p]:ATP + D-Glucose 1-phosphate <==> Pyrophosphate + ADP-glucose  
R00961[c] [c]: IDP + H2O --> IMP + Orthophosphate  
R00963[c] [c]: UMP + H2O --> Uridine + Orthophosphate  
R00965[c] [c]: Orotidine 5'-phosphate --> UMP + CO2  
R00966[c] [c]:UMP + Pyrophosphate <==> Uracil + 5-Phospho-alpha-D-ribose 1-diphosphate  
R00985[c] [c]: Chorismate + NH3 --> Anthranilate + Pyruvate + H2O

R00986[c] [c]: Chorismate + L-Glutamine --> Anthranilate + Pyruvate + L-Glutamate  
R00994[c] [c]: 2-Oxobutanoate + CO2 + NADH + H+ <=> D-erythro-3-Methylmalate + NAD+  
R00996[c] [c]: L-Threonine --> 2-Oxobutanoate + NH3  
R00999[c] [c]: O-Succinyl-L-homoserine + H2O <=> 2-Oxobutanoate + Succinate + NH3  
R01000[c] [c]: 2-Hydroxybutanoic acid + NAD+ --> 2-Oxobutanoate + NADH + H+  
R01004[c] [c]: Dolichyl diphosphate + H2O --> Dolichyl phosphate + Orthophosphate  
R01005[c] [c]: UDP-glucose + Dolichyl phosphate <=> UDP + Dolichyl beta-D-glucosyl phosphate  
R01015[c] [c]: (2R)-2-Hydroxy-3-(phosphonoxy)-propanal <=> Glycerone phosphate  
R01015[p] [p]: (2R)-2-Hydroxy-3-(phosphonoxy)-propanal <=> Glycerone phosphate  
R01049[c] [c]: ATP + D-Ribose 5-phosphate <=> AMP + 5-Phospho-alpha-D-ribose 1-diphosphate  
R01051[c] [c]: ATP + D-Ribose <=> ADP + D-Ribose 5-phosphate  
R01054[c] [c]: ADP-ribose + H2O --> AMP + D-Ribose 5-phosphate  
R01056[c] [c]: D-Ribose 5-phosphate <=> D-Ribulose 5-phosphate  
R01056[p] [p]: D-Ribose 5-phosphate <=> D-Ribulose 5-phosphate  
R01061[c] [c]: (2R)-2-Hydroxy-3-(phosphonoxy)-propanal + Orthophosphate + NAD+ <=> 3-Phospho-D-glyceroyl phosphate + NADH + H+  
R01061[p] [p]: (2R)-2-Hydroxy-3-(phosphonoxy)-propanal + Orthophosphate + NAD+ <=> 3-Phospho-D-glyceroyl phosphate + NADH + H+  
R01068[p] [p]: Glycerone phosphate + (2R)-2-Hydroxy-3-(phosphonoxy)-propanal --> D-Fructose 1,6-bisphosphate  
R01070[c] [c]: beta-D-Fructose 1,6-bisphosphate <=> Glycerone phosphate + (2R)-2-Hydroxy-3-(phosphonoxy)-propanal  
R01070[p] [p]: beta-D-Fructose 1,6-bisphosphate <=> Glycerone phosphate + (2R)-2-Hydroxy-3-(phosphonoxy)-propanal  
R01071[c] [c]: ATP + 5-Phospho-alpha-D-ribose 1-diphosphate --> Phosphoribosyl-ATP + Pyrophosphate  
R01072[c] [c]: L-Glutamine + 5-Phospho-alpha-D-ribose 1-diphosphate + H2O --> 5-Phosphoribosylamine + Pyrophosphate + L-Glutamate  
R01073[c] [c]: N-(5-Phospho-D-ribosyl)anthranilate + Pyrophosphate <=> Anthranilate + 5-Phospho-alpha-D-ribose 1-diphosphate  
R01078[c] [c]: Dethiobiotin + Sulfur --> Biotin  
R01082[m] [m]: (S)-Malate <=> Fumarate + H2O  
R01083[c] [c]: N6-(1,2-Dicarboxyethyl)-AMP <=> Fumarate + AMP  
R01086[c] [c]: N-(L-Arginino)succinate <=> Fumarate + L-Arginine  
R01092[c] [c]: ATP + D-Galactose <=> ADP + alpha-D-Galactose 1-phosphate  
R01101[c] [c]: Melibiose + H2O --> D-Galactose + D-Glucose  
R01103[c] [c]: Raffinose + H2O --> D-Galactose + Sucrose  
R01104[c] [c]: 3-beta-D-Galactosyl-sn-glycerol + H2O <=> D-Galactose + Glycerol  
R01105[c] [c]: Galactan + H2O --> D-Galactose + Galactan  
R01121[c] [c]: ATP + (R)-5-Diphosphomevalonate --> ADP + Orthophosphate + Isopentenyl diphosphate + CO2  
R01123[c] [c]: Isopentenyl diphosphate <=> Dimethylallyl diphosphate  
R01126[c] [c]: IMP + H2O --> Inosine + Orthophosphate  
R01127[c] [c]: IMP + H2O <=> 1-(5'-Phosphoribosyl)-5-formamido-4-imidazolecarboxamide  
R01130[c] [c]: IMP + NAD+ + H2O <=> Xanthosine 5'-phosphate + NADH + H+  
R01132[c] [c]: IMP + Pyrophosphate <=> Hypoxanthine + 5-Phospho-alpha-D-ribose 1-diphosphate  
R01135[c] [c]: GTP + IMP + L-Aspartate <=> GDP + Orthophosphate + N6-(1,2-Dicarboxyethyl)-AMP  
R01137[c] [c]: ATP + dADP <=> ADP + dATP  
R01138[c] [c]: dATP + Pyruvate <=> dADP + Phosphoenolpyruvate  
R01159[c] [c]: L-Histidine + S-Adenosyl-L-methionine --> N(pi)-Methyl-L-histidine + S-Adenosyl-L-homocysteine  
R01167[c] [c]: L-Histidine --> 1H-Imidazole-4-ethanamine + CO2  
R01175[x] [x]: Butanoyl-CoA + Oxygen --> H2O2 + Crotonoyl-CoA  
R01177[x] [x]: Acetyl-CoA + Butanoyl-CoA <=> CoA + 3-Oxohexanoyl-CoA  
R01184[c] [c]: myo-Inositol + Oxygen --> D-Glucuronate + H2O

R01185[c] [c]:Inositol 1-phosphate + H2O <=> myo-Inositol + Orthophosphate  
R01186[c] [c]: myo-Inositol 4-phosphate + H2O --> myo-Inositol + Orthophosphate  
R01187[c] [c]: 1D-myo-Inositol 3-phosphate + H2O --> myo-Inositol + Orthophosphate  
R01194[c] [c]:1-alpha-D-Galactosyl-myo-inositol + H2O <=> myo-Inositol + D-Galactose  
R01195[p] [p]:3 Reduced ferredoxin + 5 NADP+ + 5 H+ <=> 3 Oxidized ferredoxin + 5 NADPH  
R01209[c] [c]: 2,3-Dihydroxy-3-methylbutanoate --> 3-Methyl-2-oxobutanoic acid + H2O  
R01213[c] [c]: Acetyl-CoA + 3-Methyl-2-oxobutanoic acid + H2O --> (2S)-2-Isopropylmalate + CoA  
R01220[c] [c]:5,10-Methylenetetrahydrofolate + NADP+ <=> 5,10-Methenyltetrahydrofolate + NADPH + H+  
R01221[c] [c]:Glycine + Tetrahydrofolate + NAD+ <=> 5,10-Methylenetetrahydrofolate + NH3 + CO2 + NADH + H+  
R01221[m] [m]:Glycine + Tetrahydrofolate + NAD+ <=> 5,10-Methylenetetrahydrofolate + NH3 + CO2 + NADH + H+  
R01222[c] [c]:5,10-Methylenetetrahydrofolate + FADH2 <=> 5-Methyltetrahydrofolate + FAD  
R01224[c] [c]: 5,10-Methylenetetrahydrofolate + NADPH + H+ --> 5-Methyltetrahydrofolate + NADP+  
R01227[c] [c]: GMP + H2O --> Guanosine + Orthophosphate  
R01230[c] [c]: ATP + Xanthosine 5'-phosphate + NH3 --> AMP + Pyrophosphate + GMP  
R01231[c] [c]: ATP + Xanthosine 5'-phosphate + L-Glutamine + H2O --> AMP + Pyrophosphate + GMP + L-Glutamate  
R01248[c] [c]:L-Proline + NAD+ <=> (S)-1-Pyrroline-5-carboxylate + NADH + H+  
R01251[c] [c]:L-Proline + NADP+ <=> (S)-1-Pyrroline-5-carboxylate + NADPH + H+  
R01252[c] [c]: L-Proline + 2-Oxoglutarate + Oxygen --> trans-4-Hydroxy-L-proline + Succinate + CO2  
R01262[c] [c]: Glutathione + L-Amino acid --> Cys-Gly + (5-L-Glutamyl)-L-amino acid  
R01279[x] [x]: Palmitoyl-CoA + Oxygen --> trans-Hexadec-2-enoyl-CoA + H2O2  
R01280[x] [x]:ATP + Hexadecanoic acid + CoA <=> AMP + Palmitoyl-CoA + Pyrophosphate  
R01281[c] [c]: Palmitoyl-CoA + L-Serine --> 3-Dehydrosphinganine + CoA + CO2  
R01286[c] [c]: L-Cystathionine + H2O --> L-Homocysteine + NH3 + Pyruvate  
R01288[c] [c]:O-Succinyl-L-homoserine + Sulfide <=> L-Homocysteine + Succinate  
R01303[c] [c]: 4-Hydroxybenzoate + Acceptor + H2O --> 4-Hydroxybenzaldehyde + Reduced acceptor + Oxygen  
R01310[c] [c]: Phosphatidylcholine + H2O --> Phosphatidate + Choline  
R01324[c] [c]:Citrate <=> Isocitrate  
R01324[m] [m]:Citrate <=> Isocitrate  
R01329[c] [c]:Epimelibiose + H2O <=> D-Mannose + D-Galactose  
R01360[c] [c]:(S)-3-Hydroxy-3-methylglutaryl-CoA <=> Acetyl-CoA + Acetoacetate  
R01364[c] [c]:Acetoacetate + Fumarate <=> 4-Fumarylacetoacetate + H2O  
R01372[c] [c]: Phenylpyruvate + Oxygen --> 2-Hydroxyphenylacetate + CO2  
R01397[c] [c]: Carbamoyl phosphate + L-Aspartate --> Orthophosphate + N-Carbamoyl-L-aspartate  
R01398[c] [c]:Carbamoyl phosphate + L-Ornithine <=> Orthophosphate + L-Citrulline  
R01398[m] [m]:Carbamoyl phosphate + L-Ornithine <=> Orthophosphate + L-Citrulline  
R01398[p] [p]:Carbamoyl phosphate + L-Ornithine <=> Orthophosphate + L-Citrulline  
R01409[c] [c]: Cyanohydrin --> Cyanide + Aldehyde  
R01432[c] [c]:D-Xylose <=> D-Xylulose  
R01451[c] [c]: Cholesta-5,7-dien-3beta-ol + NADH + H+ --> Cholesterol + NAD+  
R01456[c] [c]: Cholesta-5,7-dien-3beta-ol + NADPH + H+ --> Cholesterol + NADP+  
R01457[c] [c]: Desmosterol + H+ + NADPH --> Cholesterol + NADP+  
R01466[c] [c]: O-Phospho-L-homoserine + H2O --> L-Threonine + Orthophosphate  
R01512[c] [c]:ATP + 3-Phospho-D-glycerate <=> ADP + 3-Phospho-D-glyceroyl phosphate  
R01512[p] [p]:ATP + 3-Phospho-D-glycerate <=> ADP + 3-Phospho-D-glyceroyl phosphate  
R01513[c] [c]:3-Phospho-D-glycerate + NAD+ <=> 3-Phosphonoxyypyruvate + NADH + H+  
R01518[c] [c]:2-Phospho-D-glycerate <=> 3-Phospho-D-glycerate  
R01518[p] [p]:2-Phospho-D-glycerate <=> 3-Phospho-D-glycerate  
R01523[c] [c]: ATP + D-Ribulose 5-phosphate --> ADP + D-Ribulose 1,5-bisphosphate  
R01523[p] [p]: ATP + D-Ribulose 5-phosphate --> ADP + D-Ribulose 1,5-bisphosphate

R01528[c] [c]: 6-Phospho-D-gluconate + NADP+ --> D-Ribulose 5-phosphate + CO2 + NADPH + H+

R01528[p] [p]: 6-Phospho-D-gluconate + NADP+ --> D-Ribulose 5-phosphate + CO2 + NADPH + H+

R01529[c] [c]:D-Ribulose 5-phosphate <==> D-Xylulose 5-phosphate

R01529[p] [p]:D-Ribulose 5-phosphate <==> D-Xylulose 5-phosphate

R01560[c] [c]: Adenosine + H2O --> Inosine + NH3

R01567[c] [c]: ATP + Thymidine --> ADP + dTMP

R01600[c] [c]: ATP + beta-D-Glucose --> ADP + beta-D-Glucose 6-phosphate

R01602[c] [c]:alpha-D-Glucose <==> beta-D-Glucose

R01613[c] [c]: 27 p-Coumaroyl-CoA + 31 Malonyl-CoA + 59 H+ --> Isosalipurpol + 4 CoA + 3 CO2

R01615[c] [c]: p-Coumaroyl-CoA + NADPH --> 4-Hydroxycinnamyl aldehyde + CoA + NADP+

R01616[c] [c]: ATP + 4-Coumarate + CoA --> AMP + Pyrophosphate + p-Coumaroyl-CoA

R01624[c] [c]:Acetyl-CoA + Acyl-carrier protein <==> CoA + Acetyl-[acyl-carrier protein]

R01624[p] [p]:Acetyl-CoA + Acyl-carrier protein <==> CoA + Acetyl-[acyl-carrier protein]

R01639[c] [c]:ATP + D-Xylulose <==> ADP + D-Xylulose 5-phosphate

R01641[c] [c]:D-Sedoheptulose 7-phosphate + (2R)-2-Hydroxy-3-(phosphonoxy)-propanal <==> D-Ribose 5-phosphate + D-Xylulose 5-phosphate

R01641[p] [p]:D-Sedoheptulose 7-phosphate + (2R)-2-Hydroxy-3-(phosphonoxy)-propanal <==> D-Ribose 5-phosphate + D-Xylulose 5-phosphate

R01645[c] [c]: 4-Hydroxy-2-oxo-heptanedioate --> Succinate semialdehyde + Pyruvate

R01655[c] [c]:5,10-Methenyltetrahydrofolate + H2O <==> 10-Formyltetrahydrofolate + H+

R01658[c] [c]: Dimethylallyl diphosphate + Isopentenyl diphosphate --> Pyrophosphate + Geranyl diphosphate

R01663[c] [c]: dCMP + H2O --> dUMP + NH3

R01664[c] [c]: dCMP + H2O --> Deoxycytidine + Orthophosphate

R01665[c] [c]: ATP + dCMP --> ADP + dCDP

R01679[c] [c]: Lactose + Orthophosphate --> Lactose 6-phosphate + H2O

R01687[c] [c]: (5-L-Glutamyl)-peptide + Taurine --> Peptide + 5-L-Glutamyl-aurine

R01701[c] [c]: 3-Methyl-2-oxobutanoic acid + Lipoamide --> S-(2-Methylpropanoyl)-dihydrolipoamide + CO2

R01702[c] [c]: 4-Methyl-2-oxopentanoate + Lipoamide --> S-(3-Methylbutanoyl)-dihydrolipoamide + CO2

R01714[c] [c]: 5-O-(1-Carboxyvinyl)-3-phosphoshikimate --> Chorismate + Orthophosphate

R01715[c] [c]:Chorismate <==> Prephenate

R01716[c] [c]: Chorismate + L-Glutamine --> 4-Amino-4-deoxychorismate + L-Glutamate

R01717[c] [c]:Chorismate <==> Isochorismate

R01719[c] [c]: Isomaltose + ATP + H2O --> Isomaltose + Orthophosphate + ADP

R01724[c] [c]:Nicotinate D-ribonucleotide + Pyrophosphate <==> Nicotinate + 5-Phospho-alpha-D-ribose 1-diphosphate

R01737[c] [c]: ATP + D-Gluconic acid --> ADP + 6-Phospho-D-gluconate

R01752[c] [c]:D-Glyceraldehyde + NAD+ + H2O <==> D-Glycerate + NADH + H+

R01768[c] [c]: Xanthine + NADH --> Hypoxanthine + NAD+ + H2O

R01769[c] [c]: Hypoxanthine + Oxygen + H2O --> Xanthine + H2O2

R01771[c] [c]: ATP + L-Homoserine --> ADP + O-Phospho-L-homoserine

R01773[c] [c]:L-Homoserine + NAD+ <==> L-Aspartate 4-semialdehyde + NADH + H+

R01775[c] [c]:L-Homoserine + NADP+ <==> L-Aspartate 4-semialdehyde + NADPH + H+

R01786[c] [c]: ATP + alpha-D-Glucose --> ADP + alpha-D-Glucose 6-phosphate

R01799[c] [c]: CTP + Phosphatidate --> Pyrophosphate + CDP-diacylglycerol

R01801[c] [c]: CDP-diacylglycerol + sn-Glycerol 3-phosphate --> CMP + Phosphatidylglycerophosphate

R01802[c] [c]: CDP-diacylglycerol + myo-Inositol --> CMP + 1-Phosphatidyl-D-myo-inositol

R01818[c] [c]:D-Mannose 6-phosphate <==> D-Mannose 1-phosphate

R01819[c] [c]:D-Mannose 6-phosphate <==> beta-D-Fructose 6-phosphate

R01826[c] [c]: Phosphoenolpyruvate + D-Erythrose 4-phosphate + H2O --> 2-Dehydro-3-deoxy-D-arabino-heptenate 7-phosphate + Orthophosphate

R01827[p] [p]:D-Sedoheptulose 7-phosphate + (2R)-2-Hydroxy-3-(phosphonoxy)-propanal <=> D-Erythrose 4-phosphate + beta-D-Fructose 6-phosphate

R01829[c] [c]: Glycerone phosphate + D-Erythrose 4-phosphate --> Sedoheptulose 1,7-bisphosphate

R01829[p] [p]: Glycerone phosphate + D-Erythrose 4-phosphate --> Sedoheptulose 1,7-bisphosphate

R01830[c] [c]:beta-D-Fructose 6-phosphate + (2R)-2-Hydroxy-3-(phosphonoxy)-propanal <=> D-Erythrose 4-phosphate + D-Xylulose 5-phosphate

R01830[p] [p]:beta-D-Fructose 6-phosphate + (2R)-2-Hydroxy-3-(phosphonoxy)-propanal <=> D-Erythrose 4-phosphate + D-Xylulose 5-phosphate

R01845[c] [c]: Sedoheptulose 1,7-bisphosphate + H2O --> Sedoheptulose 7-phosphate + Orthophosphate

R01845[p] [p]: Sedoheptulose 1,7-bisphosphate + H2O --> Sedoheptulose 7-phosphate + Orthophosphate

R01855[c] [c]: dGTP + H2O --> dGMP + Pyrophosphate

R01857[c] [c]:ATP + dGDP <=> ADP + dGTP

R01858[c] [c]: dGDP + Phosphoenolpyruvate --> dGTP + Pyruvate

R01870[c] [c]:Orotidine 5'-phosphate + Pyrophosphate <=> Orotate + 5-Phospho-alpha-D-ribose 1-diphosphate

R01878[c] [c]: Cytidine + H2O --> Uridine + NH3

R01887[c] [c]: gamma-Amino-gamma-cyanobutanoate + 2 H2O --> Glutamate + NH3

R01890[c] [c]: CTP + Choline phosphate --> Pyrophosphate + CDP-choline

R01900[x] [x]:cis-Aconitate + H2O <=> Isocitrate

R01909[c] [c]: ATP + Pyridoxine --> ADP + Pyridoxine phosphate

R01920[c] [c]: S-Adenosylmethioninamine + Putrescine --> 5'-Methylthioadenosine + Spermidine

R01933[c] [c]: 2-Oxoadipate + CoA + NAD+ --> Glutaryl-CoA + CO2 + NADH + H+

R01940[c] [c]: 2-Oxoadipate + Lipoamide --> S-Glutaryldihydrolipoamide + CO2

R01941[c] [c]:Caffeic aldehyde + CoA + NADP+ <=> Caffeoyl-CoA + NADPH + H+

R01942[c] [c]: S-Adenosyl-L-methionine + Caffeoyl-CoA --> S-Adenosyl-L-homocysteine + Feruloyl-CoA

R01943[c] [c]: ATP + 3,4-Dihydroxy-trans-cinnamate + CoA --> AMP + Pyrophosphate + Caffeoyl-CoA

R01954[c] [c]:ATP + L-Citrulline + L-Aspartate <=> AMP + Pyrophosphate + N-(L-Arginino)succinate

R01966[c] [c]: 13 D-Glucosamine + 13 D-Glucosaminide --> 17 D-Glucosaminide + 13 H2O

R01968[c] [c]:dGMP + H2O <=> Deoxyguanosine + Orthophosphate

R01975[x] [x]:(S)-3-Hydroxybutanoyl-CoA + NAD+ <=> Acetoacetyl-CoA + NADH

R01976[c] [c]:(S)-3-Hydroxybutanoyl-CoA + NADP+ <=> Acetoacetyl-CoA + NADPH + H+

R01978[c] [c]:(S)-3-Hydroxy-3-methylglutaryl-CoA + CoA <=> Acetyl-CoA + H2O + Acetoacetyl-CoA

R01986[c] [c]: 4-Aminobutanal + NADP+ + H2O --> 4-Aminobutanoate + NADPH

R01993[c] [c]:(S)-Dihydroorotate + H2O <=> N-Carbamoyl-L-aspartate

R02003[c] [c]: Geranyl diphosphate + Isopentenyl diphosphate --> Pyrophosphate + trans,trans-Farnesyl diphosphate

R02006[c] [c]: Geranyl diphosphate + H2O --> Sabinene hydrate + Pyrophosphate

R02016[c] [c]: Oxidized thioredoxin + NADPH + H+ --> Thioredoxin + NADP+

R02017[c] [c]: Thioredoxin + ADP --> dADP + Oxidized thioredoxin + H2O

R02018[c] [c]: Thioredoxin + UDP --> dUDP + Oxidized thioredoxin + H2O

R02019[c] [c]: GDP + Thioredoxin --> dGDP + Oxidized thioredoxin + H2O

R02024[c] [c]: Thioredoxin + CDP --> dCDP + Oxidized thioredoxin + H2O

R02026[c] [c]:O-Acetyl-L-homoserine + Thiosulfate + Thioredoxin + H+ <=> L-Homocysteine + Sulfite + Oxidized thioredoxin + Acetate

R02035[c] [c]:D-Glucono-1,5-lactone 6-phosphate + H2O <=> 6-Phospho-D-gluconate

R02035[p] [p]:D-Glucono-1,5-lactone 6-phosphate + H2O <=> 6-Phospho-D-gluconate

R02038[c] [c]: CTP + Ethanolamine phosphate --> Pyrophosphate + CDP-ethanolamine

R02051[c] [c]: Phosphatidylethanolamine + H2O --> Ethanolamine + Phosphatidate

R02057[c] [c]: CDP-ethanolamine + 1,2-Diacyl-sn-glycerol --> CMP + Phosphatidylethanolamine

R02061[c] [c]: trans,trans-Farnesyl diphosphate + Isopentenyl diphosphate --> Pyrophosphate +

Geranylgeranyl diphosphate

R02063[c] [c]: Geranylgeranyl diphosphate + 3 H+ + 3 NADPH --> Phytyl diphosphate + 3 NADP+

R02068[c] [c]: Geranylgeranyl diphosphate --> ent-Copalyl diphosphate

R02073[c] [c]: Pyrophosphate + beta-D-Fructose 6-phosphate <==> Orthophosphate + beta-D-Fructose 1,6-bisphosphate

R02080[c] [c]: 3,4-Dihydroxy-L-phenylalanine --> 4-(2-Aminoethyl)-1,2-benzenediol + CO2

R02082[c] [c]: 9 (S)-3-Hydroxy-3-methylglutaryl-CoA + 2 NADPH + 27 H+ --> 2 (R)-Mevalonate + 9 CoA + 2 NADP+

R02086[c] [c]: N-Acetyl-D-glucosamine 6-phosphate <==> N-Acetyl-D-glucosamine 1-phosphate

R02088[c] [c]: dAMP + H2O <==> Deoxyadenosine + Orthophosphate

R02093[c] [c]: ATP + dTDP <==> ADP + dTTP

R02099[c] [c]: ATP + Deoxyuridine --> ADP + dUMP

R02100[c] [c]: dUTP + H2O --> dUMP + Pyrophosphate

R02101[c] [c]: dUMP + 5,10-Methylenetetrahydrofolate <==> Dihydrofolate + dTMP

R02103[c] [c]: Xanthine + NAD+ + H2O --> Urate + NADH + H+

R02106[c] [c]: Urate + Oxygen + H2O --> 5-Hydroxyisourate + H2O2

R02107[c] [c]: Xanthine + H2O + Oxygen --> Urate + H2O2

R02110[p] [p]: 2 Amylose --> Starch

R02111[p] [p]: Amylose + Orthophosphate --> D-Glucose 1-phosphate

R02112[p] [p]: Starch --> Maltose

R02124[c] [c]: Retinol + NAD+ <==> Retinal + NADH + H+

R02157[c] [c]: S-Adenosyl-L-methionine + Quercetin --> S-Adenosyl-L-homocysteine + 3',4',5,7-Tetrahydroxy-3-methoxyflavone

R02158[c] [c]: UDP-glucose + Quercetin --> UDP + Quercetin 3-O-glucoside

R02160[c] [c]: Taxifolin + 2-Oxoglutarate + Oxygen --> Quercetin + Succinate + CO2 + H2O

R02166[c] [c]: Ubiquinol <==> Ubiquinone + 2 H+

R02173[c] [c]: Tryptamine + H2O + Oxygen --> Indole-3-acetaldehyde + NH3 + H2O2

R02175[c] [c]: 2-Hexaprenyl-3-methyl-5-hydroxy-6-methoxy-1,4-benzoquinone + S-Adenosyl-L-methionine --> Ubiquinone + S-Adenosyl-L-homocysteine

R02193[c] [c]: Feruloyl-CoA + NADPH + H+ --> Coniferyl aldehyde + CoA + NADP+

R02194[c] [c]: ATP + Ferulate + CoA --> AMP + Pyrophosphate + Feruloyl-CoA

R02199[c] [c]: (S)-3-Methyl-2-oxopentanoic acid + L-Glutamate --> L-Isoleucine + 2-Oxoglutarate

R02220[c] [c]: Sinapoyl-CoA + NADPH --> Sinapoyl aldehyde + CoA + NADP+

R02221[c] [c]: ATP + Sinapate + CoA --> AMP + Pyrophosphate + Sinapoyl-CoA

R02235[c] [c]: Dihydrofolate + NAD+ <==> Folate + NADH + H+

R02236[c] [c]: Dihydrofolate + NADP+ <==> Folate + NADPH + H+

R02240[c] [c]: ATP + 1,2-Diacyl-sn-glycerol --> ADP + Phosphatidate

R02241[c] [c]: 1-Acyl-sn-glycerol 3-phosphate + Acyl-CoA --> Phosphatidate + CoA

R02245[c] [c]: 9 ATP + 2 (R)-Mevalonate --> 9 ADP + 9 (R)-5-Phosphomevalonate + 11 H+

R02253[c] [c]: trans-Cinnamate + Oxygen + NADPH + H+ --> 4-Coumarate + NADP+ + H2O

R02255[c] [c]: ATP + trans-Cinnamate + CoA --> AMP + Pyrophosphate + Cinnamoyl-CoA

R02269[c] [c]: 5,6-Dihydrouacil + H2O <==> 3-Ureidopropionate

R02272[c] [c]: (S)-4-Amino-5-oxopentanoate --> 5-Aminolevulinate

R02282[c] [c]: N-Acetylmethionine + L-Glutamate <==> L-Ornithine + N-Acetyl-L-glutamate

R02283[c] [c]: N-Acetylmethionine + 2-Oxoglutarate <==> N-Acetyl-L-glutamate 5-semialdehyde + L-Glutamate

R02291[c] [c]: L-Aspartate 4-semialdehyde + Orthophosphate + NADP+ <==> 4-Phospho-L-aspartate + NADPH + H+

R02292[c] [c]: L-Aspartate 4-semialdehyde + Pyruvate --> L-2,3-Dihydrodipicolinate + 2 H2O

R02300[c] [c]: 5,10-Methylenetetrahydrofolate + H2O --> 5-Formyltetrahydrofolate

R02301[c] [c]: ATP + 5-Formyltetrahydrofolate --> ADP + Orthophosphate + 5,10-Methylenetetrahydrofolate

R02313[c] [c]: N6-(L-1,3-Dicarboxypropyl)-L-lysine + NAD+ + H2O <==> L-Glutamate + L-2-Amino adipate 6-semialdehyde + NADH + H+

R02320[c] [c]: NDP + Phosphoenolpyruvate --> Nucleoside triphosphate + Pyruvate

R02323[c] [c]: Nicotinamide D-ribonucleotide + H2O --> N-Ribosylnicotinamide + Orthophosphate



R02326[c] [c]:ATP + dCDP <=> ADP + dCTP  
R02331[c] [c]:ATP + dUDP <=> ADP + dUTP  
R02362[c] [c]: Pectin + H2O --> Methanol + Pectate  
R02382[c] [c]: Tyramine + H2O + Oxygen --> 4-Hydroxyphenylacetaldehyde + NH3 + H2O2  
R02410[c] [c]: Raffinose + H2O --> Melibiose + D-Fructose  
R02412[c] [c]: ATP + Shikimate --> ADP + Shikimate 3-phosphate  
R02413[c] [c]:Shikimate + NADP+ <=> 3-Dehydroshikimate + NADPH + H+  
R02425[c] [c]: (S)(+)-Allantoin + H2O --> Allantoate  
R02433[c] [c]:L-Cysteate + 2-Oxoglutarate <=> 3-Sulfopyruvate + Glutamate  
R02435[c] [c]: 2-Aminoacrylate + 3'-Phosphoadenylyl sulfate --> L-Cysteate + Adenosine 3',5'-bisphosphate  
R02444[c] [c]: Naringenin + 2-Oxoglutarate + Oxygen --> Dihydrokaempferol + Succinate + CO2  
R02446[c] [c]: Naringenin --> Isosalipurpol  
R02464[c] [c]: Sphinganine 1-phosphate --> Ethanolamine phosphate + Hexadecanal  
R02473[c] [c]: ATP + (R)-Pantoate + beta-Alanine --> AMP + Pyrophosphate + Pantothenate  
R02493[c] [c]: ATP + Pyridoxamine --> ADP + Pyridoxamine phosphate  
R02518[c] [c]: Homogentisate + Oxygen + NADPH --> Gentisate aldehyde + CO2 + NADP+ + H+ + H2O  
R02521[c] [c]: 3-(4-Hydroxyphenyl)pyruvate + Oxygen --> Homogentisate + CO2  
R02529[c] [c]: Aminoacetone + H2O + Oxygen --> Methylglyoxal + NH3 + H2O2  
R02556[c] [c]:Deoxyadenosine + H2O <=> Deoxyinosine + NH3  
R02565[c] [c]: Betaine aldehyde + NAD+ + H2O --> Betaine + NADH + H+  
R02566[c] [c]: Betaine aldehyde + NADP+ + H2O --> Betaine + NADPH  
R02568[c] [c]:D-Fructose 1-phosphate <=> Glycerone phosphate + D-Glyceraldehyde  
R02570[m] [m]:Succinyl-CoA + Enzyme N6-(dihydrolipoyl)lysine <=> CoA + [Dihydrolipoyllysine-residue succinyltransferase]S-succinylidihydrolipoyllysine  
R02571[c] [c]:Glutaryl-CoA + Dihydrolipoamide <=> CoA + S-Glutaryldihydrolipoamide  
R02596[c] [c]: Coniferyl alcohol --> Lignin  
R02613[c] [c]: Phenethylamine + Oxygen + H2O --> Phenylacetaldehyde + NH3 + H2O2  
R02619[c] [c]: 3-Sulfino-L-alanine + 2-Oxoglutarate --> 3-Sulfinylpyruvate + Glutamate  
R02649[c] [c]: ATP + N-Acetyl-L-glutamate --> ADP + N-Acetyl-L-glutamate 5-phosphate  
R02662[c] [c]: S-(2-Methylpropanoyl)-dihydrolipoamide + CoA --> 2-Methylpropanoyl-CoA + Dihydrolipoamide  
R02670[c] [c]:2 3-Hydroxyanthranilate + 2 Oxygen --> Cinnavalinate + 2 H2O2  
R02671[c] [c]: 3-Hydroxyanthranilate + Activated methyl group --> 3-Methoxyanthranilate  
R02678[c] [c]: Indole-3-acetaldehyde + NAD+ + H2O --> Indole-3-acetate + NADH + H+  
R02691[c] [c]: UDP-D-galactose + 1,2-Diacyl-sn-glycerol --> UDP + 1,2-Diacyl-3-beta-D-galactosyl-sn-glycerol  
R02719[c] [c]: Xanthosine 5'-phosphate + H2O --> Xanthosine + Orthophosphate  
R02720[c] [c]: XTP + H2O --> Xanthosine 5'-phosphate + Pyrophosphate  
R02722[c] [c]:L-Serine + Indoleglycerol phosphate <=> L-Tryptophan + (2R)-2-Hydroxy-3-(phosphonoxy)-propanal + H2O  
R02731[c] [c]: beta-D-Fructose 2,6-bisphosphate + H2O --> beta-D-Fructose 6-phosphate + Orthophosphate  
R02732[c] [c]: ATP + beta-D-Fructose 6-phosphate --> ADP + beta-D-Fructose 2,6-bisphosphate  
R02735[c] [c]:LL-2,6-Diaminoheptanedioate <=> meso-2,6-Diaminoheptanedioate  
R02736[c] [c]: beta-D-Glucose 6-phosphate + NADP+ --> D-Glucono-1,5-lactone 6-phosphate + NADPH + H+  
R02736[p] [p]: beta-D-Glucose 6-phosphate + NADP+ --> D-Glucono-1,5-lactone 6-phosphate + NADPH + H+  
R02737[c] [c]: UDP-glucose + alpha-D-Glucose 6-phosphate --> UDP + alpha,alpha'-Trehalose 6-phosphate  
R02740[c] [c]:alpha-D-Glucose 6-phosphate <=> beta-D-Fructose 6-phosphate  
R02740[p] [p]:alpha-D-Glucose 6-phosphate <=> beta-D-Fructose 6-phosphate  
R02750[c] [c]:2-Deoxy-D-ribose 5-phosphate + ADP <=> Deoxyribose + ATP  
R02756[c] [c]: Acylglycerone phosphate + NADPH + H+ --> 1-Acyl-sn-glycerol 3-phosphate +

NADP+  
 R02771[c] [c]: dTDP-glucose --> dTDP-4-dehydro-6-deoxy-alpha-D-glucose + H2O  
 R02778[c] [c]: alpha,alpha'-Trehalose 6-phosphate + H2O --> alpha,alpha'-Trehalose + Orthophosphate  
 R02811[c] [c]: Cyanohydrin --> Ketone + Cyanide  
 R02832[c] [c]: Tropinone + NADPH + H+ --> Tropine + NADP+  
 R02834[c] [c]: Cortisol + NAD+ --> Cortisone + NADH + H+  
 R02836[c] [c]: Cortisol + NADP+ --> Cortisone + NADPH + H+  
 R02872[c] [c]: Presqualene diphosphate + NADPH + H+ --> Pyrophosphate + Squalene + NADP+  
 R02873[c] [c]: Squalene + Reduced acceptor + Oxygen --> (S)-2,3-Epoxy-squalene + Acceptor + H2O  
 R02874[c] [c]: Squalene + Oxygen + NADPH + H+ --> (S)-2,3-Epoxy-squalene + NADP+ + H2O  
 R02887[c] [c]: Cellulose + H2O --> beta-D-Glucose  
 R02889[c] [c]: UDP-glucose --> UDP + Cellulose  
 R02912[c] [c]: 3-(2-Aminoethyl)-1H-indol-5-ol + Activated methyl group --> 5-Methoxytryptamine  
 R02918[c] [c]: ATP + L-Tyrosine + tRNA(Tyr) --> AMP + Pyrophosphate + L-Tyrosyl-tRNA(Tyr)  
 R02926[c] [c]: Melibiitol + H2O <==> D-Sorbitol + D-Galactose  
 R02940[c] [c]: 2-Propyn-1-ol + NAD+ + H2O --> Propynoate + NADH  
 R02946[c] [c]: (R)-Acetoin + NADH + H+ --> (R,R)-Butane-2,3-diol + NAD+  
 R02952[c] [c]: 4-Coumarate --> 4-Hydroxystyrene + CO2  
 R02957[c] [c]: D-Glucuronolactone + NAD+ + 2 H2O <==> D-Glucarate + NADH + H+  
 R02984[c] [c]: dTDP-glucose <==> dTDP-galactose  
 R03008[c] [c]: Gibberellin A1 + 2-Oxoglutarate + Oxygen --> 2beta-Hydroxygibberellin 1 + Succinate + CO2  
 R03012[c] [c]: L-Histidinol + NAD+ --> L-Histidinal + NADH + H+  
 R03026[x] [x]: Crotonoyl-CoA + H2O <==> (S)-3-Hydroxybutanoyl-CoA  
 R03038[c] [c]: ATP + L-Alanine + tRNA(Ala) <==> AMP + Pyrophosphate + L-Alanyl-tRNA  
 R03045[c] [c]: 3-Hydroxypropionyl-CoA <==> Propenoyl-CoA + H2O  
 R03050[c] [c]: 2-(alpha-Hydroxyethyl)thiamine diphosphate + Pyruvate --> 2-Acetolactate + Thiamin diphosphate  
 R03051[c] [c]: 2-Acetolactate + NADPH + H+ --> 2,3-Dihydroxy-3-methylbutanoate + NADP+  
 R03055[c] [c]: 5,6-Dihydrothymine + H2O <==> 3-Ureidoisobutyrate  
 R03057[c] [c]: Leukotriene A4 + H2O --> Leukotriene B4  
 R03067[c] [c]: 2-Amino-7,8-dihydro-4-hydroxy-6-(diphosphooxymethyl)pteridine + 4-Aminobenzoate <==> Pyrophosphate + Dihydropteroate  
 R03075[c] [c]: 1-O-Sinapoyl-beta-D-glucose + Choline --> D-Glucose + Sinapoylcholine  
 R03083[c] [c]: 2-Dehydro-3-deoxy-D-arabino-heptonate 7-phosphate --> 3-Dehydroquininate + Orthophosphate  
 R03084[c] [c]: 3-Dehydroquininate <==> 3-Dehydroshikimate + H2O  
 R03093[c] [c]: 3-Indoleacetonitrile + 2 H2O --> Indole-3-acetate + NH3  
 R03104[c] [c]: Mercaptopyruvate + NADH --> 3-Mercaptolactate + NAD+  
 R03123[c] [c]: Dihydrokaempferol + NADPH + H+ --> cis-3,4-Leucopelargonidin + NADP+  
 R03126[c] [c]: Dihydrokaempferol + 2-Oxoglutarate + Oxygen --> Kaempferol + Succinate + CO2 + H2O  
 R03132[c] [c]: O-Acetyl-L-serine + Thiosulfate --> S-Sulfo-L-cysteine + Acetate  
 R03139[c] [c]: 1,3-Diaminopropane + Oxygen + H2O --> beta-Aminopropion aldehyde + NH3 + H2O  
 R03140[p] [p]: D-Ribulose 1,5-bisphosphate + Oxygen --> 3-Phospho-D-glycerate + 2-Phosphoglycolate  
 R03174[c] [c]: S-(2-Methylbutanoyl)-dihydrolipoamide + CoA --> 2-Methylbutanoyl-CoA + Dihydrolipoamide  
 R03194[c] [c]: 2 S-Adenosyl-L-methionine + Uroporphyrinogen III --> 2 S-Adenosyl-L-homocysteine + Precorrin 2  
 R03199[c] [c]: (S)-2,3-Epoxy-squalene --> Lanosterol  
 R03200[c] [c]: (S)-2,3-Epoxy-squalene --> Cycloartenol  
 R03209[c] [c]: ATP + 6-Carboxyhexanoate + CoA --> AMP + Pyrophosphate + 6-Carboxyhexanoyl-CoA  
 R03210[c] [c]: 6-Carboxyhexanoyl-CoA + L-Alanine --> 8-Amino-7-oxononanoate + CoA + CO2

R03220[c] [c]: Coproporphyrinogen III + Oxygen --> Protoporphyrinogen IX + 2 CO2 + 2 H2O  
R03222[c] [c]: 2 Protoporphyrinogen IX + 3 Oxygen --> 2 Protoporphyrin + 6 H2O  
R03223[c] [c]: 2-Methyl-4-amino-5-hydroxymethylpyrimidine diphosphate + 4-Methyl-5-(2-phosphoethyl)-thiazole --> Pyrophosphate + Thiamin monophosphate  
R03243[c] [c]: L-Histidinol phosphate + 2-Oxoglutarate <==> 3-(Imidazol-4-yl)-2-oxopropyl phosphate + L-Glutamate  
R03245[c] [c]: ATP + (R)-5-Phosphomevalonate --> ADP + (R)-5-Diphosphomevalonate  
R03254[c] [c]: Phosphoenolpyruvate + D-Arabinose 5-phosphate + H2O --> 3-Deoxy-D-manno-octulosonate 8-phosphate + Orthophosphate  
R03260[c] [c]: O-Succinyl-L-homoserine + L-Cysteine --> L-Cystathionine + Succinate  
R03269[c] [c]: (R)-4'-Phosphopantothonyl-L-cysteine --> Pantetheine 4'-phosphate + CO2  
R03270[c] [c]: 2-(alpha-Hydroxyethyl)thiamine diphosphate + Lipoamide --> S-Acetyldihydrolipoamide + Thiamin diphosphate  
R03284[c] [c]: 3-Hydroxy-N6,N6,N6-trimethyl-L-lysine --> 4-Trimethylammoniobutanal + Glycine  
R03291[c] [c]: L-1-Pyrroline-3-hydroxy-5-carboxylate + NADH + 2H+ --> trans-4-Hydroxy-L-proline + NAD+  
R03293[c] [c]: L-1-Pyrroline-3-hydroxy-5-carboxylate + NADPH + 2H+ --> trans-4-Hydroxy-L-proline + NADP+  
R03313[c] [c]: L-Glutamate 5-semialdehyde + Orthophosphate + NADP+ <==> L-Glutamyl 5-phosphate + NADPH + H+  
R03316[m] [m]: 3-Carboxy-1-hydroxypropyl-ThPP + Enzyme N6-(lipoyl)lysine --> [Dihydrolipoyllysine-residue succinyltransferase]S-succinyl dihydrolipoyllysine + Thiamin diphosphate  
R03321[c] [c]: beta-D-Glucose 6-phosphate <==> beta-D-Fructose 6-phosphate  
R03323[c] [c]: 1-O-Sinapoyl-beta-D-glucose + (S)-Malate --> D-Glucose + Sinapoyl malate  
R03346[c] [c]: Nicotinate D-ribonucleotide + H2O <==> Nicotinate D-ribonucleoside + Orthophosphate  
R03347[c] [c]: Nicotinate D-ribonucleoside + ATP --> Nicotinate D-ribonucleotide + ADP  
R03348[c] [c]: 3 Pyridine-2,3-dicarboxylate + 5 5-Phospho-alpha-D-ribose 1-diphosphate + 6 H+ --> 3 Nicotinate D-ribonucleotide + 6 Pyrophosphate + 13 CO2  
R03351[c] [c]: CTP + 3-Deoxy-D-manno-octulosonate --> Pyrophosphate + CMP-3-deoxy-D-manno-octulosonate  
R03355[c] [c]: beta-D-Galactosyl-1,4-beta-D-glucosylceramide + H2O --> Glucosylceramide + beta-D-Galactose  
R03362[c] [c]: ATP + 1-Phosphatidyl-D-myo-inositol --> ADP + 1-Phosphatidyl-1D-myo-inositol 3-phosphate  
R03367[c] [c]: 3,4-Dihydroxy-trans-cinnamate <==> 3,4-Dihydroxystyrene + CO2  
R03393[c] [c]: 1D-myo-Inositol 1,4-bisphosphate + H2O --> myo-Inositol 4-phosphate + Orthophosphate  
R03408[c] [c]: 3beta-Hydroxyandrost-5-en-17-one + H+ + Oxygen + NADPH --> 16alpha-Hydroxydehydroepiandrosterone + NADP+ + H2O  
R03418[c] [c]: 1-alpha-D-Galactosyl-myo-inositol + Raffinose --> myo-Inositol + Stachyose  
R03425[m] [m]: Glycine + Lipoylprotein --> S-Aminomethyldihydrolipoylprotein + CO2  
R03427[c] [c]: 1D-myo-Inositol 1,3,4-trisphosphate + H2O --> D-myo-Inositol 3,4-bisphosphate + Orthophosphate  
R03443[c] [c]: N-Acetyl-L-glutamate 5-semialdehyde + Orthophosphate + NADP+ <==> N-Acetyl-L-glutamate 5-phosphate + NADPH + H+  
R03457[c] [c]: D-erythro-1-(Imidazol-4-yl)glycerol 3-phosphate --> 3-(Imidazol-4-yl)-2-oxopropyl phosphate + H2O  
R03458[c] [c]: 5-Amino-6-(5'-phosphoribosylamino)uracil + NADPH + H+ --> 5-Amino-6-(5'-phosphoribitylamino)uracil + NADP+  
R03459[c] [c]: 2,5-Diamino-6-hydroxy-4-(5'-phosphoribosylamino)pyrimidine + H2O --> 5-Amino-6-(5'-phosphoribosylamino)uracil + NH3  
R03460[c] [c]: Phosphoenolpyruvate + Shikimate 3-phosphate <==> Orthophosphate + 5-O-(1-Carboxyvinyl)-3-phosphoshikimate  
R03469[c] [c]: ATP + 1-Phosphatidyl-1D-myo-inositol 4-phosphate --> ADP + 1-Phosphatidyl-D-myo-inositol 4,5-bisphosphate

R03472[c] [c]: Aminoimidazole ribotide --> 4-Amino-5-hydroxymethyl-2-methylpyrimidine  
R03503[c] [c]: ATP + 2-Amino-4-hydroxy-6-hydroxymethyl-7,8-dihydropteridine <==> AMP + 2-Amino-7,8-dihydro-4-hydroxy-6-(diphosphoxymethyl)pteridine  
R03504[c] [c]: 2-Amino-4-hydroxy-6-(D-erythro-1,2,3-trihydroxypropyl)-7,8-dihydropteridine --> Glycolaldehyde + 2-Amino-4-hydroxy-6-hydroxymethyl-7,8-dihydropteridine  
R03508[c] [c]: 1-(2-Carboxyphenylamino)-1'-deoxy-D-ribulose 5'-phosphate --> Indoleglycerol phosphate + CO2 + H2O  
R03509[c] [c]: N-(5-Phospho-D-ribosyl)anthranilate --> 1-(2-Carboxyphenylamino)-1'-deoxy-D-ribulose 5'-phosphate  
R03522[c] [c]: RX + Glutathione --> HX + R-S-Glutathione  
R03527[c] [c]: D-Glucoside + H2O --> ROH + alpha-D-Glucose  
R03530[c] [c]: ATP + dIDP <==> ADP + dITP  
R03531[c] [c]: dITP + H2O --> 2'-Deoxyinosine 5'-phosphate + Pyrophosphate  
R03540[c] [c]: Maleamate + H2O --> Maleic acid + NH3  
R03542[c] [c]: alpha-Aminopropionitrile + 2 H2O --> Alanine + NH3  
R03546[c] [c]: Cyanate + H+ + HCO3- <==> CO2 + Carbamate  
R03600[c] [c]: Selenite + Reduced ferredoxin + H2O <==> Selenide + Oxidized ferredoxin + H2O  
R03601[c] [c]: O-Acetyl-L-serine + Selenide --> Selenocysteine + Acetate  
R03616[c] [c]: 3-beta-D-Galactosyl-sn-glycerol + H2O --> Galactose + Glycerol  
R03634[c] [c]: Stachyose + H2O --> Raffinose + D-Galactose  
R03635[c] [c]: Stachyose + H2O --> D-Gal alpha 1->6D-Gal alpha 1->6D-Glucose + D-Fructose  
R03636[c] [c]: Taxifolin + NADPH --> Leucocyanidin + NADP+  
R03640[c] [c]: Eriodictyol + 2-Oxoglutarate + Oxygen --> Taxifolin + Succinate + CO2  
R03646[c] [c]: ATP + L-Arginine + tRNA(Arg) <==> AMP + Pyrophosphate + L-Arginyl-tRNA(Arg)  
R03648[c] [c]: ATP + L-Asparagine + tRNA(Asn) --> AMP + Pyrophosphate + L-Asparaginyl-tRNA(Asn)  
R03650[c] [c]: ATP + L-Cysteine + tRNA(Cys) --> AMP + Pyrophosphate + L-Cysteinyl-tRNA(Cys)  
R03652[c] [c]: ATP + L-Glutamine + tRNA(Gln) --> AMP + Pyrophosphate + GlutaminyL-tRNA(Gln)  
R03654[c] [c]: ATP + Glycine + tRNA(Gly) --> AMP + Pyrophosphate + Glycyl-tRNA(Gly)  
R03655[c] [c]: ATP + L-Histidine + tRNA(His) --> AMP + Pyrophosphate + L-Histidyl-tRNA(His)  
R03656[c] [c]: ATP + L-Isoleucine + tRNA(Ile) --> AMP + Pyrophosphate + L-Isoleucyl-tRNA(Ile)  
R03658[c] [c]: ATP + L-Lysine + tRNA(Lys) --> AMP + Pyrophosphate + L-Lysyl-tRNA(Lys)  
R03659[c] [c]: ATP + L-Methionine + tRNA(Met) --> AMP + Pyrophosphate + L-Methionyl-tRNA(Met)  
R03660[c] [c]: ATP + L-Phenylalanine + tRNA(Phe) --> AMP + Pyrophosphate + L-Phenylalanyl-tRNA(Phe)  
R03661[c] [c]: ATP + L-Proline + tRNA(Pro) --> AMP + Pyrophosphate + L-Prolyl-tRNA(Pro)  
R03662[c] [c]: ATP + L-Serine + tRNA(Ser) --> AMP + Pyrophosphate + L-Seryl-tRNA(Ser)  
R03663[c] [c]: ATP + L-Threonine + tRNA(Thr) --> AMP + Pyrophosphate + L-Threonyl-tRNA(Thr)  
R03664[c] [c]: ATP + L-Tryptophan + tRNA(Trp) --> AMP + Pyrophosphate + L-Tryptophanyl-tRNA(Trp)  
R03665[c] [c]: ATP + L-Valine + tRNA(Val) --> AMP + Pyrophosphate + L-Valyl-tRNA(Val)  
R03719[c] [c]: CoA + 3alpha,7alpha,12alpha-Trihydroxy-5beta-24-oxocholestanoyl-CoA --> Propanoyl-CoA + Choloyl-CoA  
R03738[c] [c]: Tryptamine + Secologanin --> 3-alpha(S)-Strictosidine + H2O  
R03777[x] [x]: Octanoyl-CoA + Oxygen --> trans-Oct-2-enoyl-CoA + H2O2  
R03778[x] [x]: Octanoyl-CoA + Acetyl-CoA <==> CoA + 3-Oxodecanoyl-CoA  
R03806[c] [c]: Gibberellin A44 diacid + 2-Oxoglutarate + Oxygen --> Gibberellin A19 + Succinate + CO2 + H2O  
R03807[c] [c]: Gibberellin A19 --> Gibberellin A20 + CO2  
R03809[c] [c]: 65 Gibberellin A20 + 84 2-Oxoglutarate + 65 Oxygen <=> 70 Gibberellin A29 + 65 Succinate + 65 CO2  
R03815[c] [c]: Dihydrolipoylprotein + NAD+ --> Lipoylprotein + NADH + H+  
R03824[c] [c]: gamma-Carotene + Reduced acceptor + H+ --> beta-Carotene + Acceptor

R03847[c] [c]: Corticosterone + NAD+ --> 11-Dehydrocorticosterone + NADH + H+  
R03848[c] [c]: Corticosterone + NADP+ --> 11-Dehydrocorticosterone + NADPH + H+  
R03857[x] [x]: Lauroyl-CoA + Oxygen --> 2-trans-Dodecenoyl-CoA + H2O2  
R03858[x] [x]:Lauroyl-CoA + Acetyl-CoA <==> CoA + 3-Oxotetradecanoyl-CoA  
R03867[c] [c]: Leukotriene C4 + H2O --> Leukotriene D4 + Glutamate  
R03869[c] [c]: (S)-Methylmalonate semialdehyde + NAD+ + H2O --> Methylmalonate + NADH  
R03877[c] [c]: ATP + Protoporphyrin + Magnesium + H2O --> ADP + Orthophosphate +  
Magnesium protoporphyrin + 2 H+  
R03916[c] [c]: R-S-Glutathione + H2O --> R-S-Alanylglycine + L-Glutamate  
R03918[c] [c]: Sinapoyl aldehyde + NADPH --> Sinapyl alcohol + NADP+  
R03919[c] [c]: Sinapyl alcohol --> Lignin  
R03920[c] [c]: ATP + beta-D-Fructose --> ADP + beta-D-Fructose 6-phosphate  
R03921[c] [c]: Sucrose 6-phosphate + H2O --> beta-D-Fructose + alpha-D-Glucose 6-phosphate  
R03940[c] [c]: L-Methionyl-tRNA(Met) + 10-Formyltetrahydrofolate --> Tetrahydrofolate + N-  
Formylmethionyl-tRNA  
R03943[c] [c]: N-Methyltyramine + S-Adenosyl-L-methionine --> Hordenine + S-Adenosyl-L-  
homocysteine  
R03955[c] [c]: Xanthurenic acid --> 8-Methoxykynurenate  
R03968[c] [c]:(2S)-2-Isopropylmalate <==> 2-Isopropylmaleate + H2O  
R03970[c] [c]: 3-Cyano-L-alanine + L-Glutamate --> gamma-Glutamyl-beta-cyanoalanine + H2O  
R03971[c] [c]: 3-Cyano-L-alanine + Glutamate --> gamma-Glutamyl-beta-aminopropionitrile +  
H2O + CO2  
R03990[x] [x]: Tetradecanoyl-CoA + Oxygen --> trans-Tetradec-2-enoyl-CoA + H2O2  
R04001[c] [c]:(2R,3S)-3-Isopropylmalate <==> 2-Isopropylmaleate + H2O  
R04004[c] [c]:4-Coumaryl alcohol + NADP+ <==> 4-Hydroxycinnamyl aldehyde + NADPH  
R04007[c] [c]: 4-Coumaryl alcohol --> Lignin  
R04008[c] [c]:4-Guanidinobutanal + CO2 <==> 2-Oxoarginine  
R04019[c] [c]: Digalactosylceramide + H2O --> Galactosylceramide + Galactose  
R04027[c] [c]: N-Methylputrescine + Oxygen --> 1-Methylpyrrolinium + H2O2 + NH3  
R04035[c] [c]: Phosphoribosyl-ATP + H2O --> Phosphoribosyl-AMP + Pyrophosphate  
R04037[c] [c]: Phosphoribosyl-AMP + H2O --> 5-(5-Phospho-D-ribosylaminoformimino)-1-(5-  
phosphoribosyl)-imidazole-4-carboxamide  
R04065[c] [c]: Imidazole-4-acetaldehyde + NAD+ + H2O --> Imidazole-4-acetate + NADH + H+  
R04094[c] [c]: Glucobrassicin + H2O --> 3-Indoleacetonitrile + D-Glucose + Sulfate + Sulfur  
R04095[c] [c]: 3-Methylbutanoyl-CoA + FAD --> 3-Methylcrotonyl-CoA + FADH2  
R04097[c] [c]: S-(3-Methylbutanoyl)-dihydrolipoamide + CoA --> 3-Methylbutanoyl-CoA +  
Dihydrolipoamide  
R04109[c] [c]: L-Glutamyl-tRNA(Glu) + NADPH + H+ --> (S)-4-Amino-5-oxopentanoate +  
tRNA(Glu) + NADP+  
R04125[c] [c]:Tetrahydrofolate + S-Aminomethyldihydrolipoylprotein <==> 5,10-  
Methylenetetrahydrofolate + NH3 + Dihydrolipoylprotein  
R04134[c] [c]: 2-Hydroxyhepta-2,4-dienedioate --> 2-Oxohept-3-enedioate  
R04137[c] [c]:3-Hydroxyisovaleryl-CoA <==> 3-Methylcrotonyl-CoA + H2O  
R04138[c] [c]: ATP + 3-Methylcrotonyl-CoA + HCO3- --> ADP + Orthophosphate + 3-  
Methylglutaconyl-CoA  
R04144[c] [c]: ATP + 5-Phosphoribosylamine + Glycine --> ADP + Orthophosphate + 5'-  
Phosphoribosylglycinamide  
R04172[c] [c]: 3-Hydroxy-L-kynurenine --> 3-Hydroxykynurenamine + CO2  
R04173[c] [c]:O-Phospho-L-serine + 2-Oxoglutarate <==> 3-Phosphonoxyypyruvate + L-Glutamate  
R04198[c] [c]: L-2,3-Dihydrodipicolinate + NADH + H+ --> 2,3,4,5-Tetrahydrodipicolinate + NAD+  
R04199[c] [c]: L-2,3-Dihydrodipicolinate + NADPH + H+ --> 2,3,4,5-Tetrahydrodipicolinate +  
NADP+  
R04204[c] [c]: 2-Methylbut-2-enoyl-CoA + H2O --> (2S,3S)-3-Hydroxy-2-methylbutanoyl-CoA  
R04209[c] [c]:1-(5-Phospho-D-ribosyl)-5-amino-4-imidazolecarboxylate <==> Aminoimidazole  
ribotide + CO2  
R04223[c] [c]: (Z)-5-Oxohex-2-enedioate + H2O --> 4-Hydroxy-2-oxopentanoate + CO2

R04224[c] [c]: 2-Methylprop-2-enoyl-CoA + H2O --> (S)-3-Hydroxyisobutyryl-CoA  
R04225[c] [c]: 3-Methyl-2-oxopentanoate + Lipoamide --> S-(2-Methylbutanoyl)-dihydrolipoamide + CO2  
R04242[c] [c]: Tetrahydrofolyl-[Glu](n) --> Poly-L-glutamate + Tetrahydrofolate  
R04247[c] [c]: CTP + (2-Aminoethyl)phosphonate --> Pyrophosphate + CMP-2-aminoethylphosphonate  
R04254[c] [c]: (R)-3-Hydroxybutanoyl-CoA --> Poly-beta-hydroxybutyrate + CoA  
R04254[m] [m]: (R)-3-Hydroxybutanoyl-CoA --> Poly-beta-hydroxybutyrate + CoA  
R04254[p] [p]: (R)-3-Hydroxybutanoyl-CoA --> Poly-beta-hydroxybutyrate + CoA  
R04254[x] [x]: (R)-3-Hydroxybutanoyl-CoA --> Poly-beta-hydroxybutyrate + CoA  
R04257[c] [c]: 3,4',5-Trihydroxystilbene --> 3,3',4'5-Tetrahydroxystilbene  
R04276[c] [c]: cis-3,4-Leucopelargonidin + 2-Oxoglutarate + Oxygen --> Pelargonidin + Succinate + CO2 + 2 H2O  
R04292[c] [c]: Iminoaspartate + Glycerone phosphate --> Pyridine-2,3-dicarboxylate + 2 H2O + Orthophosphate  
R04300[c] [c]: 4-(2-Aminoethyl)-1,2-benzenediol + H2O + Oxygen --> 3,4-Dihydroxyphenylacetaldehyde + NH3 + H2O2  
R04313[c] [c]: Protein N6,N6,N6-trimethyl-L-lysine + H2O --> N6,N6,N6-Trimethyl-L-lysine + Protein  
R04326[c] [c]: 5'-Phosphoribosylglycinamide + 5,10-Methenyltetrahydrofolate + H2O <==> 5'-Phosphoribosyl-N-formylglycinamide + Tetrahydrofolate  
R04355[p] [p]: Acetyl-[acyl-carrier protein] + Malonyl-[acyl-carrier protein] --> Acetoacetyl-[acp] + CO2 + Acyl-carrier protein  
R04360[c] [c]: O-Alkylglycerone phosphate + NADPH --> 1-Alkyl-sn-glycero-3-phosphate + NADP+  
R04361[c] [c]: Acyl-CoA + 1-Alkyl-sn-glycero-3-phosphate --> CoA + 2-Acyl-1-alkyl-sn-glycero-3-phosphate  
R04377[c] [c]: 3-D-Glucosyl-1,2-diacylglycerol + UDP-glucose --> Diglucosyl-diacylglycerol + UDP  
R04378[c] [c]: 1-(5'-Phosphoribosyl)-5-amino-4-imidazolecarboxamide + Pyrophosphate <==> 5-Amino-4-imidazolecarboxamide + 5-Phospho-alpha-D-ribose 1-diphosphate  
R04405[c] [c]: 5-Methyltetrahydropteroyltri-L-glutamate + L-Homocysteine --> Tetrahydropteroyltri-L-glutamate + L-Methionine  
R04426[c] [c]: (2R,3S)-3-Isopropylmalate + NAD+ <==> (2S)-2-Isopropyl-3-oxosuccinate + NADH + H+  
R04432[c] [c]: Electron-transferring flavoprotein + Propanoyl-CoA <==> Reduced electron-transferring flavoprotein + Propenoyl-CoA  
R04440[c] [c]: (R)-2,3-Dihydroxy-3-methylbutanoate + NADP+ <==> 3-Hydroxy-3-methyl-2-oxobutanoic acid + NADPH  
R04441[c] [c]: (R)-2,3-Dihydroxy-3-methylbutanoate --> 3-Methyl-2-oxobutanoic acid + H2O  
R04448[c] [c]: ATP + 5-(2-Hydroxyethyl)-4-methylthiazole --> ADP + 4-Methyl-5-(2-phosphoethyl)-thiazole  
R04457[c] [c]: 5-Amino-6-(1-D-ribitylamino)uracil + 3,4-Dihydroxy-2-butanone 4-phosphate --> 6,7-Dimethyl-8-(1-D-ribityl)lumazine + 2 H2O + Orthophosphate  
R04463[c] [c]: ATP + 5'-Phosphoribosyl-N-formylglycinamide + L-Glutamine + H2O --> ADP + Orthophosphate + 2-(Formamido)-N1-(5'-phosphoribosyl)acetamidine + L-Glutamate  
R04470[c] [c]: Digalactosyl-diacylglycerol + H2O --> 1,2-Diacyl-3-beta-D-galactosyl-sn-glycerol + Galactose  
R04506[c] [c]: 3alpha,7alpha-Dihydroxy-5beta-cholestan-26-al + NAD+ + H2O --> 3alpha,7alpha-Dihydroxy-5beta-cholestanate + NADH + H+  
R04509[c] [c]: ATP + 4-Amino-2-methyl-5-phosphomethylpyrimidine --> ADP + 2-Methyl-4-amino-5-hydroxymethylpyrimidine diphosphate  
R04513[c] [c]: Phosphatidylinositol-3,4,5-trisphosphate + H2O --> 1-Phosphatidyl-D-myo-inositol 4,5-bisphosphate + Orthophosphate  
R04515[c] [c]: (4R,5S)-4,5,6-Trihydroxy-2,3-dioxohexanoate + H2O <==> L-Xylonate + CO2  
R04546[c] [c]: CoA + 3alpha,7alpha-Dihydroxy-5beta-cholestanoyl-CoA --> Propanoyl-CoA + Chenodeoxycholoyl-CoA  
R04547[c] [c]: 3alpha,7alpha-Dihydroxy-5beta-cholestanoyl-CoA + FAD --> 3alpha,7alpha-

Dihydroxy-5beta-cholest-24-enoyl-CoA + FADH2  
 R04559[c] [c]: 1-(5'-Phosphoribosyl)-5-amino-4-(N-succinocarboxamide)-imidazole <=> Fumarate + 1-(5'-Phosphoribosyl)-5-amino-4-imidazolecarboxamide  
 R04560[c] [c]: 10-Formyltetrahydrofolate + 1-(5'-Phosphoribosyl)-5-amino-4-imidazolecarboxamide --> Tetrahydrofolate + 1-(5'-Phosphoribosyl)-5-formamido-4-imidazolecarboxamide  
 R04591[c] [c]: ATP + 1-(5-Phospho-D-ribosyl)-5-amino-4-imidazolecarboxylate + L-Aspartate <=> ADP + Orthophosphate + 1-(5'-Phosphoribosyl)-5-amino-4-(N-succinocarboxamide)-imidazole  
 R04592[c] [c]: 3alpha,7alpha,12alpha-Trihydroxy-5beta-cholestanoyl-CoA + FAD --> 3alpha,7alpha,12alpha-Trihydroxy-5beta-cholest-24-enoyl-CoA + FADH2  
 R04621[c] [c]: Dihydroneopterin phosphate + H2O --> 2-Amino-4-hydroxy-6-(D-erythro-1,2,3-trihydroxypropyl)-7,8-dihydropteridine + Orthophosphate  
 R04638[c] [c]: 2-Amino-4-hydroxy-6-(erythro-1,2,3-trihydroxypropyl)dihydropteridine triphosphate + H2O --> Dihydroneopterin phosphate + Pyrophosphate  
 R04639[c] [c]: 2,5-Diamino-6-(5'-triphosphoryl-3',4'-trihydroxy-2'-oxopentyl)-amino-4-oxopyrimidine --> 2-Amino-4-hydroxy-6-(erythro-1,2,3-trihydroxypropyl)dihydropteridine triphosphate + H2O  
 R04640[c] [c]: 5-(5-Phospho-D-ribosylaminoformimino)-1-(5-phosphoribosyl)-imidazole-4-carboxamide --> N-(5'-Phospho-D-1'-ribulosylformimino)-5-amino-1-(5"-phospho-D-ribosyl)-4-imidazolecarboxamide  
 R04666[c] [c]: 3-Ureidoisobutyrate + H2O --> 3-Aminoisobutanoate + CO2 + NH3  
 R04671[c] [c]: 4alpha-Methylcholesta-8-en-3beta-ol --> Methostenol  
 R04672[c] [c]: 2-(alpha-Hydroxyethyl)thiamine diphosphate + Pyruvate --> (S)-2-Acetolactate + Thiamin diphosphate  
 R04673[c] [c]: 2-Oxobutanoate + 2-(alpha-Hydroxyethyl)thiamine diphosphate --> (S)-2-Aceto-2-hydroxybutanoate + Thiamin diphosphate  
 R04711[c] [c]: S-Adenosyl-L-methionine + 3-Hexaprenyl-4,5-dihydroxybenzoate --> S-Adenosyl-L-homocysteine + 3-Hexaprenyl-4-hydroxy-5-methoxybenzoate  
 R04726[c] [c]: Dodecanoyl-[acyl-carrier protein] + Malonyl-[acyl-carrier protein] --> 3-Oxotetradecanoyl-[acp] + CO2 + Acyl-carrier protein  
 R04726[p] [p]: Dodecanoyl-[acyl-carrier protein] + Malonyl-[acyl-carrier protein] --> 3-Oxotetradecanoyl-[acp] + CO2 + Acyl-carrier protein  
 R04732[c] [c]: 5-Amino-4-imidazole carboxylate --> 5-Aminoimidazole + CO2  
 R04737[x] [x]: (S)-3-Hydroxyhexadecanoyl-CoA + NAD+ <=> 3-Oxopalmitoyl-CoA + NADH  
 R04739[x] [x]: (S)-3-Hydroxytetradecanoyl-CoA + NAD+ <=> 3-Oxotetradecanoyl-CoA + NADH  
 R04741[x] [x]: (S)-3-Hydroxydodecanoyl-CoA + NAD+ <=> 3-Oxododecanoyl-CoA + NADH  
 R04742[x] [x]: Decanoyl-CoA + Acetyl-CoA <=> CoA + 3-Oxododecanoyl-CoA  
 R04743[x] [x]: (S)-Hydroxydecanoyl-CoA + NAD+ <=> 3-Oxodecanoyl-CoA + NADH  
 R04745[x] [x]: (S)-Hydroxyoctanoyl-CoA + NAD+ <=> 3-Oxoctanoyl-CoA + NADH  
 R04747[x] [x]: Hexanoyl-CoA + Acetyl-CoA <=> CoA + 3-Oxoctanoyl-CoA  
 R04748[x] [x]: (S)-Hydroxyhexanoyl-CoA + NAD+ <=> 3-Oxohexanoyl-CoA + NADH  
 R04751[x] [x]: Hexanoyl-CoA + Oxygen --> trans-Hex-2-enoyl-CoA + H2O2  
 R04754[x] [x]: Decanoyl-CoA + Oxygen --> trans-Dec-2-enoyl-CoA + H2O2  
 R04757[c] [c]: 11beta-Hydroxyandrost-4-ene-3,17-dione + NAD+ --> Adrenosterone + NADH + H+  
 R04758[c] [c]: 11beta-Hydroxyandrost-4-ene-3,17-dione + NADP+ --> Adrenosterone + NADPH + H+  
 R04764[c] [c]: 2-Hydroxyestradiol-17beta + S-Adenosyl-L-methionine --> 2-Methoxyestradiol-17beta + S-Adenosyl-L-homocysteine  
 R04771[c] [c]: ATP + Selenomethionine + H2O --> Orthophosphate + Pyrophosphate + Se-Adenosylselenomethionine  
 R04772[c] [c]: S-Adenosyl-L-methionine + Selenomethionine --> S-Adenosyl-L-homocysteine + Se-Methylselenomethionine  
 R04773[c] [c]: ATP + Selenomethionine + tRNA(Met) --> AMP + Pyrophosphate + Selenomethionyl-tRNA(Met)  
 R04777[c] [c]: 4-Hydroxyphenylacetyl-CoA + Glycine --> 4-Hydroxyphenylacetyl-glycine + CoA  
 R04779[c] [c]: ATP + beta-D-Fructose 6-phosphate --> ADP + beta-D-Fructose 1,6-bisphosphate  
 R04779[p] [p]: ATP + beta-D-Fructose 6-phosphate --> ADP + beta-D-Fructose 1,6-bisphosphate  
 R04780[c] [c]: beta-D-Fructose 1,6-bisphosphate + H2O --> beta-D-Fructose 6-phosphate + Orthophosphate

R04780[p] [p]: beta-D-Fructose 1,6-bisphosphate + H2O --> beta-D-Fructose 6-phosphate + Orthophosphate

R04783[c] [c]:3-Ketolactose + H2O <==> 3-Keto-beta-D-galactose + beta-D-Glucose

R04784[c] [c]:(4R,5S)-4,5,6-Trihydroxy-2,3-dioxohexanoate + H2O <==> L-Lyxonate + CO2

R04786[c] [c]: Phytoene --> Phytofluene + Hydrogen

R04787[c] [c]:Phytofluene <==> zeta-Carotene

R04798[c] [c]: zeta-Carotene --> Neurosporene + Hydrogen

R04800[c] [c]: Neurosporene + Reduced acceptor + Oxygen --> Lycopene + Acceptor + 2 H2O

R04801[c] [c]: Neurosporene + Acceptor + H+ --> beta-Zeacarotene + Reduced acceptor

R04803[c] [c]: beta-Zeacarotene + Acceptor --> gamma-Carotene + Hydrogen + Reduced acceptor

R04804[c] [c]: Zymosterol --> 5alpha-Cholesta-7,24-dien-3beta-ol

R04805[c] [c]: 3alpha,7alpha,26-Trihydroxy-5beta-cholestane + NAD+ --> 3alpha,7alpha-Dihydroxy-5beta-cholestan-26-al + NADH

R04811[c] [c]: CoA + 3alpha,7alpha-Dihydroxy-5beta-24-oxocholestanoyl-CoA --> Propanoyl-CoA + Chenodeoxyglycocholoyl-CoA

R04839[c] [c]: Tetrahydrocorticosterone + NAD+ --> 3alpha,21-Dihydroxy-5beta-pregnane-11,20-dione + NADH + H+

R04840[c] [c]: Tetrahydrocorticosterone + NADP+ --> 3alpha,21-Dihydroxy-5beta-pregnane-11,20-dione + NADPH + H+

R04858[c] [c]: S-Adenosyl-L-methionine + DNA cytosine --> S-Adenosyl-L-homocysteine + DNA 5-methylcytosine

R04869[c] [c]: Holo-[carboxylase] --> N6-D-Biotinyl-L-lysine + Peptide

R04880[c] [c]:3,4-Dihydroxyphenylethyleneglycol + NAD+ <==> 3,4-Dihydroxymandelaldehyde + NADH

R04885[c] [c]: 2-Carboxy-2,3-dihydro-5,6-dihydroxyindole --> 5,6-Dihydroxyindole + CO2

R04903[c] [c]: 5-Hydroxyindoleacetaldehyde + NAD+ + H2O --> 5-Hydroxyindoleacetate + H+ + NADH

R04910[c] [c]: 5-(3'-Carboxy-3'-oxopropenyl)-4,6-dihydroxypicolinate + NADPH --> 5-(3'-Carboxy-3'-oxopropyl)-4,6-dihydroxypicolinate + NADP+

R04920[c] [c]: CMP-2-aminoethylphosphonate + Diacylglycerol --> CMP + Diacylglycerol-2-aminoethylphosphonate

R04928[c] [c]: ATP + Adenylylselenate --> ADP + 3'-Phosphoadenylylselenate

R04929[c] [c]:ATP + Selenate <==> Pyrophosphate + Adenylylselenate

R04935[c] [c]: (5-L-Glutamyl)-peptide + Se-Methylselenocysteine --> Peptide + gamma-Glutamyl-Se-methylselenocysteine

R04936[c] [c]: Se-Adenylylselenohomocysteine + H2O --> Adenosine + Selenohomocysteine

R04939[c] [c]: R + Se-Adenylylselenomethionine --> CH3-R + Se-Adenylylselenohomocysteine

R04941[c] [c]: Selenocystathionine + H2O --> Selenohomocysteine + NH3 + Pyruvate

R04944[c] [c]: O-Phosphorylhomoserine + Selenocysteine --> Selenocystathionine + Orthophosphate

R04945[c] [c]: O-Acetylhomoserine + Selenocysteine --> Selenocystathionine + Acetate

R04946[c] [c]: O-Succinylhomoserine + Selenocysteine --> Selenocystathionine + Succinate

R04949[c] [c]: Cyanoglycoside + H2O --> Cyanohydrin + Glucose

R04951[c] [c]: R-S-Alanylglycine --> R-S-Alanine + Glycine

R04952[c] [c]: 15 Butyryl-[acp] + 4 Malonyl-[acyl-carrier protein] + 18 H+ --> 4 3-Oxohexanoyl-[acp] + 4 CO2 + 15 Acyl-carrier protein

R04952[p] [p]: 15 Butyryl-[acp] + 4 Malonyl-[acyl-carrier protein] + 18 H+ --> 4 3-Oxohexanoyl-[acp] + 4 CO2 + 15 Acyl-carrier protein

R04954[c] [c]:(R)-3-Hydroxyhexanoyl-[acp] <==> trans-Hex-2-enoyl-[acp] + H2O

R04954[p] [p]:(R)-3-Hydroxyhexanoyl-[acp] <==> trans-Hex-2-enoyl-[acp] + H2O

R04957[c] [c]: Hexanoyl-[acp] + Malonyl-[acyl-carrier protein] --> 3-Oxo-octanoyl-[acp] + CO2 + Acyl-carrier protein

R04957[p] [p]: Hexanoyl-[acp] + Malonyl-[acyl-carrier protein] --> 3-Oxo-octanoyl-[acp] + CO2 + Acyl-carrier protein

R04960[c] [c]: Octanoyl-[acp] + Malonyl-[acyl-carrier protein] --> 3-Oxodecanoyl-[acp] + CO2 + Acyl-carrier protein

R04960[p] [p]: Octanoyl-[acp] + Malonyl-[acyl-carrier protein] --> 3-Oxodecanoyl-[acp] + CO2 +



Acyl-carrier protein

R04963[c] [c]: Decanoyl-[acp] + Malonyl-[acyl-carrier protein] --> 3-Oxododecanoyl-[acp] + CO<sub>2</sub> + Acyl-carrier protein

R04963[p] [p]: Decanoyl-[acp] + Malonyl-[acyl-carrier protein] --> 3-Oxododecanoyl-[acp] + CO<sub>2</sub> + Acyl-carrier protein

R04968[c] [c]: Tetradecanoyl-[acp] + Malonyl-[acyl-carrier protein] --> 3-Oxohexadecanoyl-[acp] + CO<sub>2</sub> + Acyl-carrier protein

R04968[p] [p]: Tetradecanoyl-[acp] + Malonyl-[acyl-carrier protein] --> 3-Oxohexadecanoyl-[acp] + CO<sub>2</sub> + Acyl-carrier protein

R04982[c] [c]: 2-Hexaprenyl-6-methoxyphenol + Oxygen --> 2-Hexaprenyl-6-methoxy-1,4-benzoquinone + H<sub>2</sub>O

R04983[c] [c]: 2-Hexaprenyl-6-methoxy-1,4-benzoquinone + S-Adenosyl-L-methionine --> 2-Hexaprenyl-3-methyl-6-methoxy-1,4-benzoquinone + S-Adenosyl-L-homocysteine

R04990[c] [c]: 2-Octaprenyl-6-methoxy-1,4-benzoquinone + S-Adenosyl-L-methionine --> 2-Octaprenyl-3-methyl-6-methoxy-1,4-benzoquinone + S-Adenosyl-L-homocysteine

R04993[c] [c]: 2-Demethylmenaquinone + S-Adenosyl-L-methionine --> Menaquinone + S-Adenosyl-L-homocysteine

R04998[c] [c]: cis-beta-D-Glucosyl-2-hydroxycinnamate + H<sub>2</sub>O --> cis-2-Hydroxycinnamate + D-Glucose

R05027[c] [c]: Undecaprenyl-diphospho-N-acetylmuramoyl-L-alanyl-D-glutamyl-L-lysyl-D-alanyl-D-alanine + UDP-N-acetyl-D-glucosamine --> Undecaprenyl-diphospho-N-acetylmuramoyl-(N-acetylglucosamine)-L-alanyl-D-glutamyl-L-lysyl-D-alanyl-D-alanine + UDP

R05028[c] [c]: ATP + Undecaprenyl-diphospho-N-acetylmuramoyl-(N-acetylglucosamine)-L-alanyl-D-glutamyl-L-lysyl-D-alanyl-D-alanine + NH<sub>3</sub> --> ADP + Orthophosphate + Undecaprenyl-diphospho-N-acetylmuramoyl-(N-acetylglucosamine)-L-alanyl-D-glutamyl-L-lysyl-D-alanyl-D-alanine

R05030[c] [c]: ATP + Undecaprenyl-diphospho-N-acetylmuramoyl-(N-acetylglucosamine)-L-alanyl-gamma-D-glutamyl-L-lysyl-D-alanyl-D-alanine + NH<sub>3</sub> --> ADP + Orthophosphate + Undecaprenyl-diphospho-N-acetylmuramoyl-(N-acetylglucosamine)-L-alanyl-D-isoglutaminyl-L-lysyl-D-alanyl-D-alanine

R05032[c] [c]: Undecaprenyl-diphospho-N-acetylmuramoyl-L-alanyl-D-glutamyl-meso-2,6-diaminopimeloyl-D-alanyl-D-alanine + UDP-N-acetyl-D-glucosamine --> Undecaprenyl-diphospho-N-acetylmuramoyl-(N-acetylglucosamine)-L-alanyl-D-glutamyl-meso-2,6-diaminopimeloyl-D-alanyl-D-alanine + UDP

R05033[c] [c]: ATP + Undecaprenyl-diphospho-N-acetylmuramoyl-(N-acetylglucosamine)-L-alanyl-D-glutamyl-meso-2,6-diaminopimeloyl-D-alanyl-D-alanine + NH<sub>3</sub> --> ADP + Orthophosphate + Undecaprenyl-diphospho-N-acetylmuramoyl-(N-acetylglucosamine)-L-alanyl-D-glutamyl-meso-2,6-diaminopimeloyl-D-alanyl-D-alanine

R05035[c] [c]: S-Adenosyl-L-methionine + Kaempferol --> S-Adenosyl-L-homocysteine + 3-Methoxyapigenin

R05036[c] [c]: Leucocyanidin + 2-Oxoglutarate + Oxygen --> Cyanidin + Succinate + CO<sub>2</sub> + 2 H<sub>2</sub>O

R05037[c] [c]: 32 Leucodelphinidin + 28 2-Oxoglutarate + 28 Oxygen --> 28 Delphinidin + 43 Succinate + 28 CO<sub>2</sub> + 28 H<sub>2</sub>O + 80 H<sup>+</sup>

R05038[c] [c]: Dihydromyricetin + NADPH + H<sup>+</sup> --> Leucodelphinidin + NADP<sup>+</sup>

R05039[c] [c]: Pentahydroxyflavanone + 2-Oxoglutarate + Oxygen --> Dihydromyricetin + Succinate + CO<sub>2</sub>

R05046[c] [c]: Formamidopyrimidine nucleoside triphosphate + H<sub>2</sub>O --> 2,5-Diaminopyrimidine nucleoside triphosphate + Formate

R05048[c] [c]: 2,5-Diaminopyrimidine nucleoside triphosphate --> 2,5-Diamino-6-(5'-triphosphoryl-3',4'-trihydroxy-2'-oxopentyl)-amino-4-oxopyrimidine

R05050[c] [c]: N<sub>4</sub>-Acetylamino-2-butanone + NAD<sup>+</sup> + H<sub>2</sub>O --> 4-Acetamidobutanoate + NADH + H<sup>+</sup>

R05066[c] [c]: (S)-3-Hydroxyisobutyrate + NAD<sup>+</sup> <==> (S)-Methylmalonate semialdehyde + NADH + H<sup>+</sup>

R05068[c] [c]: (R)-2,3-Dihydroxy-3-methylpentanoate + NADP<sup>+</sup> <==> (R)-3-Hydroxy-3-methyl-2-oxopentanoate + NADPH + H<sup>+</sup>

R05070[c] [c]: (R)-2,3-Dihydroxy-3-methylpentanoate --> (S)-3-Methyl-2-oxopentanoic acid + H<sub>2</sub>O

R05085[c] [c]: O-Phospho-4-hydroxy-L-threonine + 2-Oxoglutarate <==> 2-Oxo-3-hydroxy-4-phosphobutanoate + L-Glutamate

R05086[c] [c]: O-Phospho-4-hydroxy-L-threonine + H2O --> 4-Hydroxy-L-threonine + Orthophosphate  
R05092[c] [c]: ent-Copalyl diphosphate --> ent-Kaurene + Pyrophosphate  
R05097[c] [c]: Gibberellin A53 + 2-Oxoglutarate + Oxygen --> Gibberellin A44 diacid + Succinate + CO2  
R05119[c] [c]: 3-Butyn-1-al + NAD+ + H2O --> 3-Butynoate + NADH  
R05196[c] [c]: Maltose --> Amylose + Glucose  
R05196[p] [p]: Maltose --> Amylose + Glucose  
R05201[c] [c]: Methylcobalamin + Phosphonoacetaldehyde --> 2-Hydroxypropylphosphonate + Vitamin B12  
R05265[c] [c]: 4-Nitrocatechol + Oxygen + 3 H+ --> Benzene-1,2,4-triol + Nitrite + H2O  
R05341[c] [c]:Lycopene <==> gamma-Carotene  
R05352[c] [c]: 1-Phenylethanol --> Acetophenone + 2 e- + 2 H+  
R05376[c] [c]: Bis(4'-chlorophenyl)acetate --> Bis(4'-chlorophenyl)methane + CO2  
R05395[c] [c]: cis-2,3-Dihydrodiol 1,1,1-Trichloro-2,2-bis(4'-chlorophenyl)ethane + NAD+ --> 2,3-Dihydroxy 1,1,1-Trichloro-2,2-bis(4'-chlorophenyl)ethane + NADH + H+  
R05396[c] [c]: cis-2,3-Dihydrodiol 1,1,1-Trichloro-2,2-bis(4'-chlorophenyl)ethane + NADP+ --> 2,3-Dihydroxy 1,1,1-Trichloro-2,2-bis(4'-chlorophenyl)ethane + NADPH + H+  
R05492[c] [c]: 1,1,1-Trichloro-2,2-bis(4-chlorophenyl)ethane + Oxygen --> cis-2,3-Dihydrodiol 1,1,1-Trichloro-2,2-bis(4'-chlorophenyl)ethane  
R05494[c] [c]: Fluorene + Oxygen + 2 H+ + 2 e- --> Fluoren-9-ol + H2O  
R05506[c] [c]: Benzoyl acetyl-CoA + CoA --> S-Benzoate coenzyme A + Acetyl-CoA  
R05549[c] [c]: D-Gal alpha 1->6D-Gal alpha 1->6D-Glucose + H2O --> D-Galactose + Melibiose  
R05553[c] [c]: 4-Amino-4-deoxychorismate --> 4-Aminobenzoate + Pyruvate  
R05555[c] [c]:trans,trans-Farnesyl diphosphate + Isopentenyl diphosphate <==> trans,trans,cis-Geranylgeranyl diphosphate + Pyrophosphate  
R05556[c] [c]:trans,trans,cis-Geranylgeranyl diphosphate + Isopentenyl diphosphate <==> Dehydrodolichol diphosphate + Pyrophosphate  
R05583[c] [c]: 2,6-Dihydroxycyclohexane-1-carboxyl-CoA + Acceptor --> 6-Oxo-2-hydroxycyclohexane-1-carboxyl-CoA + Reduced acceptor  
R05586[c] [c]: 3-Oxopimeloyl-CoA + CoA --> Glutaryl-CoA + Acetyl-CoA  
R05591[c] [c]: Benzonitrile + 2 H2O --> Benzoate + NH3  
R05593[c] [c]: 6-Oxo-2-hydroxycyclohexane-1-carboxyl-CoA + H2O --> 3-Hydroxypimeloyl-CoA  
R05595[c] [c]: Crotonoyl-CoA + H2O --> 3-Hydroxybutanoyl-CoA  
R05616[c] [c]: all-trans-Hexaprenyl diphosphate + 4-Hydroxybenzoate --> 3-Hexaprenyl-4-hydroxybenzoate + Pyrophosphate  
R05617[c] [c]:37 1,4-Dihydroxy-2-naphthoate + 14 all-trans-Octaprenyl diphosphate <==> 47 2-Demethylmenaquinone + 14 Pyrophosphate + 27 CO2 + 121 H+  
R05618[c] [c]: Chlorophyll a + H2O --> Chlorophyllide + Phytol  
R05634[c] [c]: 4-(Cytidine 5'-diphospho)-2-C-methyl-D-erythritol + ATP --> 2-Phospho-4-(cytidine 5'-diphospho)-2-C-methyl-D-erythritol + ADP  
R05636[c] [c]: Pyruvate + (2R)-2-Hydroxy-3-(phosphonoxy)-propanal --> 1-Deoxy-D-xylulose 5-phosphate + CO2  
R05648[c] [c]: cis-4-(1'-Hydroxynaphth-2'-yl)-2-oxobut-3-enoate + H2O --> 1-Hydroxy-2-naphthaldehyde + Pyruvate  
R05657[c] [c]: 1-Phenanthrol + CH3-R --> 1-Methoxyphenanthrene + R  
R05662[c] [c]:MurAc(oyl-L-Ala-D-gamma-Glu-L-Lys-D-Ala-D-Ala)-diphospho-undecaprenol + UDP-N-acetyl-D-glucosamine <==> Undecaprenyl-diphospho-N-acetylmuramoyl-(N-acetylglucosamine)-L-alanyl-gamma-D-glutamyl-L-lysyl-D-alanyl-D-alanine + UDP  
R05688[c] [c]: 1-Deoxy-D-xylulose 5-phosphate + NADPH + H+ --> 2-C-Methyl-D-erythritol 4-phosphate + NADP+  
R05692[c] [c]: GDP-4-dehydro-6-deoxy-D-mannose + NADPH + H+ --> GDP-L-fucose + NADP+  
R05723[c] [c]: Leucocyanidin + 2-Oxoglutarate + Oxygen --> Taxifolin + Succinate + CO2 + H2O  
R05765[c] [c]: Geranyl diphosphate --> (-)-alpha-Pinene + Pyrophosphate  
R05766[c] [c]: Geranyl diphosphate --> (-)-beta-Pinene + Pyrophosphate  
R05775[c] [c]: UDP-glucose + HSO3- --> UDP-6-sulfoquinovose + H2O

R05825[c] [c]: Polyneuridine aldehyde + H2O --> 16-Epivellosimine + CO2 + Methanol  
R05841[c] [c]: Phenylacetyl-CoA + Glycine <==> Phenylacetyl-glycine + CoA  
R05883[c] [c]: 2-C-Methyl-D-erythritol 2,4-cyclodiphosphate + Protein dithiol --> 1-Hydroxy-2-methyl-2-butenyl 4-diphosphate + H2O + Protein disulfide  
R05884[c] [c]: 1-Hydroxy-2-methyl-2-butenyl 4-diphosphate + NADPH + H+ --> Isopentenyl diphosphate + NADP+ + H2O  
R05916[c] [c]: UDP-N-acetyl-D-glucosamine + 1-Phosphatidyl-D-myo-inositol --> UDP + G00143  
R05919[c] [c]: Dolichyl phosphate D-mannose + G00145 --> Dolichyl phosphate + G00146  
R05922[c] [c]: Dolichyl phosphate D-mannose + G00148 --> Dolichyl phosphate + G00149  
R05961[c] [c]: H2O + Globotriaosylceramide <==> alpha-D-Galactose + Lactosylceramide  
R05963[c] [c]: H2O + Globoside <==> N-Acetyl-D-galactosamine + Globotriaosylceramide  
R05968[c] [c]: GDP-L-fucose + Galactosyl-globoside <==> GDP + Globo-H  
R05969[c] [c]: UDP-N-acetyl-D-glucosamine + Dolichyl phosphate --> UMP + N-Acetyl-D-glucosaminyldiphosphodolichol  
R05970[c] [c]: UDP-N-acetyl-D-glucosamine + N-Acetyl-D-glucosaminyldiphosphodolichol --> UDP + N,N'-Chitobiosyldiphosphodolichol  
R05972[c] [c]: GDP-D-mannose + N,N'-Chitobiosyldiphosphodolichol --> GDP + G00003  
R05976[c] [c]: Protein asparagine + G00008 --> Dolichyl diphosphate + G00009  
R05979[c] [c]: H2O + G00009 --> D-Glucose + G00171  
R05982[c] [c]: G00011 + 4 H2O <==> G00012 + 4 D-Mannose  
R05983[c] [c]: UDP-N-acetyl-D-glucosamine + G00012 <==> UDP + G00013  
R05984[c] [c]: G00013 + 2 H2O --> G00014 + 2 D-Mannose  
R06004[c] [c]: GM2 + H2O --> GM3 + N-Acetyl-D-galactosamine  
R06010[c] [c]: GM1 + H2O --> GM2 + Galactose  
R06024[c] [c]: GDP-L-fucose + Paragloboside <==> GDP + IV2Fuc-nLc4Cer  
R06027[c] [c]: GDP-L-fucose + nLc5Cer <==> GDP + Type II B antigen  
R06031[c] [c]: GDP-L-fucose + G00057 <==> GDP + Type IIIH glycolipid  
R06035[c] [c]: GDP-L-fucose + nLc6Cer <==> GDP + VI2Fuc-nLc6  
R06041[c] [c]: GDP-L-fucose + G00073 <==> GDP + G00074  
R06085[c] [c]: GDP-L-fucose + iso-nLc8Cer <==> GDP + Monofucosyllactoisooctaosylceramide  
R06086[c] [c]: GDP-L-fucose + Monofucosyllactoisooctaosylceramide <==> GDP + G00079  
R06156[c] [c]: GDP-L-fucose + Lc4Cer <==> GDP + IV2Fuc-Lc4Cer  
R06170[c] [c]: GDP-L-fucose + G00038 --> GDP + Type IB glycolipid  
R06223[c] [c]: 2 trans,trans-Farnesyl diphosphate + NADPH + H+ --> Squalene + 2 Pyrophosphate + NADP+  
R06258[c] [c]: Dolichyl phosphate D-mannose + G00006 --> Dolichyl phosphate + G10595  
R06259[c] [c]: Dolichyl phosphate D-mannose + G10595 --> Dolichyl phosphate + G10596  
R06261[c] [c]: Dolichyl phosphate D-mannose + G10597 --> Dolichyl phosphate + G00007  
R06262[c] [c]: Dolichyl D-glucosyl phosphate + G00007 --> Dolichyl phosphate + G10598  
R06263[c] [c]: Dolichyl D-glucosyl phosphate + G10598 --> Dolichyl phosphate + G10599  
R06264[c] [c]: Dolichyl D-glucosyl phosphate + G10599 --> Dolichyl phosphate + G00008  
R06265[c] [c]: Magnesium protoporphyrin monomethyl ester + NADPH + H+ + Oxygen <==> 13(1)-Hydroxy-magnesium-protoporphyrin IX 13-monomethyl ester + NADP+ + H2O  
R06266[c] [c]: 13(1)-Hydroxy-magnesium-protoporphyrin IX 13-monomethyl ester + NADPH + H+ + Oxygen <==> 13(1)-Oxo-magnesium-protoporphyrin IX 13-monomethyl ester + NADP+ + 2 H2O  
R06267[c] [c]: 13(1)-Oxo-magnesium-protoporphyrin IX 13-monomethyl ester + NADPH + H+ + Oxygen <==> Divinylprotochlorophyllide + NADP+ + 2 H2O  
R06284[c] [c]: Chlorophyllide + Phytyl diphosphate --> Chlorophyll a + Pyrophosphate  
R06291[c] [c]: ent-Kaurene + Oxygen + NADPH + H+ --> Kaur-16-en-18-ol + H2O + NADP+  
R06292[c] [c]: Kaur-16-en-18-ol + Oxygen + H+ + NADPH --> Kaur-16-en-18-al + 2 H2O + NADP+  
R06293[c] [c]: Kaur-16-en-18-al + Oxygen + NADPH --> Kaur-16-en-18-oic acid + H2O + NADP+  
R06294[c] [c]: Kaur-16-en-18-oic acid + Oxygen + H+ + NADPH --> ent-7alpha-Hydroxykaur-16-en-19-oic acid + H2O + NADP+  
R06295[c] [c]: ent-7alpha-Hydroxykaur-16-en-19-oic acid + Oxygen + H+ + NADPH --> Gibberellin A12 aldehyde + 2 H2O + NADP+

R06296[c] [c]: ent-7alpha-Hydroxykaur-16-en-19-oic acid + Oxygen + H+ + NADPH --> 6beta,7beta-Dihydroxykaurenoic acid + H2O + NADP+  
R06297[c] [c]: Gibberellin A12 aldehyde + Oxygen + NADPH --> Gibberellin A12 + H2O + NADP+  
R06322[c] [c]: Gibberellin A12 + 2-Oxoglutarate + Oxygen --> Gibberellin A15 open lactone + Succinate + CO2  
R06323[c] [c]: Gibberellin A15 open lactone + 2-Oxoglutarate + Oxygen --> Gibberellin A24 + Succinate + CO2 + H2O  
R06326[c] [c]: Gibberellin A24 --> Gibberellin A9 + CO2  
R06336[c] [c]: 70 Gibberellin A9 + 89 2-Oxoglutarate + 70 Oxygen --> 75 Gibberellin A4 + 70 Succinate + 70 CO2  
R06337[c] [c]: 70 Gibberellin A9 + 89 2-Oxoglutarate + 70 Oxygen --> 75 Gibberellin A51 + 70 Succinate + 70 CO2  
R06338[c] [c]: 65 Gibberellin A4 + 84 2-Oxoglutarate + 65 Oxygen --> 70 Gibberellin A34 + 65 Succinate + 65 CO2  
R06364[c] [c]: CDP-ethanolamine + 1-Alkyl-2-acylglycerol --> CMP + 1-Alkyl-2-acylglycerophosphoethanolamine  
R06366[c] [c]: Perillyl aldehyde + H2O + NAD+ --> Perillic acid + NADH + H+  
R06370[c] [c]: 2-Hydroxy-4-isopropenylcyclohexane-1-carboxyl-CoA + Acceptor --> 4-Isopropenyl-2-oxy-cyclohexanecarboxyl-CoA + Reduced acceptor  
R06401[c] [c]: alpha-Pinene + Reduced acceptor --> Myrtenol + H2O + Acceptor  
R06402[c] [c]: Myrtenol + Oxygen + Acceptor --> Myrtenal + 2 H2O + Reduced acceptor  
R06404[c] [c]: alpha-Pinene + Oxygen + H+ --> Pinocarveol + H2O  
R06405[c] [c]: Pinocarveol --> Pinocarvone + H+  
R06411[c] [c]: cis-2-Methyl-5-isopropylhexa-2,5-dienoyl-CoA + H2O --> 3-Hydroxy-2,6-dimethyl-5-methylene-heptanoyl-CoA  
R06412[c] [c]: trans-2-Methyl-5-isopropylhexa-2,5-dienoyl-CoA + H2O --> 3-Hydroxy-2,6-dimethyl-5-methylene-heptanoyl-CoA  
R06413[c] [c]: 3-Hydroxy-2,6-dimethyl-5-methylene-heptanoyl-CoA + NAD+ --> 2,6-Dimethyl-5-methylene-3-oxo-heptanoyl-CoA + NADH + H+  
R06414[c] [c]: 2,6-Dimethyl-5-methylene-3-oxo-heptanoyl-CoA + CoA --> 3-Isopropylbut-3-enoyl-CoA + Propanoyl-CoA  
R06415[c] [c]: 3-Isopropylbut-3-enoyl-CoA + H2O --> 3-Isopropylbut-3-enoic acid + CoA  
R06447[c] [c]: 5 trans,trans,cis-Geranylgeranyl diphosphate + 2 Isopentenyl diphosphate --> 2 di-trans,poly-cis-Undecaprenyl diphosphate + 5 Pyrophosphate  
R06513[c] [c]: dTDP-glucose <=> 4,6-Dideoxy-4-oxo-dTDP-D-glucose + H2O  
R06516[c] [c]: Sphingosine 1-phosphate --> Ethanolamine phosphate + Hexadecanal  
R06519[c] [c]: Dihydroceramide + Reduced acceptor + Oxygen --> N-Acylsphingosine + Acceptor + 2 H2O  
R06537[c] [c]: Apigenin + NADPH + H+ + Oxygen --> Luteolin + NADP+ + H2O  
R06538[c] [c]: Kaempferol + NADPH + H+ + Oxygen --> Quercetin + NADP+ + H2O  
R06539[c] [c]: Dihydromyricetin + 2-Oxoglutarate + Oxygen --> Myricetin + Succinate + CO2 + H2O  
R06540[c] [c]: cis-3,4-Leucopelargonidin + 2-Oxoglutarate + Oxygen --> Dihydrokaempferol + Succinate + CO2 + H2O  
R06541[c] [c]: Pelargonidin + 2 NADP+ --> (-)-Epiarzelechin + 2 NADPH + H+  
R06542[c] [c]: Cyanidin + 2 NADP+ --> (-)-Epicatechin + 2 NADPH + H+  
R06543[c] [c]: Delphinidin + 2 NADP+ --> (-)-Epigallocatechin + 2 NADPH + H+  
R06556[c] [c]: Isoliquiritigenin <=> Liquiritigenin  
R06568[c] [c]: 27 p-Coumaroyl-CoA + 31 Malonyl-CoA + 21 NADPH + 80 H+ <=> 21 Isoliquiritigenin + 58 CoA + 21 CO2 + 21 NADP+ + 21 H2O  
R06611[c] [c]: Kaempferol + UDP-glucose --> Kaempferol 3-O-glucoside + UDP  
R06735[c] [c]: Tropine --> Acetyltropine  
R06736[c] [c]: Pseudotropine --> Acetylpsudotropine  
R06740[c] [c]: Cadaverine + H2O + Oxygen --> 5-Aminopentanal + NH3 + H2O2  
R06853[c] [c]: Benzene-1,2,4-triol --> 2-Hydroxy-1,4-benzoquinone  
R06854[c] [c]: 2-Hydroxy-1,4-benzoquinone --> p-Benzoquinone + H2O

R06858[c] [c]: 1,4-Dihydroxy-2-naphthoate + Phytyl diphosphate --> 2-Phytyl-1,4-naphthoquinone + CO2 + Pyrophosphate  
R06859[c] [c]: 2-Phytyl-1,4-naphthoquinone + S-Adenosyl-L-methionine --> Phylloquinone + S-Adenosyl-L-homocysteine  
R06867[c] [c]: UDP-6-sulfoquinovose + Diacylglycerol --> Sulfoquinovosyldiacylglycerol + UDP  
R06872[c] [c]: sn-Glycerol 3-phosphate + Acyl-CoA --> 2-Acyl-sn-glycerol 3-phosphate + CoA  
R06895[c] [c]: Coproporphyrinogen III + 2 S-Adenosyl-L-methionine --> Protoporphyrinogen IX + 2 CO2 + 2 L-Methionine + 2 5'-Deoxyadenosine  
R06905[c] [c]: Naphthyl-2-methyl-succinyl-CoA --> Naphthyl-2-methylene-succinyl-CoA + 2 H+  
R06907[c] [c]: Naphthyl-2-hydroxymethyl-succinyl CoA --> Naphthyl-2-oxomethyl-succinyl-CoA + 2 H+  
R06908[c] [c]: Naphthyl-2-oxomethyl-succinyl-CoA + CoA --> 2-Naphthoyl-CoA + Succinyl-CoA  
R06917[c] [c]: 1-Hydroxymethylnaphthalene + NAD+ --> 1-Naphthaldehyde + NADH + H+  
R06920[c] [c]: cis-1,2-Dihydroxy-1,2-dihydro-8-carboxynaphthalene --> 1,2-Dihydroxy-8-carboxynaphthalene  
R06925[c] [c]: 2-Hydroxyisophthalic acid --> Salicylate + CO2  
R06927[c] [c]: (2-Naphthyl)methanol + NAD+ --> 2-Naphthaldehyde + NADH + H+  
R06940[c] [c]: N-Cyclohexylformamide + H2O --> Cyclohexylamine + Formate  
R06942[c] [c]: 5-Carboxy-2-pentenoyl-CoA + H2O --> (3S)-3-Hydroxyadipyl-CoA  
R06960[c] [c]: Neurosporene --> alpha-Zeacarotene  
R06961[c] [c]: alpha-Zeacarotene --> delta-Carotene  
R06962[c] [c]: delta-Carotene --> alpha-Carotene  
R06963[c] [c]: Lycopene --> delta-Carotene  
R06965[c] [c]: gamma-Carotene --> alpha-Carotene  
R06983[c] [c]: S-(Hydroxymethyl)glutathione + NAD+ --> S-Formylglutathione + NADH + H+  
R07002[c] [c]: (1R,2S)-Naphthalene 1,2-oxide + Glutathione --> (1R)-Hydroxy-(2R)-glutathionyl-1,2-dihydronaphthalene  
R07003[c] [c]: (1S,2R)-Naphthalene 1,2-oxide + Glutathione --> (1R)-Glutathionyl-(2R)-hydroxy-1,2-dihydronaphthalene  
R07004[c] [c]: (1S,2R)-Naphthalene 1,2-oxide + Glutathione --> (1S)-Hydroxy-(2S)-glutathionyl-1,2-dihydronaphthalene  
R07023[c] [c]: 1-Nitronaphthalene-7,8-oxide + Glutathione --> 1-Nitro-7-hydroxy-8-glutathionyl-7,8-dihydronaphthalene  
R07024[c] [c]: 1-Nitronaphthalene-7,8-oxide + Glutathione --> 1-Nitro-7-glutathionyl-8-hydroxy-7,8-dihydronaphthalene  
R07025[c] [c]: 1-Nitronaphthalene-5,6-oxide + Glutathione --> 1-Nitro-5-hydroxy-6-glutathionyl-5,6-dihydronaphthalene  
R07026[c] [c]: 1-Nitronaphthalene-5,6-oxide + Glutathione --> 1-Nitro-5-glutathionyl-6-hydroxy-5,6-dihydronaphthalene  
R07034[c] [c]: 2 Glutathione + 5(S)-HPETE --> Oxidized glutathione + 5(S)-HETE + H2O  
R07035[c] [c]: 2 Glutathione + 15(S)-HPETE --> Oxidized glutathione + (15S)-15-Hydroxy-5,8,11-cis-13-trans-eicosatetraenoate + H2O  
R07069[c] [c]: Bromobenzene-3,4-oxide + Glutathione --> 3,4-Dihydro-3-hydroxy-4-S-glutathionyl bromobenzene  
R07070[c] [c]: Bromobenzene-2,3-oxide + Glutathione --> 2,3-Dihydro-2-S-glutathionyl-3-hydroxy bromobenzene  
R07083[c] [c]: Benzo[a]pyrene-4,5-oxide + Glutathione --> 4,5-Dihydro-4-hydroxy-5-S-glutathionyl-benzo[a]pyrene  
R07084[c] [c]: Benzo[a]pyrene-7,8-diol + Glutathione --> 7,8-Dihydro-7-hydroxy-8-S-glutathionyl-benzo[a]pyrene + H2O  
R07091[c] [c]: 2,2-Dichloroacetaldehyde + Glutathione --> S-(2,2-Dichloro-1-hydroxy)ethyl glutathione  
R07092[c] [c]: 1,1-Dichloroethylene epoxide + Glutathione --> 2-(S-Glutathionyl)acetyl chloride + HCl  
R07093[c] [c]: Chloroacetyl chloride + Glutathione --> S-(2-Chloroacetyl)glutathione + HCl  
R07094[c] [c]: 2-(S-Glutathionyl)acetyl chloride + Glutathione --> 2-(S-Glutathionyl)acetyl glutathione

+ HCl

R07100[c] [c]: Trichloroethene + Glutathione --> S-(1,2-Dichlorovinyl)glutathione + HCl

R07105[c] [c]: Chloral hydrate + NADH + H+ --> Trichloroethanol + NAD+ + H2O

R07113[c] [c]: 1,2-Dibromoethane + Glutathione --> Glutathione episulfonium ion + 2 Hydrobromic acid

R07116[c] [c]: 2-Bromoacetaldehyde + Glutathione --> S-(Formylmethyl)glutathione + Hydrobromic acid

R07263[c] [c]: 2-Succinylbenzoyl-CoA <==> 1,4-Dihydroxy-2-naphthoyl-CoA + H2O

R07281[c] [c]: D-Ribulose 5-phosphate --> 3,4-Dihydroxy-2-butanone 4-phosphate + Formate

R07384[c] [c]: O-1-Alk-1-enyl-2-acyl-sn-glycero-3-phosphoethanolamine + CMP <==> 1-Alkenyl-2-acylglycerol + CDP-ethanolamine

R07385[c] [c]: O-1-Alk-1-enyl-2-acyl-sn-glycero-3-phosphoethanolamine + H2O --> 2-Acyl-1-(1-alkenyl)-sn-glycero-3-phosphate + Ethanolamine

R07409[c] [c]: Choline + Oxygen + 2 Reduced ferredoxin + 2 H+ --> Betaine aldehyde + 2 H2O + 2 Oxidized ferredoxin

R07411[c] [c]: Heme --> Heme O

R07413[c] [c]: Digalacturonate + H2O --> 2 D-Galacturonate

R07429[c] [c]: Campestan-4-en-3-one + NADPH --> 5alpha-Campestan-3-one + NADP+

R07430[c] [c]: 6-Oxocampestanol + Oxygen + NADPH --> Cathasterone + NADP+ + H2O

R07431[c] [c]: Cathasterone + Oxygen + Reduced acceptor --> Teasterone + H2O + Acceptor

R07436[c] [c]: p-Coumaroyl-CoA --> Caffeoyl-CoA

R07437[c] [c]: 4-Hydroxycinnamyl aldehyde + NADPH + H+ --> 4-Coumaryl alcohol + NADP+

R07440[c] [c]: Ferulate + NADPH + H+ + Oxygen --> 5-Hydroxyferulate + NADP+ + H2O

R07441[c] [c]: Sinapoyl aldehyde + NAD+ + H2O --> Sinapate + NADH + H+

R07442[c] [c]: Sinapoyl aldehyde + NADP+ + H2O --> Sinapate + NADPH + H+

R07443[c] [c]: 5-Hydroxyconiferyl alcohol --> 5-Hydroxy-guaiacyl lignin

R07444[c] [c]: Teasterone <==> 3-Dehydroteasterone

R07445[c] [c]: Campesterol + Oxygen + NADPH --> 22alpha-Hydroxy-campesterol + NADP+ + H2O

R07447[c] [c]: 22alpha-Hydroxy-campestan-4-en-3-one + NADPH --> 22alpha-Hydroxy-5alpha-campestan-3-one + NADP+

R07448[c] [c]: 6-Deoxocathasterone + Oxygen --> 6-Deoxoteasterone + H2O

R07449[c] [c]: 6-Deoxoteasterone <==> 3-Dehydro-6-deoxoteasterone

R07450[c] [c]: 6-Deoxocastasterone + Oxygen --> 6alpha-Hydroxy-castasterone + H2O

R07451[c] [c]: 6alpha-Hydroxy-castasterone --> Castasterone

R07452[c] [c]: Campestan-4-en-3-one + Oxygen + NADPH --> 22alpha-Hydroxy-campestan-4-en-3-one + NADP+ + H2O

R07453[c] [c]: 5alpha-Campestan-3-one + Oxygen + NADPH --> 22alpha-Hydroxy-5alpha-campestan-3-one + NADP+ + H2O

R07454[c] [c]: Campestanol + Oxygen + NADPH --> 6-Deoxocathasterone + NADP+ + H2O

R07455[c] [c]: 6-Deoxoteasterone + Oxygen --> Teasterone + H2O

R07457[c] [c]: 3-Dehydro-6-deoxoteasterone + Oxygen --> 3-Dehydroteasterone + H2O

R07458[c] [c]: 6-Deoxotyphasterol + Oxygen --> Typhasterol + H2O

R07460[c] [c]: C15811 + L-Cysteine --> C15812 + L-Alanine

R07481[c] [c]: Cycloartenol + S-Adenosyl-L-methionine --> 24-Methylenecycloartanol + S-Adenosyl-L-homocysteine

R07483[c] [c]: 4alpha-Methyl-5alpha-ergosta-8,14,24(28)-trien-3beta-ol + NADPH + H+ --> 4alpha-Methylfecosterol + NADP+

R07484[c] [c]: 4alpha-Methylfecosterol --> 24-Methylene lophenol

R07486[c] [c]: delta7-Avenasterol --> 5-Dehydroavenasterol

R07487[c] [c]: 5-Dehydroavenasterol --> Isofucosterol

R07488[c] [c]: Isofucosterol + NADPH + H+ --> Sitosterol + NADP+

R07489[c] [c]: Sitosterol --> Stigmasterol

R07491[c] [c]: Episterol --> 5-Dehydroepisterol

R07492[c] [c]: 5-Dehydroepisterol --> 24-Methylenecholesterol

R07493[c] [c]: 24-Methylenecholesterol + NADPH + H+ --> Campesterol + NADP+

R07498[c] [c]: Zymosterol + NADPH + H+ --> 5alpha-Cholest-8-en-3beta-ol + NADP+  
R07499[c] [c]: 14-Demethylstanosterol + NADPH + H+ --> 4,4-Dimethyl-5alpha-cholesta-8-en-3beta-ol + NADP+  
R07500[c] [c]: Phytol diphosphate + Homogentisate --> 2-Methyl-6-phytylquinol + Pyrophosphate + CO2  
R07502[c] [c]: 2,3-Dimethyl-5-phytylquinol --> gamma-Tocopherol  
R07503[c] [c]: 2-Methyl-6-phytylquinol --> delta-Tocopherol  
R07504[c] [c]: delta-Tocopherol + S-Adenosyl-L-methionine --> beta-Tocopherol + S-Adenosyl-L-homocysteine  
R07507[c] [c]: 7-Dehydrodesmosterol + NADPH + H+ --> Cholesta-5,7-dien-3beta-ol + NADP+  
R07509[c] [c]: 2 14-Demethylstanosterol + 2 NADPH + 3 Oxygen --> 2 4alpha-Methylzymosterol-4-carboxylate + 2 NADP+ + 2 H2O + 4 H+  
R07530[c] [c]: alpha-Carotene --> Zeinoxanthin  
R07531[c] [c]: Zeinoxanthin --> Lutein  
R07554[c] [c]: (2'S)-Deoxymyxol 2'-(2,4-di-O-methyl-alpha-L-fucoside) --> (3R,2'S)-Myxol 2'-(2,4-di-O-methyl-alpha-L-fucoside)  
R07556[c] [c]: (2'S)-Deoxymyxol 2'-alpha-L-fucoside --> (3R,2'S)-Myxol 2'-alpha-L-fucoside  
R07558[c] [c]: beta-Carotene --> beta-Cryptoxanthin  
R07559[c] [c]: beta-Cryptoxanthin --> Zeaxanthin  
R07561[c] [c]: Echinenone --> 3'-Hydroxyechinenone  
R07562[c] [c]: Echinenone --> 3-Hydroxyechinenone  
R07568[c] [c]: Canthaxanthin --> Phoenicoxanthin  
R07569[c] [c]: 3'-Hydroxyechinenone --> Adonixanthin  
R07570[c] [c]: 3-Hydroxyechinenone --> Adonixanthin  
R07572[c] [c]: Phoenicoxanthin --> Astaxanthin  
R07599[c] [c]: 3-Methyl-2-oxobutanoic acid + Thiamin diphosphate --> 2-Methyl-1-hydroxypropyl-ThPP + CO2  
R07600[c] [c]: 2-Methyl-1-hydroxypropyl-ThPP + Enzyme N6-(lipoyl)lysine --> [Dihydrolipoyllysine-residue (2-methylpropanoyl)transferase] S-(2-methylpropanoyl)dihydrolipoyllysine + Thiamin diphosphate  
R07601[c] [c]: 4-Methyl-2-oxopentanoate + Thiamin diphosphate --> 3-Methyl-1-hydroxybutyl-ThPP + CO2  
R07602[c] [c]: 3-Methyl-1-hydroxybutyl-ThPP + Enzyme N6-(lipoyl)lysine --> [Dihydrolipoyllysine-residue (2-methylpropanoyl)transferase] S-(3-methylbutanoyl)dihydrolipoyllysine + Thiamin diphosphate  
R07603[c] [c]: (S)-3-Methyl-2-oxopentanoic acid + Thiamin diphosphate --> 2-Methyl-1-hydroxybutyl-ThPP + CO2  
R07604[c] [c]: 2-Methyl-1-hydroxybutyl-ThPP + Enzyme N6-(lipoyl)lysine --> [Dihydrolipoyllysine-residue (2-methylpropanoyl)transferase] S-(2-methylbutanoyl)dihydrolipoyllysine + Thiamin diphosphate  
R07613[c] [c]: LL-2,6-Diaminoheptanedioate + 2-Oxoglutarate <==> 2,3,4,5-Tetrahydrodipicolinate + L-Glutamate + H2O  
R07618[m] [m]: Enzyme N6-(dihydrolipoyl)lysine + NAD+ <==> Enzyme N6-(lipoyl)lysine + NADH + H+  
R07672[c] [c]: GDP-mannose <==> GDP-L-gulose  
R07673[c] [c]: GDP-L-gulose <==> GDP-L-galactose  
R07674[c] [c]: L-Galactose 1-phosphate + H2O --> L-Galactose + Orthophosphate  
R07675[c] [c]: L-Galactose + NAD+ --> L-Galactono-1,4-lactone + NADH + H+  
R07678[c] [c]: GDP-L-galactose + Orthophosphate --> L-Galactose 1-phosphate + GDP  
R07679[c] [c]: Ascorbate + 2 Ferricytochrome c --> L-Dehydroascorbate + 2 Ferrocyclochrome c + 2 H+  
R07687[c] [c]: Anthracene + Oxygen + 2 H+ + 2 e- --> Anthracene-9,10-dihydrodiol  
R07688[c] [c]: Anthracene-9,10-dihydrodiol --> 9,10-Dihydroxyanthracene + 2 H+  
R07697[c] [c]: Phenylboronic acid + Oxygen --> Phenol + H2O  
R07700[c] [c]: Aniline + Oxygen --> Catechol + NH3  
R07706[c] [c]: Nitrobenzene + Oxygen --> Catechol + Nitrite  
R07759[c] [c]: 3-Oxostearoyl-CoA + NADPH + H+ --> 3-Hydroxyoctadecanoyl-CoA + NADP+  
R07760[c] [c]: 3-Hydroxyoctadecanoyl-CoA --> (2E)-Octadecenoyl-CoA + H2O  
R07761[c] [c]: (2E)-Octadecenoyl-CoA + NADPH + H+ --> Stearoyl-CoA + NADP+  
R07762[c] [c]: Hexadecanoyl-[acp] + Malonyl-[acyl-carrier protein] --> 3-Oxostearoyl-[acp] + Acyl-

carrier protein + CO2

R07763[c] [c]: 3-Oxostearoyl-[acp] + NADPH + H+ --> 3-Hydroxyoctadecanoyl-[acp] + NADP+  
R07764[c] [c]: 3-Hydroxyoctadecanoyl-[acp] --> (2E)-Octadecenoyl-[acp] + H2O  
R07765[c] [c]:(2E)-Octadecenoyl-[acp] + NADH + H+ <==> Octadecanoyl-[acyl-carrier protein] + NAD+  
R07766[c] [c]: Octanoyl-[acp] + Apoprotein --> Protein N6-(octanoyl)lysine + Acyl-carrier protein  
R07767[c] [c]: Protein N6-(octanoyl)lysine + 2 Sulfur + 2 S-Adenosyl-L-methionine --> Protein N6-(lipoyl)lysine + 2 L-Methionine + 2 5'-Deoxyadenosine  
R07768[c] [c]: Octanoyl-[acp] + 2 Sulfur + 2 S-Adenosyl-L-methionine --> Lipoyl-[acp] + 2 L-Methionine + 2 5'-Deoxyadenosine  
R07769[c] [c]: Lipoyl-[acp] + Apoprotein --> Protein N6-(lipoyl)lysine + Acyl-carrier protein  
R07779[c] [c]: 3,5-Dibromo-4-hydroxybenzotrile + 2 NADPH + 2 H+ + Oxygen --> 2,6-Dibromohydroquinone + 2 NADP+ + Hydrogen cyanide + H2O  
R07804[c] [c]: (+)-(3S,4R)-cis-3,4-Dihydroxy-3,4-dihydrofluorene --> 3,4-Dihydroxyfluorene + 2 H+  
R07807[c] [c]: G13032 + H2O --> G06780 + D-Galactose  
R07809[c] [c]: G13033 + H2O --> G08421 + N-Acetyl-D-galactosamine  
R07810[c] [c]: G06780 + H2O --> G08421 + N-Acetyl-D-galactosamine  
R07816[c] [c]: G13038 + H2O --> G13039 + N-Acetyl-D-glucosamine  
R07826[c] [c]: 4-Coumarate --> 3,4-Dihydroxy-trans-cinnamate  
R07840[c] [c]: delta-Carotene --> epsilon-Carotene  
R07850[c] [c]: alpha-Carotene --> alpha-Cryptoxanthin  
R07851[c] [c]: alpha-Cryptoxanthin --> Lutein  
R07855[c] [c]: Phenylacetonitrile + 2 H2O --> Phenylacetic acid + NH3  
R07856[c] [c]: beta-Zeacarotene --> 7,8-Dihydro-beta-carotene  
R07863[c] [c]: 13(S)-HPOT --> (9Z,15Z)-(13S)-12,13-Epoxyoctadeca-9,11,15-trienoic acid + H2O  
R07864[c] [c]: (9Z,12Z,15Z)-Octadecatrienoic acid + Oxygen --> 9(S)-HPOT  
R07865[c] [c]: 9(S)-HPOT --> 9,10-EOT + H2O  
R07868[c] [c]: 9(S)-HPOT --> 9-Oxononanoic acid + 3,6-Nonadienal  
R07869[c] [c]: (9Z,12Z,15Z)-Octadecatrienoic acid + Oxygen --> 13(S)-HPOT  
R07870[c] [c]: 13(S)-HPOT --> 12-Oxo-9(Z)-dodecenoic acid + 3-Hexenal  
R07874[c] [c]: Pelargonidin 3-O-glucoside + UDP-glucose --> Pelargonin + UDP  
R07887[c] [c]: ATP + 8-[(1R,2R)-3-Oxo-2-{(Z)-pent-2-enyl}cyclopentyl]octanoate + CoA --> AMP + Pyrophosphate + OPC8-CoA  
R07888[c] [c]: OPC8-CoA + FAD --> trans-2-Enoyl-OPC8-CoA + FADH2  
R07889[c] [c]: trans-2-Enoyl-OPC8-CoA + H2O --> 3-Hydroxy-OPC8-CoA  
R07890[c] [c]: 3-Hydroxy-OPC8-CoA + NAD+ --> 3-Oxo-OPC8-CoA + NADH + H+  
R07891[c] [c]: CoA + 3-Oxo-OPC8-CoA --> OPC6-CoA + Acetyl-CoA  
R07892[c] [c]: OPC6-CoA + FAD --> trans-2-Enoyl-OPC6-CoA + FADH2  
R07893[c] [c]: trans-2-Enoyl-OPC6-CoA + H2O --> 3-Hydroxy-OPC6-CoA  
R07894[c] [c]: 3-Hydroxy-OPC6-CoA + NAD+ --> 3-Oxo-OPC6-CoA + NADH + H+  
R07895[c] [c]: CoA + 3-Oxo-OPC6-CoA --> OPC4-CoA + Acetyl-CoA  
R07896[c] [c]: OPC4-CoA + FAD --> trans-2-Enoyl-OPC4-CoA + FADH2  
R07897[c] [c]: trans-2-Enoyl-OPC4-CoA + H2O --> 3-Hydroxy-OPC4-CoA  
R07898[c] [c]: 3-Hydroxy-OPC4-CoA + NAD+ --> 3-Oxo-OPC4-CoA + NADH + H+  
R07899[c] [c]: CoA + 3-Oxo-OPC4-CoA --> (+)-7-Isojasmonic acid CoA + Acetyl-CoA  
R07911[c] [c]: Delphinidin 3-O-glucoside + UDP-glucose --> Delphin + UDP  
R07916[c] [c]: Geranylgeranyl diphosphate --> Phytoene  
R07934[c] [c]: (6Z,9Z,12Z,15Z,18Z,21Z)-Tetracosahexaenoyl-CoA + FAD --> (2E,6Z,9Z,12Z,15Z,18Z,21Z)-Tetracosahexa-2,6,9,12,15,18,21-enoyl-CoA + FADH2  
R07942[c] [c]: 1-Methylxanthine + H2O + Oxygen --> 1-Methyluric acid + H2O2  
R07950[c] [c]: (6Z,9Z,12Z,15Z,18Z)-Tetracosapentaenoyl-CoA + FAD --> (2E,6Z,9Z,12Z,15Z,18Z)-Tetracosahexa-2,6,9,12,15,18-enoyl-CoA + FADH2  
R07977[c] [c]: 1,7-Dimethylxanthine + Oxygen + H2O --> 1,7-Dimethyluric acid + H2O2  
R07978[c] [c]: Theobromine + H2O + Oxygen --> 3,7-Dimethyluric acid + H2O2  
R07979[c] [c]: 7-Methylxanthine + Oxygen + H2O --> 7-Methyluric acid + H2O2  
R07981[c] [c]: 2 1,3,7-Trimethyluric acid + 3 Oxygen + 2 H2O + 2 H+ --> 2 3,6,8-Trimethylallantoin +



2 CO<sub>2</sub> + 2 H<sub>2</sub>O<sub>2</sub>

R07987[c] [c]: 15 Cinnamoyl-CoA + 19 Malonyl-CoA + 35 H<sup>+</sup> --> 12 Pinocebrin chalcone + 34 CoA + 12 CO<sub>2</sub>

R07988[c] [c]: 4 Caffeoyle-CoA + 4 Malonyl-CoA + 8 H<sup>+</sup> --> 3 Eriodictyol chalcone + 8 CoA + 3 CO<sub>2</sub>

R07989[c] [c]: 27 Feruloyl-CoA + 29 Malonyl-CoA + 49 H<sup>+</sup> --> 21 Homoeriodictyol chalcone + 56 CoA + 21 CO<sub>2</sub>

R07990[c] [c]: Pinocebrin chalcone --> Pinocebrin

R07993[c] [c]: Pinocebrin + 2-Oxoglutarate + Oxygen --> Pinobanksin + Succinate + CO<sub>2</sub>

R07995[c] [c]: Butein --> Butin

R07996[c] [c]: Liquiritigenin + 2-Oxoglutarate + Oxygen --> Garbanzol + Succinate + CO<sub>2</sub>

R07997[c] [c]: Butin + 2-Oxoglutarate + Oxygen --> Fustin + Succinate + CO<sub>2</sub>

R07998[c] [c]: Garbanzol + NADPH + H<sup>+</sup> --> 5-Deoxyleucopelargonidin + NADP<sup>+</sup>

R07999[c] [c]: Fustin + NADPH + H<sup>+</sup> --> Fisetinidol-4beta-ol + NADP<sup>+</sup>

R08002[c] [c]: Liquiritigenin + NADPH + H<sup>+</sup> + Oxygen --> Butin + NADP<sup>+</sup> + H<sub>2</sub>O

R08032[c] [c]: Garbanzol + NADPH + H<sup>+</sup> + Oxygen --> Fustin + NADP<sup>+</sup> + H<sub>2</sub>O

R08051[c] [c]: Dimethylallyl diphosphate + ATP --> Isopentenyladenosine-5'-triphosphate + Pyrophosphate

R08052[c] [c]: Dimethylallyl diphosphate + ADP --> Isopentenyladenosine-5'-diphosphate + Pyrophosphate

R08053[c] [c]: Isopentenyladenosine-5'-triphosphate + Reduced flavoprotein + Oxygen --> trans-Zeatin riboside triphosphate + Oxidized flavoprotein + H<sub>2</sub>O

R08054[c] [c]: Isopentenyladenosine-5'-diphosphate + Reduced flavoprotein + Oxygen --> trans-Zeatin riboside diphosphate + Oxidized flavoprotein + H<sub>2</sub>O

R08055[c] [c]: N6-(delta2-Isopentenyl)-adenosine 5'-monophosphate + Reduced flavoprotein + Oxygen --> trans-Zeatin riboside monophosphate + Oxidized flavoprotein + H<sub>2</sub>O

R08075[c] [c]: Zeatin + UDP-glucose --> trans-Zeatin-7-beta-D-glucoside + UDP

R08076[c] [c]: Dihydrozeatin + UDP-glucose --> Dihydrozeatin-O-glucoside + UDP

R08082[c] [c]: Pinobanksin + 2-Oxoglutarate + Oxygen --> Galangin + Succinate + CO<sub>2</sub> + H<sub>2</sub>O

R08091[c] [c]: 7-Methyl-3-oxo-6-octenoyl-CoA + CoA --> 5-Methylhex-4-enoyl-CoA + Acetyl-CoA

R08093[c] [c]: (2E)-5-Methylhexa-2,4-dienoyl-CoA + H<sub>2</sub>O --> 3-Hydroxy-5-methylhex-4-enoyl-CoA

R08095[c] [c]: 5-Methyl-3-oxo-4-hexenoyl-CoA + CoA --> 3-Methylcrotonyl-CoA + Acetyl-CoA

R08105[c] [c]: 4-Fluorocyclohexadiene-cis,cis-1,2-diol + NAD<sup>+</sup> --> 4-Fluorocatechol + NADH + H<sup>+</sup>

R08120[c] [c]: 5-Fluoromuconolactone + H<sub>2</sub>O --> 2-Maleylacetate + Hydrofluoric acid

R08121[c] [c]: 4-Fluoromuconolactone + H<sub>2</sub>O --> 2-Maleylacetate + Hydrofluoric acid

R08157[c] [c]: Octanoyl-[acp] + H<sub>2</sub>O --> Acyl-carrier protein + Octanoic acid

R08158[c] [c]: Decanoyl-[acp] + H<sub>2</sub>O --> Acyl-carrier protein + Decanoic acid

R08159[c] [c]: Tetradecanoyl-[acp] + H<sub>2</sub>O --> Acyl-carrier protein + Tetradecanoic acid

R08161[c] [c]: Hexadecanoyl-[acp] + Reduced acceptor + Oxygen --> Hexadecenoyl-[acyl-carrier protein] + Acceptor + 2 H<sub>2</sub>O

R08162[c] [c]: Hexadecenoyl-[acyl-carrier protein] + H<sub>2</sub>O --> Acyl-carrier protein + (9Z)-Hexadecenoic acid

R08163[c] [c]: Octadecanoyl-[acyl-carrier protein] + H<sub>2</sub>O --> Acyl-carrier protein + Octadecanoic acid

R08174[c] [c]: Stearoyl-CoA + H<sub>2</sub>O --> CoA + Octadecanoic acid

R08175[c] [c]: Eicosanoyl-CoA + H<sub>2</sub>O --> CoA + Icosanoic acid

R08176[c] [c]: Oleoyl-CoA + H<sub>2</sub>O --> CoA + (9Z)-Octadecenoic acid

R08177[c] [c]: Linoleoyl-CoA + H<sub>2</sub>O --> CoA + Linoleate

R08178[c] [c]: (9Z,12Z,15Z)-Octadecatrienoyl-CoA + H<sub>2</sub>O --> CoA + (9Z,12Z,15Z)-Octadecatrienoic acid

R08179[c] [c]: (5Z,8Z,11Z,14Z,17Z)-Icosapentaenoyl-CoA + H<sub>2</sub>O --> CoA + (5Z,8Z,11Z,14Z,17Z)-Icosapentaenoic acid

R08180[c] [c]: (4Z,7Z,10Z,13Z,16Z,19Z)-Docosahexaenoyl-CoA + H<sub>2</sub>O --> CoA + (4Z,7Z,10Z,13Z,16Z,19Z)-Docosahexaenoic acid

R08181[c] [c]: gamma-Linolenoyl-CoA + H<sub>2</sub>O --> CoA + (6Z,9Z,12Z)-Octadecatrienoic acid

R08182[c] [c]: 8,11,14-Eicosatrienoyl-CoA + H<sub>2</sub>O --> CoA + (8Z,11Z,14Z)-Icosatrienoic acid

R08183[c] [c]: Arachidonyl-CoA + H<sub>2</sub>O --> CoA + (5Z,8Z,11Z,14Z)-Icosatetraenoic acid

R08184[c] [c]: Docosanoyl-CoA + H<sub>2</sub>O --> CoA + Docosanoic acid

R08185[c] [c]: Tetracosanoyl-CoA + H2O --> CoA + Tetracosanoic acid  
R08186[c] [c]: Icosenoyl-CoA + H2O --> CoA + Icosenoic acid  
R08187[c] [c]: Docosenoyl-CoA + H2O --> CoA + (13Z)-Docosenoic acid  
R08188[c] [c]: Tetracosenoyl-CoA + H2O --> CoA + (15Z)-Tetracosenoic acid  
R08189[c] [c]: (7Z,10Z,13Z,16Z,19Z)-Docosapentaenoyl-CoA + H2O --> CoA + (7Z,10Z,13Z,16Z,19Z)-Docosa-7,10,13,16,19-pentaenoic acid  
R08190[c] [c]: (11Z,14Z)-Icosadienoyl-CoA + H2O --> CoA + Icosadienoic acid  
R08191[c] [c]: (7Z,10Z,13Z,16Z)-Docosatetraenoyl-CoA + H2O --> CoA + 7,10,13,16-Docosatetraenoic acid  
R08192[c] [c]: (11Z,14Z,17Z)-Icosatrienoyl-CoA + H2O --> CoA + Icosatrienoic acid  
R08193[c] [c]: N-Acetyl-D-glucosamine 6-phosphate <=> N-Acetyl-alpha-D-glucosamine 1-phosphate  
R08221[c] [c]: 5'-Deoxy-5-fluorocytidine + H2O --> 5'-Deoxy-5-fluorouridine + NH3  
R08227[c] [c]: 5,6-Dihydro-5-fluorouracil + H2O --> alpha-Fluoro-beta-ureidopropionic acid  
R08228[c] [c]: alpha-Fluoro-beta-ureidopropionic acid + H2O --> alpha-Fluoro-beta-alanine + CO2 + NH3  
R08231[c] [c]: 5-FU + 5-Phospho-alpha-D-ribose 1-diphosphate --> 5-Fluorouridine monophosphate + Pyrophosphate  
R08233[c] [c]: 5-Fluorodeoxyuridine + ATP --> 5-Fluorodeoxyuridine monophosphate + ADP  
R08235[c] [c]: 2 6-Mercaptopurin + 2 H2O + 3 Oxygen --> 2 6-Thiourate + 3 H2O2  
R08237[c] [c]: 6-Mercaptopurin + 5-Phospho-alpha-D-ribose 1-diphosphate --> 6-Thioinosine 5'-monophosphate + Pyrophosphate  
R08238[c] [c]: 6-Methylmercaptapurine + 5-Phospho-alpha-D-ribose 1-diphosphate --> 6-Methylthiopurine 5'-monophosphate ribonucleotide + Pyrophosphate  
R08240[c] [c]: 6-Thioinosine 5'-monophosphate + NAD+ + H2O --> 6-Thioxanthine 5'-monophosphate + NADH + H+  
R08243[c] [c]: 6-Mercaptopurine ribonucleoside triphosphate + H2O --> 6-Thioinosine 5'-monophosphate + Pyrophosphate  
R08244[c] [c]: 6-Thioxanthine 5'-monophosphate + ATP + L-Glutamine + H2O --> 6-Thioguanosine monophosphate + AMP + Pyrophosphate + L-Glutamate  
R08245[c] [c]: Thioguanine + 5-Phospho-alpha-D-ribose 1-diphosphate --> 6-Thioguanosine monophosphate + Pyrophosphate  
R08266[c] [c]: Tamoxifen + Oxygen + NADPH + H+ --> Tamoxifen N-oxide + NADP+ + H2O  
R08273[c] [c]: (13Z,16Z)-Docosadi-13,16-enoyl-CoA + H2O --> CoA + 13,16-Docosadienoic acid  
R08280[c] [c]: Aldophosphamide + Glutathione --> 4-Glutathionyl cyclophosphamide + H2O  
R08281[c] [c]: Aldophosphamide + NADH + H+ --> Alcophosphamide + NAD+  
R08306[c] [c]: 2-Phenyl-1,3-propanediol monocarbamate + NAD+ --> 3-Carbamoyl-2-phenylpropionaldehyde + NADH + H+  
R08310[c] [c]: 4-Hydroxy-5-phenyltetrahydro-1,3-oxazin-2-one + NAD+ --> 5-Phenyl-1,3-oxazinane-2,4-dione + NADH + H+  
R08359[c] [c]: S-Adenosylmethioninamine + Cadaverine --> 5'-Methylthioadenosine + Aminopropylcadaverine  
R08363[c] [c]: Ribonucleoside diphosphate + Tryparedoxin --> 2'-Deoxyribonucleoside diphosphate + Tryparedoxin disulfide + H2O  
R08364[c] [c]: Ribonucleoside diphosphate + Trypanothione --> 2'-Deoxyribonucleoside diphosphate + Trypanothione disulfide + H2O  
R08379[c] [c]: Retinol + NADP+ <=> Retinal + NADPH + H+  
R08383[c] [c]: 9-cis-Retinol + NADP+ <=> 9-cis-Retinal + NADPH + H+  
R05578[c] [c]: 12 tRNA(Glu) + 26 L-Glutamate + 33 ATP + 26 H+ <=> 6 L-Glutamyl-tRNA(Glu) + 22 Diphosphate + 43 AMP  
R04208[c] [c]: ATP + 2-(Formamido)-N1-(5'-phosphoribosyl)acetamidine <=> ADP + Orthophosphate + Aminoimidazole ribotide  
R00737[c] [c]: L-Tyrosine <=> 4-Coumarate + NH3  
R00185[c] [c]: ATP + Adenosine <=> ADP + AMP  
R03657[c] [c]: ATP + L-Leucine + tRNA(Leu) <=> AMP + Diphosphate + L-Leucyl-tRNA  
R02466[c] [c]: 3-Sulfino-L-alanine <=> Hypotaurine + CO2  
R02519[c] [c]: Homogentisate + Oxygen <=> 4-Maleylacetoacetate

R04972[c] [c]: Uroporphyrinogen I <=> Coproporphyrinogen I + 4 CO2  
R01354[c] [c]: ATP + Propanoate <=> Diphosphate + Propionyladenylate  
R01547[c] [c]: ATP + dAMP <=> ADP + dADP  
R00351[x] [x]: Citrate + CoA <=> Acetyl-CoA + H2O + Oxaloacetate  
R00351[m] [m]: Citrate + CoA <=> Acetyl-CoA + H2O + Oxaloacetate  
R00214[c] [c]: (S)-Malate + NAD+ <=> Pyruvate + CO2 + NADH + H+  
R04969[c] [c]: Hexadecanoyl-[acp] + NAD+ <=> trans-Hexadec-2-enoyl-[acp] + NADH + H+  
R04969[p] [p]: Hexadecanoyl-[acp] + NAD+ <=> trans-Hexadec-2-enoyl-[acp] + NADH + H+  
R05071[c] [c]: (S)-2-Acetylacetyl-CoA <=> 3-Hydroxy-3-methyl-2-oxobutanoic acid  
R01470[c] [c]: sn-glycero-3-Phosphoethanolamine + H2O <=> Ethanolamine + sn-Glycerol 3-phosphate  
R06869[c] [c]: S-Adenosyl-L-methionine + Phosphodimethylethanolamine <=> S-Adenosyl-L-homocysteine + Choline phosphate  
R03361[c] [c]: ATP + 1-Phosphatidyl-D-myo-inositol <=> ADP + 1-Phosphatidyl-1D-myo-inositol 4-phosphate  
R04859[c] [c]: O-Acetyl-L-serine + Thiosulfate + Thioredoxin + H+ <=> L-Cysteine + Sulfite + Thioredoxin disulfide + Acetate  
R01063[p] [p]: D-Glyceraldehyde 3-phosphate + Orthophosphate + NADP+ <=> 3-Phospho-D-glyceroyl phosphate + NADPH + H+  
R00372[x] [x]: Glycine + 2-Oxoglutarate <=> Glyoxylate + L-Glutamate  
R00533[c] [c]: Sulfite + Oxygen + H2O <=> Sulfate + H2O2  
R05973[c] [c]: GDP-D-mannose + G00003 <=> GDP + G00004  
R07396[c] [c]: 4-Methylthio-2-oxobutanoic acid + L-Glutamate <=> L-Methionine + 2-Oxoglutarate  
R00709[m] [m]: Isocitrate + NAD+ <=> 2-Oxoglutarate + CO2 + NADH + H+  
R03024[c] [c]: 4-Nitrophenyl phosphate + H2O <=> 4-Nitrophenol + Orthophosphate  
R01021[c] [c]: ATP + Choline <=> ADP + Choline phosphate  
R00485[c] [c]: L-Asparagine + H2O <=> L-Aspartate + NH3  
R00897[c] [c]: O-Acetyl-L-serine + Hydrogen sulfide <=> L-Cysteine + Acetate  
R02722[p] [p]: L-Serine + Indoleglycerol phosphate <=> L-Tryptophan + D-Glyceraldehyde 3-phosphate + H2O  
R05970[p] [p]: UDP-N-acetyl-D-glucosamine + N-Acetyl-D-glucosaminyldiphosphodolichol <=> UDP +, N,N'-Chitobiosyldiphosphodolichol  
R07613[p] [p]: LL-2,6-Diaminoheptanedioate + 2-Oxoglutarate <=> 2,3,4,5-Tetrahydrodipicolinate + L-Glutamate + H2O  
R08990[c] [c]: 5-Deoxystrigol <=> Strigol  
R03876[c] [c]: ATP + Ubiquitin + Protein lysine <=> AMP + Diphosphate + Protein N-ubiquityllysine  
R03632[c] [c]: ATP + Protamine <=> ADP + O-Phosphoprotamine  
R02418[m] [m]: Ubiquitin C-terminal thiolester + H2O <=> Ubiquitin + Thiol  
R02418[c] [c]: Ubiquitin C-terminal thiolester + H2O <=> Ubiquitin + Thiol  
R08782[c] [c]: Homogentisate + all-trans-Nonaprenyl diphosphate <=> 2-Methyl-6-solanlyl-1,4-benzoquinol + Diphosphate + CO2  
R08900[p] [p]: UDP-N-acetyl-D-glucosamine + Ribostamycin <=> UDP +, 2'''-N-Acetyl-6'''-deamino-6'''-hydroxyneomycin C  
R05644[c] [c]: ATP + D-glycero-D-manno-Heptose 1-phosphate <=> Diphosphate + ADP-D-glycero-D-manno-heptose  
R00281[p] [p]: Acceptor + NADH + H+ <=> Reduced acceptor + NAD+  
R00644[m] [m]: Ascorbate + H2O2 <=> Dehydroascorbate + 2 H2O  
R04273[c] [c]: Peptidylproline (omega=180) <=> Peptidylproline (omega=0)  
R00444[m] [m]: Nucleoside triphosphate + RNA <=> Diphosphate + RNA  
R06088[c] [c]: Neohancoside D + H2O <=> beta-D-Fructose + alpha-D-Glucose  
R03020[m] [m]: tRNA uridine <=> tRNA pseudouridine  
R08549[c] [c]: 2-Oxoglutarate + CoA + NAD+ <=> Succinyl-CoA + CO2 + NADH + H+  
R08558[c] [c]: Choline + NADP+ <=> Betaine aldehyde + NADPH + H+  
R08143[c] [c]: 20-Hydroxyecdysone <=> 20,26-Dihydroxyecdysone  
R08987[c] [c]: N1,N5,N10-Tri-(hydroxyferuloyl)-spermidine + S-Adenosyl-L-methionine <=> N1,N5-Tri-di(hydroxyferuloyl)-N10-sinapoyl-spermidine + S-Adenosyl-L-homocysteine

R00527[c] [c]: S-Formylglutathione + H2O <=> Formate + Glutathione  
R08766[m] [m]: 3-(4-Hydroxyphenyl)lactate <=> 4-Coumarate + H2O  
R03840[c] [c]: ATP + 5'-Dephospho-DNA <=> ADP + 5'-Phospho-DNA  
R02248[c] [c]: 3'-Phosphopolynucleotide + H2O <=> Polynucleotide + Orthophosphate  
R04496[c] [c]: S-Adenosyl-L-methionine + Protein C-terminal S-farnesyl-L-cysteine <=> S-Adenosyl-L-homocysteine + Protein C-terminal S-farnesyl-L-cysteine methyl ester  
R02569[m] [m]: Acetyl-CoA + Enzyme N6-(dihydrolipoyl)lysine <=> CoA + [Dihydrolipoyllysine-residue acetyltransferase] S-acetyldihydrolipoyllysine  
R00598[m] [m]: S-Adenosyl-L-methionine + tRNA guanine <=> S-Adenosyl-L-homocysteine + tRNA containing N2-methylguanine  
R03992[c] [c]: Tetradecanoyl-CoA + Glycylpeptide <=> CoA + N-Tetradecanoylglycylpeptide  
R06954[c] [c]: Xanthoxin + NAD+ <=> Abscisic aldehyde + NADH + H+  
R03599[c] [c]: Selenocysteine + Reduced acceptor <=> Selenide + L-Alanine + Acceptor  
R07381[m] [m]: O-1-Alk-1-enyl-2-acyl-sn-glycero-3-phosphoethanolamine + H2O <=> 1-Alkenyl-2-acylglycerol + Ethanolamine phosphate  
R00248[m] [m]: L-Glutamate + NADP+ + H2O <=> 2-Oxoglutarate + NH3 + NADPH + H+  
R07350[c] [c]: n-Alkanal + NADP+ <=> Alk-2-enal + NADPH + H+  
R07641[c] [c]: 2 ATP + HCO3- + NH3 <=> 2 ADP + Orthophosphate + Carbamoyl phosphate  
R06159[c] [c]: Starch <=> 1,4-alpha-D-Glucan + Maltose  
R08694[c] [c]: Pectate <=> Oligosaccharide with 4-deoxy-alpha-D-gluc-4-enuronosyl group + Pectate  
R04238[c] [c]: N-Substituted aminoacyl-tRNA + H2O <=> N-Substituted amino acid + tRNA  
R08469[c] [c]: S-Adenosyl-L-methionine + Peptide 2-[3-carboxy-3-(dimethylammonio)propyl]-L-histidine <=> S-Adenosyl-L-homocysteine + Peptide diphthine  
R04319[c] [c]: trans-2,3-Dehydroacyl-CoA + NADP+ <=> trans,trans-2,3,4,5-Tetrahydroacyl-CoA + NADPH + H+  
R08707[c] [c]: 4-N-(N-Acetyl-D-glucosaminy)-protein + H2O <=> N-Acetyl-beta-D-glucosaminyamine + Peptide L-aspartate  
R07815[m] [m]: Acetyl-CoA + G13037 <=> CoA + G13038  
R04867[m] [m]: S-Adenosyl-L-methionine + Protein N6,N6-dimethyl-L-lysine <=> S-Adenosyl-L-homocysteine + Protein N6,N6,N6-trimethyl-L-lysine  
R07360[p] [p]: Prenyl-L-cysteine + Oxygen + H2O <=> Prenal + L-Cysteine + H2O2  
R07140[c] [c]: S-(Hydroxymethyl)glutathione + NADP+ <=> S-Formylglutathione + NADPH + H+  
R00082[c] [c]: Oxygen + 4 Ferrocyclochrome c2 <=> 4 Ferricyclocchrome c2 + 2 H2O  
R00164[c] [c]: Phosphoprotein + H2O <=> Protein + Orthophosphate  
R03402[c] [c]: (9Z,15Z)-(13S)-12,13-Epoxyoctadeca-9,11,15-trienoic acid <=> 12-OPDA  
R00082[p] [p]: Oxygen + 4 Ferrocyclochrome c2 <=> 4 Ferricyclocchrome c2 + 2 H2O  
R08550[c] [c]: Protein N6-(dihydrolipoyl)lysine + NAD+ <=> Protein N6-(lipoyl)lysine + NADH + H+  
R08360[c] [c]: Tryparedoxin + ROOH <=> Tryparedoxin disulfide + H2O + ROH  
R08893[c] [c]: 2-Deoxy-scylo-inosamine + S-Adenosyl-L-methionine <=> 3-Amino-2,3-dideoxy-scylo-inosose + L-Methionine +, 5'-Deoxyadenosine  
R02161[c] [c]: Ubiquinol + 2 Ferricyclocchrome c <=> Ubiquinone + 2 Ferrocyclochrome c + 2 H+  
R08409[c] [c]: Plastoquinol-9 + 2 Oxidized plastocyanin <=> Plastoquinone-9 + 2 Reduced plastocyanin  
R08218[c] [c]: ATP + L-Serine + tRNA(Sec) <=> AMP + Diphosphate + L-Seryl-tRNA(Sec)  
R04718[c] [c]: S-Adenosyl-L-methionine + Histone L-arginine <=> S-Adenosyl-L-homocysteine + Histone N(omega)-methyl-L-arginine  
R01754[c] [c]: ATP + L-Arabinose <=> ADP + beta-L-Arabinose 1-phosphate  
R03552[c] [c]: Acetyl-CoA + Histone-L-lysine <=> CoA + Histone N6-acetyl-L-lysine  
R01868[c] [c]: (S)-Dihydroorotate + Quinone <=> Orotate + Hydroquinone  
R08901[c] [c]: 2'''-N-Acetyl-6'''-deamino-6'''-hydroxyneomycin C + H2O <=> 6'''-Deamino-6'''-hydroxyneomycin C + Acetate  
R01385[c] [c]: UDP-glucuronate <=> UDP-D-galacturonate  
R05776[c] [c]: S-Adenosyl-L-methionine + 24-Methylene lophenol <=> S-Adenosyl-L-homocysteine + 24-Ethylidene lophenol  
R03435[c] [c]: 1-Phosphatidyl-D-myo-inositol 4,5-bisphosphate + H2O <=> D-myo-Inositol 1,4,5-

trisphosphate + 1,2-Diacyl-sn-glycerol  
 R03683[c] [c]: Hemoglobin + FADH2 + 3 Oxygen <=> Globin + Biliverdin + CO + Fe3+ + FAD + 3 H2O  
 R00275[c] [c]: 2 O2.- + 2 H+ <=> H2O2 + Oxygen  
 R04096[c] [c]: 3-Methylbutanoyl-CoA + Acceptor <=> 3-Methylcrotonyl-CoA + Reduced acceptor  
 R08551[c] [c]: Oxidized flavoprotein + NADPH + H+ <=> Reduced flavoprotein + NADP+  
 R00670[c] [c]: L-Ornithine <=> Putrescine + CO2  
 R07297[c] [c]: 5'-Ribonucleotide + H2O <=> Ribonucleoside + Orthophosphate  
 R01341[c] [c]: (S)-2-Hydroxy acid + Oxygen <=> 2-Oxo acid + H2O2  
 R08931[c] [c]: dTDP-4-oxo-2,3,6-trideoxy-D-glucose + L-Glutamate <=> dTDP-4-amino-2,3,4,6-tetradexoxy-D-glucose + 2-Oxoglutarate  
 R07214[c] [c]: 1-Aminocyclopropane-1-carboxylate + Ascorbate + Oxygen <=> Ethylene + Cyanide + Dehydroascorbate + CO2 + 2 H2O  
 R03789[c] [c]: tRNA guanine + Queuine <=> tRNA queuine + Guanine  
 R07135[c] [c]: Mannitol + NAD+ <=> D-Mannose + NADH + H+  
 R02164[c] [c]: Ubiquinone + Succinate <=> Ubiquinol + Fumarate  
 R01899[c] [c]: Isocitrate + NADP+ <=> Oxalosuccinate + NADPH + H+  
 R08362[c] [c]: Trypanothione + ROOH <=> Trypanothione disulfide + H2O + ROH  
 R03744[c] [c]: ATP + tau-Protein <=> ADP + O-Phospho-tau-protein  
 R07952[c] [c]: (6Z,9Z,12Z,15Z,18Z)-3-Hydroxytetraacosapenta-6,9,12,15,18-enoyl-CoA + NAD+ <=> (6Z,9Z,12Z,15Z,18Z)-3-Oxotetraacosapenta-6,9,12,15,18-enoyl-CoA + NADH + H+  
 R08094[c] [c]: 3-Hydroxy-5-methylhex-4-enoyl-CoA + NAD+ <=> 5-Methyl-3-oxo-4-hexenoyl-CoA + NADH + H+  
 R08845[c] [c]: UTP + alpha-D-Aldose 1-phosphate <=> Diphosphate + UDP-sugar  
 R02364[c] [c]: 2 Quinone + NADPH + H+ <=> 2 Semiquinone + NADP+  
 R07861[c] [c]: (9Z,12Z,15Z)-Octadecatrienoic acid + Reduced acceptor + Oxygen <=> Stearidonic acid + Acceptor + 2 H2O  
 R02590[c] [c]: CTP + N-Trimethyl-2-aminoethylphosphonate <=> Diphosphate + CMP-N-trimethyl-2-aminoethylphosphonate  
 R07202[c] [c]: Abscisate + NADPH + H+ + Oxygen <=> 8'-Hydroxyabscisate + NADP+ + H2O  
 R02406[c] [c]: ITP + Itaconate + CoA <=> IDP + Orthophosphate + Itaconyl-CoA  
 R02404[c] [c]: ATP + Itaconate + CoA <=> ADP + Orthophosphate + Itaconyl-CoA  
 R08676[c] [c]: ADP + Sucrose <=> ADP-glucose + D-Fructose  
 R08637[c] [c]: 2-Aminobut-2-enoate + H2O <=> 2-Oxobutanoate + NH3  
 R06131[c] [c]: alpha-Amino acid <=> 2-Oxo acid + NH3  
 R07386[c] [c]: O-1-Alk-1-enyl-2-acyl-sn-glycero-3-phosphoethanolamine + Choline <=> Plasmenylcholine + Ethanolamine  
 R03896[c] [c]: (R)-2-Methylmalate <=> 2-Methylmaleate + H2O  
 R07343[c] [c]: myo-Inositol phosphate + H2O <=> myo-Inositol + Orthophosphate  
 R08648[c] [c]: Pyruvate + 2-Oxobutanoate <=> (S)-2-Aceto-2-hydroxybutanoate + CO2  
 R07395[c] [c]: 2,3-Diketo-5-methylthiopentyl-1-phosphate + H2O <=> 1,2-Dihydroxy-5-(methylthio)pent-1-en-3-one + Orthophosphate  
 R01530[c] [c]: D-Arabinose 5-phosphate <=> D-Ribulose 5-phosphate  
 R01662[c] [c]: 3-Phospho-D-glyceroyl phosphate <=> 2,3-Bisphospho-D-glycerate  
 R00486[c] [c]: 3-Cyano-L-alanine + 2 H2O <=> L-Aspartate + NH3  
 R06073[c] [c]: UDP-D-glucose + D-Fructose 6-phosphate <=> UDP + Sucrose 6-phosphate  
 R04190[c] [c]: S-Adenosyl-L-methionine + Protein L-isoaspartate <=> S-Adenosyl-L-homocysteine + Protein L-isoaspartate methyl ester  
 R01401[c] [c]: 5'-Methylthioadenosine + H2O <=> Adenine + 5-Methylthio-D-ribose  
 R08639[c] [c]: D-Glucose 1-phosphate <=> D-Glucose 6-phosphate  
 R09009[c] [c]: UDP-L-arabinose <=> UDP-L-arabinofuranose  
 R06102[c] [c]: Sucrose 6-phosphate + H2O <=> beta-D-Fructose + alpha-D-Glucose 6-phosphate  
 R06174[c] [c]: G10556 + UDP-N-acetyl-D-glucosamine <=> G10555 + UDP  
 R08688[c] [c]: desulfo-Glucosinolate + 3'-Phosphoadenylyl sulfate <=> Glucosinolate + Adenosine 3',5'-bisphosphate  
 R06171[c] [c]: L-Allothreonine <=> Glycine + Acetaldehyde

R00293[c] [c]: UDP-glucose <=> UDP-4-dehydro-6-deoxy-D-glucose + H2O  
R08512[c] [c]: Sulfuric monoester + Glutathione <=> Sulfate + R-S-Glutathione  
R06152[c] [c]: Stachyose + H2O <=> Raffinose + D-Galactose  
R01473[c] [c]: UDP-L-arabinose <=> UDP-D-xylose  
R00217[c] [c]: Oxaloacetate <=> Pyruvate + CO2  
R08198[c] [c]: 2-Hydroxyglutarate + NAD+ <=> 2-Oxoglutarate + NADH + H+  
R00435[c] [c]: ATP + RNA <=> Diphosphate + RNA  
R07363[c] [c]: 2 1,2-Dihydroxy-5-(methylthio)pent-1-en-3-one + 3 Oxygen <=> 2 3-(Methylthio)propionic acid + 4 Formate + 3 CO + 2 H+  
R07364[c] [c]: 1,2-Dihydroxy-5-(methylthio)pent-1-en-3-one + Oxygen <=> 4-Methylthio-2-oxobutanoic acid + Formate  
R04469[c] [c]: 1,2-Diacyl-3-beta-D-galactosyl-sn-glycerol + UDP-D-galactose <=> Digalactosyl-diacylglycerol + UDP  
R07606[c] [c]: L-Methionine + Thioredoxin disulfide + H2O <=> L-Methionine (S)-S-oxide + Thioredoxin  
R07324[c] [c]: D-Glucose 6-phosphate <=> 1D-myo-Inositol 3-phosphate  
R00585[c] [c]: L-Serine + Pyruvate <=> Hydroxypyruvate + L-Alanine  
R07145[c] [c]: L-Iditol + NAD+ <=> L-Sorbose + NADH + H+  
R06583[c] [c]: 5-Hydroxyferulate + CoA + ATP <=> 5-Hydroxyferuloyl-CoA + AMP + Diphosphate  
R07316[c] [c]: Carbamate <=> NH3 + CO2  
R09031[c] [c]: D-Allulose 6-phosphate <=> D-Fructose 6-phosphate  
R08823[c] [c]: Betanin + 1-O-Feruloyl-beta-D-glucose <=> Lampranthin II + D-Glucose  
R06092[c] [c]: Cellobiose + H2O <=> 2 beta-D-Glucose  
R03805[c] [c]: S-Adenosyl-L-methionine + G(5')pppR-RNA + H+ <=> S-Adenosyl-L-homocysteine + m7G(5')pppR-RNA  
R02884[c] [c]: ATP + Caldesmon <=> ADP + Caldesmon phosphate  
R06137[c] [c]: Cyclic amidines + H2O <=> Cyclic amide + NH3  
R08718[c] [c]: G00595 + H2O <=> G00971 + D-Mannose  
R05630[c] [c]: UDP-N-acetylmuramoyl-L-alanyl-D-glutamyl-6-carboxy-L-lysyl-D-alanyl- D-alanine + di-trans,poly-cis-Undecaprenyl phosphate <=> UMP + Undecaprenyl-diphospho-N-acetylmuramoyl-L-alanyl-D-glutamyl-meso- 2,6-diaminopimeloyl-D-alanyl-D-alanine  
R02853[c] [c]: D-O-Phosphoserine + H2O <=> D-Serine + Orthophosphate  
R08575[c] [c]: Sedoheptulose 7-phosphate + D-Glyceraldehyde 3-phosphate <=> D-Erythrose 4-phosphate + D-Fructose 6-phosphate  
R00558[c] [c]: L-Arginine + Oxygen + NADPH + H+ <=> N-(omega)-Hydroxyarginine + NADP+ + H2O  
R08972[c] [c]: DIBOA-glucoside + 2-Oxoglutarate + Oxygen <=> TRIBOA-glucoside + Succinate + CO2  
R08689[c] [c]: 5 2-C-Methyl-D-erythritol 2,4-cyclodiphosphate + 2 Reduced ferredoxin + 5 H+ <=> 5 1-Hydroxy-2-methyl-2-butenyl 4-diphosphate + 5 H2O + 2 Oxidized ferredoxin  
R01263[c] [c]: N-Acyl-L-amino acid + H2O <=> Carboxylate + L-Amino acid  
R07215[c] [c]: 5alpha-Cholest-7-en-3beta-ol + NADPH + H+ + Oxygen <=> Cholesta-5,7-dien-3beta-ol + NADP+ + 2 H2O  
R08756[c] [c]: Tetrahydrogeranylgeranyl diphosphate + NADPH + H+ <=> Phytlyl diphosphate + NADP+  
R05635[c] [c]: Formyl-L-methionyl peptide + H2O <=> Methionyl peptide + Formate  
R05576[c] [c]: 3-Hydroxybutanoyl-CoA + NADP+ <=> Acetoacetyl-CoA + NADPH + H+  
R07060[c] [c]: GDP-4-keto-6-L-deoxygalactose + NADPH + H+ <=> GDP-L-fucose + NADP+  
R02113[c] [c]: UDP-glucose + Sterol <=> UDP + Sterol 3-beta-D-glucoside  
R04606[c] [c]: UDP-2,3-bis(3-hydroxytetradecanoyl)glucosamine + 2,3-Bis(3-hydroxytetradecanoyl)-beta-D-glucosaminyl 1-phosphate <=> UDP +', 2,3,2',3'-Tetrakis(3-hydroxytetradecanoyl)-D-glucosaminyl-1,6-beta- D-glucosamine 1-phosphate  
R05918[c] [c]: G00144 + Palmitoyl-CoA <=> G00145 + CoA  
R01123[p] [p]: Isopentenyl diphosphate <=> Dimethylallyl diphosphate  
R00267[p] [p]: Isocitrate + NADP+ <=> 2-Oxoglutarate + CO2 + NADPH + H+  
R00268[c] [c]: Oxalosuccinate <=> 2-Oxoglutarate + CO2

R04120[c] [c]: Peptide-L-methionine + Thioredoxin disulfide + H2O <=> Peptide-L-methionine (S)-S-oxide + Thioredoxin  
R08511[c] [c]: Nitrile + Glutathione <=> Hydrogen cyanide + R-S-Glutathione  
R08512[p] [p]: Sulfuric monoester + Glutathione <=> Sulfate + R-S-Glutathione  
R04521[c] [c]: 13(S)-HPOT <=> (9Z)-(13S)-12,13-Epoxyoctadeca-9,11-dienoic acid + H2O  
R04906[c] [c]: 6 5-Hydroxyindoleacetate + 7 H+ <=> 5-Hydroxyindoleacetyl-glycine  
R04147[c] [c]: Isopenicillin N <=> Penicillin N  
R02421[c] [c]: ADP-glucose + Amylose <=> ADP + Amylose  
R00256[c] [c]: L-Glutamine + H2O <=> L-Glutamate + NH3  
R00483[c] [c]: ATP + L-Aspartate + NH3 <=> AMP + Diphosphate + L-Asparagine  
R02814[c] [c]: Oleoyl-[acyl-carrier protein] + H2O <=> Acyl-carrier protein + (9Z)-Octadecenoic acid  
R02163[c] [c]: Ubiquinol + NAD+ <=> Ubiquinone + NADH + H+  
R01130[p] [p]: IMP + NAD+ + H2O <=> Xanthosine 5'-phosphate + NADH + H+  
R03370[c] [c]: Octadecanoyl-[acyl-carrier protein] + Reduced acceptor + Oxygen <=> Oleoyl-[acyl-carrier protein] + Acceptor + 2 H2O  
R03467[c] [c]: 1,2-Diacyl-3-beta-D-galactosyl-sn-glycerol + 2 H2O <=> 3-beta-D-Galactosyl-sn-glycerol + 2 Carboxylate  
R01313[c] [c]: Phosphatidylcholine + H2O <=> 1-Acyl-sn-glycero-3-phosphocholine + Carboxylate  
R00948[p] [p]: ATP + D-Glucose 1-phosphate <=> Diphosphate + ADP-glucose  
R03626[c] [c]: Linoleate + Oxygen <=> (9Z,11E)-(13S)-13-Hydroperoxyoctadeca-9,11-dienoic acid  
R08656[c] [c]: L-Tyrosine + 2 Oxygen + 2 NADPH + 2 H+ <=> (Z)-4-Hydroxyphenylacetaldehyde-oxime + 2 NADP+ + 3 H2O + CO2  
R05731[c] [c]: 2 Obtusifoliol + 3 Oxygen + 2 NADPH <=> 2 4alpha-Methyl-5alpha-ergosta-8,14,24(28)-trien-3beta-ol + 2 Formate + 2 NADP+ + 2 H2O + 4 H+  
R07680[c] [c]: L-Galactono-1,4-lactone + H2O <=> L-Galactonate  
R04206[c] [c]: 3-Phospho-D-erythronate <=> Phosphoenol-4-deoxy-3-tetralosonate + H2O  
R00667[c] [c]:L-Ornithine + 2-Oxoglutarate <=> L-Glutamate 5-semialdehyde + L-Glutamate  
R01290[c] [c]:L-Serine + L-Homocysteine <=> L-Cystathionine + H2O  
R07943[c] [c]:1,7-Dimethylxanthine <=> 1-Methylxanthine  
R00636[c] [c]:2-Oxo acid <=> Aldehyde + CO2  
R04942[c] [c]:L-Serine + Selenohomocysteine <=> Selenocystathionine + H2O  
R03217[c] [c]:O-Acetyl-L-homoserine + L-Cysteine <=> L-Cystathionine + Acetate  
R01253[c] [c]:L-Proline + Acceptor <=> (S)-1-Pyrroline-5-carboxylate + Reduced acceptor  
R05450[c] [c]:2-Hydroxyphenylacetate + Oxygen + NADH + H+ <=> Homogentisate + NAD+ + H2O  
R00233[c] [c]:Malonyl-CoA <=> Acetyl-CoA + CO2  
R00967[c] [c]:UTP + Uridine <=> UDP + UMP  
R00978[c] [c]:5,6-Dihydrouracil + NADP+ <=> Uracil + NADPH + H+  
R01549[c] [c]:dATP + Uridine <=> dADP + UMP  
R02332[c] [c]:dUTP + Uridine <=> dUDP + UMP  
R01880[c] [c]:dGTP + Uridine <=> dGDP + UMP  
R01168[c] [c]:L-Histidine <=> Urocanate + NH3  
R02150[c] [c]:1H-Imidazole-4-ethanamine + Oxygen + H2O <=> Imidazole-4-acetaldehyde + NH3 + H2O  
R03295[c] [c]:trans-4-Hydroxy-L-proline + FAD <=> L-1-Pyrroline-3-hydroxy-5-carboxylate + FADH2  
R04444[c] [c]:L-1-Pyrroline-3-hydroxy-5-carboxylate + NAD+ + 2 H2O <=> L-erythro-4-Hydroxyglutamate + NADH + H+  
R04445[c] [c]:L-1-Pyrroline-3-hydroxy-5-carboxylate + NADP+ + 2 H2O <=> L-erythro-4-Hydroxyglutamate + NADPH + H+  
R08618[c] [c]:L-Methionine + 2-Oxo acid <=> 4-Methylthio-2-oxobutanoic acid + L-Amino acid  
R05487[c] [c]:Phenylacetic acid + Oxygen + NADH + H+ <=> 2-Hydroxyphenylacetate + NAD+ + H2O  
R00784[c] [c]:Nitric oxide + H2O + Ferricytochrome c2 <=> Nitrite + Ferrocycytochrome c2 + H+  
R00941[c] [c]:10-Formyltetrahydrofolate + NADP+ + H2O <=> Tetrahydrofolate + CO2 + NADPH + H+  
R02261[c] [c]:2-Dehydro-3-deoxy-L-rhamnonate <=> (S)-Lactaldehyde + Pyruvate

R02577[c] [c]:Propane-1,2-diol + NADP+ <=> Lactaldehyde + NADPH + H+  
R01226[c] [c]:5,10-Methylenetetrahydrofolate + 3-Methyl-2-oxobutanoic acid + H2O <=>  
Tetrahydrofolate + 2-Dehydropantoate  
R00891[c] [c]:L-Serine + Hydrogen sulfide <=> L-Cysteine + H2O  
R05259[c] [c]:Parathion + Reduced flavoprotein + Oxygen <=> Paraoxon + Oxidized flavoprotein +  
Sulfur + H2O  
R08579[c] [c]:Parathion <=> Paraoxon  
R01287[c] [c]:O-Acetyl-L-homoserine + Hydrogen sulfide <=> L-Homocysteine + Acetate  
R02846[c] [c]:Cysteine + Cyanide <=> Hydrogen sulfide + 3-Cyano-L-alanine  
R01178[c] [c]:Butanoyl-CoA + Acceptor <=> Crotonoyl-CoA + Reduced acceptor  
R03097[c] [c]:Indole-3-acetate + Oxygen <=> 2-Formaminobenzoylacetate  
R00274[c] [c]:H2O2 + 2 Glutathione <=> Glutathione disulfide + 2 H2O  
R03173[c] [c]:2-Methylbutanoyl-CoA + Acceptor <=> 2-Methylbut-2-enoyl-CoA + Reduced acceptor  
R03394[c] [c]:D-myo-Inositol 1,4,5-trisphosphate + H2O <=> 1D-myo-Inositol 1,4-bisphosphate +  
Orthophosphate  
R03871[c] [c]:Methylmalonate + H2O2 <=> (S)-Methylmalonate semialdehyde + Oxygen + H2O  
R04131[c] [c]:2-Oxohept-3-enedioate + H2O <=> 4-Hydroxy-2-oxo-heptanedioate  
R02085[c] [c]:(S)-3-Hydroxy-3-methylglutaryl-CoA <=> 3-Methylglutaconyl-CoA + H2O  
R05337[c] [c]:4-Hydroxybutyryl-CoA <=> Vinylacetyl-CoA + H2O  
R00371[c] [c]:Acetyl-CoA + Glycine <=> CoA + L-2-Amino-3-oxobutanoic acid  
R00224[c] [c]:Pyruvate <=> Acetaldehyde + CO2  
R00830[c] [c]:Succinyl-CoA + Glycine <=> 5-Aminolevulinate + CoA + CO2  
R00432[c] [c]:GTP + Succinate + CoA <=> GDP + Orthophosphate + Succinyl-CoA  
R05064[c] [c]:(S)-3-Hydroxyisobutyryl-CoA + H2O <=> CoA + (S)-3-Hydroxyisobutyrate  
R03302[c] [c]:3,4-Dihydroxyphenylacetaldehyde + NADP+ + H2O <=> 3,4-Dihydroxyphenylacetate +  
NADPH + H+  
R01468[c] [c]:ATP + Ethanolamine <=> ADP + Ethanolamine phosphate  
R06870[c] [c]:Ethanolamine phosphate + H2O <=> Ethanolamine + Orthophosphate  
R00635[c] [c]:Aldehyde + Oxygen + H2O <=> Carboxylate + H2O2  
R08589[c] [c]:12 Cyclic de-hypoxanthine fufalosine <=> 14 1,4-Dihydroxy-6-naphthoate + 25 H+  
R05452[c] [c]:Benzoyl acetate + CoA + ATP <=> Diphosphate + Benzoyl acetyl-CoA + AMP  
R05243[c] [c]:2,5-Dichloro-2,5-cyclohexadiene-1,4-diol + NAD+ <=> 2,5-Dichlorohydroquinone +  
NADH + H+  
R06838[c] [c]:trans-4-Carboxymethylenebut-2-en-4-olide + H2O <=> 2-Maleylacetate  
R05397[c] [c]:3,6-Dichloro-cis-1,2-dihydroxycyclohexa-3,5-diene + NAD+ <=> 3,6-Dichlorocatechol  
+ NADH + H+  
R05409[c] [c]:3,6-Dichlorocatechol + Oxygen <=> 2,5-Dichloro-cis,cis-muconate  
R05511[c] [c]:cis-2-Chloro-4-carboxymethylenebut-2-en-1,4-olide + H2O <=> 2-Chloromaleylacetate  
R05246[c] [c]:p-Benzenediol + Oxygen <=> cis,trans-4-Hydroxymuconic semialdehyde  
R06851[c] [c]:p-Benzenediol + NADPH + H+ + Oxygen <=> Benzene-1,2,4-triol + NADP+ + H2O  
R05257[c] [c]:[2,3-Dihydroxy 1,1,1-Trichloro-2,2-bis(4'-chlorophenyl)ethane +, 'Oxygen <=>', 6-Oxo-  
2-hydroxy-7-(4'-chlorophenyl)-3,8,8,8-tetrachloroocta-2E,4E-, 'dienoate  
R05412[c] [c]:1,2-Dihydroxyfluorene + Oxygen <=> 2-Hydroxy-4-(2-oxo-1,3-dihydro-2H-inden-1-  
ylidene)but-2-enoic acid  
R02487[c] [c]:Glutaryl-CoA + FAD <=> FADH2 + Crotonoyl-CoA + CO2  
R02488[c] [c]:Glutaryl-CoA + Acceptor <=> Crotonoyl-CoA + Reduced acceptor + CO2  
R00964[c] [c]:ATP + Uridine <=> ADP + UMP  
R02065[c] [c]:2 Geranylgeranyl diphosphate <=> Diphosphate + Prephytoene diphosphate  
R05637[c] [c]:[2-Phospho-4-(cytidine 5'-diphospho)-2-C-methyl-D-erythritol <=>, '2-C-Methyl-D-  
erythritol 2,4-cyclodiphosphate + CMP  
R07270[c] [c]:Prephytoene diphosphate <=> Phytoene + Diphosphate  
R00968[c] [c]:GTP + Uridine <=> GDP + UMP  
R04117[c] [c]:Naphthalene-1,2-diol + Oxygen <=> 2-Hydroxychromene-2-carboxylate  
R05136[c] [c]:Salicylaldehyde + Pyruvate <=> trans-O-Hydroxybenzylidenepyruvate + H2O  
R05649[c] [c]:1-Hydroxy-2-naphthaldehyde + NAD+ + H2O <=> 1-Hydroxy-2-naphthoate + NADH +  
H+



R01333[c] [c]:Glycolaldehyde + NAD+ + H2O <=> Glycolate + NADH + H+  
R05633[c] [c]:2-C-Methyl-D-erythritol 4-phosphate + CTP <=> 4-(Cytidine', 5'-diphospho)-2-C-methyl-D-erythritol + Diphosphate]  
R03103[c] [c]:L-2-Aminoadipate 6-semialdehyde + NADP+ + H2O <=> L-2-Aminoadipate + NADPH + H+  
R03102[c] [c]:L-2-Aminoadipate 6-semialdehyde + NAD+ + H2O <=> L-2-Aminoadipate + NADH + H+  
R01352[c] [c]:2-Acylglycerol + H2O <=> Glycerol + Fatty acid  
R05351[c] [c]:Ethylene oxide + CoA + NAD+ <=> Acetyl-CoA + NADH + H+  
R07382[c] [c]:1-(1-Alkenyl)-sn-glycero-3-phosphate + Acyl-CoA <=> 2-Acyl-1-(1-alkenyl)-sn-glycero-3-phosphate + CoA  
R07388[c] [c]:1-(1-Alkenyl)-sn-glycero-3-phosphoethanolamine + H2O <=> 1-(1-Alkenyl)-sn-glycero-3-phosphate + Ethanolamine  
R07269[c] [c]:di-trans,poly-cis-Decaprenyl diphosphate + Isopentenyl diphosphate <=> Diphosphate + di-trans,poly-cis-Undecaprenyl diphosphate  
R08748[c] [c]:trans,trans,cis-Geranylgeranyl diphosphate + Isopentenyl diphosphate <=> di-trans,poly-cis-Pentaprenyl diphosphate + Diphosphate  
R08749[c] [c]:di-trans,poly-cis-Pentaprenyl diphosphate + Isopentenyl diphosphate <=> di-trans,poly-cis-Hexaprenyl diphosphate + Diphosphate  
R08750[c] [c]:di-trans,poly-cis-Hexaprenyl diphosphate + Isopentenyl diphosphate <=> di-trans,poly-cis-Heptaprenyl diphosphate + Diphosphate  
R08751[c] [c]:di-trans,poly-cis-Heptaprenyl diphosphate + Isopentenyl diphosphate <=> di-trans,poly-cis-Octaprenyl diphosphate + Diphosphate  
R08752[c] [c]:di-trans,poly-cis-Octaprenyl diphosphate + Isopentenyl diphosphate <=> di-trans,poly-cis-Nonaprenyl diphosphate + Diphosphate  
R08753[c] [c]:di-trans,poly-cis-Nonaprenyl diphosphate + Isopentenyl diphosphate <=> di-trans,poly-cis-Decaprenyl diphosphate + Diphosphate  
R03036[c] [c]:[Dephospho-CoA + H2O <=> Pantetheine 4'-phosphate + AMP]  
R02204[c] [c]:L-Pipecolate + Oxygen <=> (S)-2,3,4,5-Tetrahydropyridine-2-carboxylate + H2O2  
R02681[c] [c]:Indole-3-acetaldehyde + Oxygen + H2O <=> Indole-3-acetate + H2O2  
R04093[c] [c]:Indole-3-acetaldehyde oxime <=> 3-Indoleacetonitrile + H2O  
R02699[c] [c]:ATP + 4-Hydroxyphenylacetate + CoA <=> AMP + Diphosphate + 4-Hydroxyphenylacetyl-CoA  
R04817[c] [c]:7alpha-Hydroxy-5beta-cholestan-3-one + NADP+ <=> 7alpha-Hydroxycholest-4-en-3-one + NADPH + H+  
R04819[c] [c]:3alpha,7alpha-Dihydroxy-5beta-cholestane + NADP+ <=> 7alpha-Hydroxy-5beta-cholestan-3-one + NADPH + H+  
R05703[c] [c]:5alpha-Cholest-7-en-3beta-ol + NADP+ <=> 5alpha-Cholesta-7,24-dien-3beta-ol + NADPH + H+  
R03353[c] [c]:5alpha-Cholest-7-en-3beta-ol <=> 5alpha-Cholest-8-en-3beta-ol  
R04818[c] [c]:3alpha,7alpha-Dihydroxy-5beta-cholestane + NAD+ <=> 7alpha-Hydroxy-5beta-cholestan-3-one + NADH + H+  
R04809[c] [c]:3alpha,7alpha-Dihydroxy-5beta-cholest-24-enoyl-CoA + H2O <=> 3alpha,7alpha,24-Trihydroxy-5beta-cholestanoyl-CoA  
R04810[c] [c]:3alpha,7alpha,24-Trihydroxy-5beta-cholestanoyl-CoA + NAD+ <=> 3alpha,7alpha-Dihydroxy-5beta-24-oxocholestanoyl-CoA + NADH + H+  
R07172[c] [c]:NADPH + H+ + Oxygen <=> NADP+ + H2O2  
R02701[c] [c]:5-Hydroxy-L-tryptophan <=> Serotonin + CO2  
R08604[c] [c]:Tryptamine + Oxygen + NADPH <=> N-Hydroxyl-tryptamine + H2O + NADP+  
R08605[c] [c]:N-Hydroxyl-tryptamine <=> Indole-3-acetaldehyde oxime  
R00685[c] [c]:L-Tryptophan <=> Tryptamine + CO2  
R08160[c] [c]:L-Tryptophan + 2 Oxygen + 2 NADPH + 2 H+ <=> Indole-3-acetaldehyde oxime + 3 H2O + 2 NADP+ + CO2  
R01384[c] [c]:UDP-glucuronate <=> UDP-D-xylose + CO2  
R02829[c] [c]:Nitrile + Oxygen + NADPH + H+ <=> Cyanohydrin + NADP+ + H2O  
R04948[c] [c]:UDP-glucose + Cyanohydrin <=> Cyanoglycoside + UDP

R01318[c] [c]:Acyl-CoA + 1-Acyl-sn-glycero-3-phosphocholine <=> CoA + Phosphatidylcholine  
R01351[c] [c]:1-Acylglycerol + H2O <=> Glycerol + Fatty acid  
R06367[c] [c]:Perillic acid + CoA + ATP <=> Perillyl-CoA + H2O + ADP + Orthophosphate  
R06369[c] [c]:Perillyl-CoA + H2O <=> 2-Hydroxy-4-isopropenylcyclohexane-1-carboxyl-CoA  
R06368[c] [c]:Perillic acid + CoA + ATP <=> Perillyl-CoA + H2O + AMP + Diphosphate  
R05613[c] [c]:all-trans-Pentaprenyl diphosphate + Isopentenyl diphosphate <=> all-trans-Hexaprenyl  
diphosphate + Diphosphate  
R07475[c] [c]:Geranylgeranyl diphosphate + Isopentenyl diphosphate <=> all-trans-Pentaprenyl  
diphosphate + Diphosphate  
R07088[c] [c]:1,1-Dichloroethylene + NADPH + Oxygen + H+ <=> 2,2-Dichloroacetaldehyde +  
NADP+ + H2O  
R07090[c] [c]:1,1-Dichloroethylene + NADPH + Oxygen + H+ <=> Chloroacetyl chloride + NADP+ +  
H2O  
R07089[c] [c]:1,1-Dichloroethylene + NADPH + Oxygen + H+ <=> 1,1-Dichloroethylene epoxide +  
NADP+ + H2O  
R07099[c] [c]:Trichloroethene + NADPH + Oxygen + H+ <=> Chloral + NADP+ + H2O  
R02669[c] [c]:3-Hydroxyanthranilate <=> 2-Aminophenol + CO2  
R07730[c] [c]:o-Hydroxylaminobenzoate <=> 3-Hydroxyanthranilate  
R05410[c] [c]:3,4-Dihydroxyfluorene + Oxygen <=> 2-Hydroxy-4-(1-oxo-1,3-dihydro-2H-inden-2-  
ylidene)-but-2-enoic acid  
R03401[c] [c]:8-[(1R,2R)-3-Oxo-2-{(Z)-pent-2-enyl}cyclopentyl]octanoate + NADP+ <=> 12-OPDA  
+ NADPH + H+  
R06918[c] [c]:1-Naphthaldehyde + NAD+ + H2O <=> 1-Naphthoic acid + NADH + 2 H+  
R06923[c] [c]:2-Hydroxy-3-carboxybenzalpyruvate + H2O <=> 3-Formylsalicylic acid + Pyruvate  
R06928[c] [c]:2-Naphthaldehyde + NAD+ + H2O <=> 2-Naphthoic acid + NADH + 2 H+  
R05231[c] [c]:6-Hydroxyhexanoic acid + NADP+ <=> Adipate semialdehyde + NADPH + H+  
R06941[c] [c]:(3S)-3-Hydroxyadipyl-CoA + NAD+ <=> 3-Oxadipyl-CoA + NADH + H+  
R06943[c] [c]:Adipyl-CoA + FAD <=> 5-Carboxy-2-pentenoyl-CoA + FADH2  
R06944[c] [c]:Adipate + CoA + ATP <=> Adipyl-CoA + AMP + Diphosphate  
R07924[c] [c]:28 Albireodelphin <=> 25 Gentiodelphin  
R08092[c] [c]:5-Methylhex-4-enoyl-CoA + FAD <=> (2E)-5-Methylhexa-2,4-dienoyl-CoA + FADH2  
R08122[c] [c]:6 2-Fluorocyclohexadiene-cis,cis-1,2-diol-1-carboxylate + 6 H+ <=> 7 Catechol  
R08123[c] [c]:6-Fluorocyclohexadiene-cis,cis-1,2-diol-1-carboxylate <=> 3-Fluorocatechol  
R04427[c] [c]:S-Adenosyl-L-methionine + Zymosterol <=> S-Adenosyl-L-homocysteine + Fecosterol  
R03775[c] [c]:Cycloeucalenol <=> Obtusifoliol  
R07473[c] [c]:3-Dehydro-6-deoxoteasterone <=> 6-Deoxotyphasterol  
R07791[c] [c]:22alpha-Hydroxy-5alpha-campestan-3-one <=> 3-Dehydro-6-deoxoteasterone  
R07677[c] [c]:L-Ascorbate 6-phosphate + H2O <=> 3-Dehydro-L-gulonate 6-phosphate  
R02027[c] [c]:Phosphatidylglycerol + H2O <=> 1,2-Diacyl-sn-glycerol + sn-Glycerol 3-phosphate  
R02097[c] [c]:dTTP + Uridine <=> dTDP + UMP  
R02541[c] [c]:Sphingomyelin + H2O <=> N-Acylsphingosine + Choline phosphate  
R01321[c] [c]:CDP-choline + 1,2-Diacyl-sn-glycerol <=> CMP + Phosphatidylcholine  
R01312[c] [c]:Phosphatidylcholine + H2O <=> 1,2-Diacyl-sn-glycerol + Choline phosphate  
R00970[c] [c]:ITP + Uridine <=> IDP + UMP  
R02327[c] [c]:dCTP + Uridine <=> dCDP + UMP  
R00771[c] [c]:D-Glucose 6-phosphate <=> D-Fructose 6-phosphate  
R00876[c] [c]:ITP + D-Fructose <=> IDP + D-Fructose 6-phosphate  
R00770[c] [c]:ITP + D-Fructose 6-phosphate <=> IDP + D-Fructose 1,6-bisphosphate  
R00764[c] [c]:Diphosphate + D-Fructose 6-phosphate <=> Orthophosphate + D-Fructose 1,6-  
bisphosphate  
R00756[c] [c]:ATP + D-Fructose 6-phosphate <=> ADP + D-Fructose 1,6-bisphosphate  
R00763[c] [c]:beta-D-Fructose 2,6-bisphosphate + H2O <=> D-Fructose 6-phosphate + Orthophosphate  
R01843[c] [c]:ATP + Sedoheptulose 7-phosphate <=> ADP + Sedoheptulose 1,7-bisphosphate  
R00769[c] [c]:UTP + D-Fructose 6-phosphate <=> UDP + D-Fructose 1,6-bisphosphate  
R03105[c] [c]:Mercaptopyruvate + Sulfite <=> Thiosulfate + Pyruvate  
R01698[c] [c]:Dihydrolipoamide + NAD+ <=> Lipoamide + NADH + H+

R04984[c] [c]:2-Hexaprenyl-3-methyl-6-methoxy-1,4-benzoquinone + Oxygen + NADPH + H+ <=> 2-Hexaprenyl-3-methyl-5-hydroxy-6-methoxy-1,4-benzoquinone + NADP+ + H2O  
R01627[c] [c]:3-Dehydroshikimate <=> 3,4-Dihydroxybenzoate + H2O  
R01521[c] [c]:beta-D-Glucose + NADP+ <=> D-Glucono-1,5-lactone + NADPH + H+  
R01520[c] [c]:beta-D-Glucose + NAD+ <=> D-Glucono-1,5-lactone + NADH + H+  
R08714[c] [c]:Putrescine + Pyruvate <=> 4-Aminobutanal + L-Alanine  
R08609[c] [c]:Indole <=> Indole-3-acetate  
R02978[c] [c]:Sphinganine + NADP+ <=> 3-Dehydrosphinganine + NADPH + H+  
R02976[c] [c]:ATP + Sphinganine <=> ADP + Sphinganine 1-phosphate  
R06973[c] [c]:3-Oxopropanoate <=> Acetaldehyde + CO2  
R08527[c] [c]:(5Z,8Z,11Z,14Z)-Icosatetraenoic acid + Oxygen <=> Leukotriene A4 + H2O  
R01595[c] [c]:(5Z,8Z,11Z,14Z)-Icosatetraenoic acid + Oxygen <=> 5(S)-HPETE  
R03058[c] [c]:5(S)-HPETE <=> Leukotriene A4 + H2O  
R03197[c] [c]:Uroporphyrinogen III <=> Coproporphyrinogen III + 4 CO2  
R02979[c] [c]:Sphinganine + FAD <=> FADH2 + Sphingosine  
R03354[c] [c]:Glucosylceramide + UDP-D-galactose <=> beta-D-Galactosyl-1,4-beta-D-glucosylceramide + UDP  
R04823[c] [c]:7alpha,12alpha-Dihydroxy-5beta-cholestan-3-one + NADP+ <=> 4-Cholesten-7alpha,12alpha-diol-3-one + NADPH + H+  
R04825[c] [c]:3alpha,7alpha,12alpha-Trihydroxy-5beta-cholestane + NADP+ <=> 7alpha,12alpha-Dihydroxy-5beta-cholestan-3-one + NADPH + H+  
R04824[c] [c]:3alpha,7alpha,12alpha-Trihydroxy-5beta-cholestane + NAD+ <=> 7alpha,12alpha-Dihydroxy-5beta-cholestan-3-one + NADH + H+  
R04986[c] [c]:3-Octaprenyl-4-hydroxybenzoate <=> 2-Octaprenylphenol + CO2  
R04988[c] [c]:2-Octaprenyl-6-hydroxyphenol + S-Adenosyl-L-methionine <=> 2-Octaprenyl-6-methoxyphenol + S-Adenosyl-L-homocysteine  
R04989[c] [c]:2-Octaprenyl-6-methoxyphenol + Oxygen + NADPH <=> 2-Octaprenyl-6-methoxy-1,4-benzoquinone + NADP+ + H2O  
R05611[c] [c]:all-trans-Octaprenyl diphosphate + Diphosphate <=> all-trans-Heptaprenyl diphosphate + Isopentenyl diphosphate  
R05615[c] [c]:all-trans-Octaprenyl diphosphate + 4-Hydroxybenzoate <=> 3-Octaprenyl-4-hydroxybenzoate + Diphosphate  
R05258[c] [c]:p-Benzoquinone + Nitrite + NADP+ + H2O <=> 4-Nitrophenol + Oxygen + NADPH + H+  
R05488[c] [c]:Styrene + Oxygen + NADPH + H+ + FAD <=> Styrene oxide + NADP+ + FADH2 + H2O  
R01926[c] [c]:Sphingosine + ATP <=> Sphingosine 1-phosphate + ADP  
R06906[c] [c]:Naphthyl-2-methylene-succinyl-CoA + H2O <=> Naphthyl-2-hydroxymethyl-succinyl CoA  
R06913[c] [c]:2-Hydroxy-3-methylbenzalpyruvate + H2O <=> 3-Methylsalicylaldehyde + Pyruvate  
R06914[c] [c]:3-Methylsalicylaldehyde + NAD+ + H2O <=> 3-Methylsalicylate + NADH + H+  
R06916[c] [c]:1-Methylnaphthalene + Oxygen + NADH + H+ <=> 1-Hydroxymethylnaphthalene + NAD+ + H2O  
R07171[c] [c]:NADH + H+ + Oxygen <=> NAD+ + H2O2  
R06926[c] [c]:2-Methylnaphthalene + Oxygen + NADH + H+ <=> (2-Naphthyl)methanol + NAD+ + H2O  
R07020[c] [c]:beta-Naphthol + NADPH + Oxygen + H+ <=> Naphthalene-1,2-diol + NADP+ + H2O  
R07015[c] [c]:1,2-Dihydronaphthalene-1,2-diol + NADP+ <=> Naphthalene-1,2-diol + NADPH + H+  
R01593[c] [c]:(5Z,8Z,11Z,14Z)-Icosatetraenoic acid + Oxygen <=> 15(S)-HPETE  
R05639[c] [c]:14-Demethylsterol + NADP+ <=> 4,4-Dimethyl-5alpha-cholesta-8,14,24-trien-3beta-ol + NADPH + H+  
R05640[c] [c]:2 Lanosterol + 3 Oxygen + 2 NADPH <=> 2 4,4-Dimethyl-5alpha-cholesta-8,14,24-trien-3beta-ol + 2 Formate + 2 NADP+ + 2 H2O + 4 H+  
R07501[c] [c]:2-Methyl-6-phytylquinol + S-Adenosyl-L-methionine <=> 2,3-Dimethyl-5-phytylquinol + S-Adenosyl-L-homocysteine  
R07701[c] [c]:1,2-Anthracenediol + Oxygen <=> 4-(3-Hydroxy-2-naphthyl)-2-oxobut-3-enoic acid

R08086[c] [c]:Geranial + NAD+ + H2O <=> Geranic acid + NADH + 2 H+  
R04385[c] [c]:ATP + Holo-[carboxylase] + HCO3- <=> ADP + Orthophosphate + Carboxybiotin-carboxyl-carrier protein  
R04386[c] [c]:Acetyl-CoA + Carboxybiotin-carboxyl-carrier protein <=> Malonyl-CoA + Holo-[carboxylase]  
R00858[c] [c]:Hydrogen sulfide + NADP+ + 3 H2O <=> Sulfite + NADPH + 5 H+  
R03592[c] [c]:Morphine + NADP+ <=> Morphinone + NADPH + H+  
R00272[c] [c]:2-Oxoglutarate <=> Succinate semialdehyde + CO2  
R02143[c] [c]:Xanthosine + H2O <=> Xanthine + D-Ribose  
R02517[c] [c]:3-Hydroxyphenylacetate + Oxygen + NADPH + H+ <=> Homogentisate + NADP+ + H2O  
R00134[c] [c]:Formate + NADP+ <=> CO2 + NADPH  
R02618[c] [c]:3-Sulfinyl-L-alanine + NAD+ + H2O <=> 3-Sulfinylpyruvate + NH3 + NADH + H+  
R00019[c] [c]:2 Reduced ferredoxin + 2 H+ <=> Hydrogen + 2 Oxidized ferredoxin  
R00045[c] [c]:Oxygen + 2 3,4-Dihydroxy-L-phenylalanine <=> 2 Dopaquinone + 2 H2O  
R00031[c] [c]:Oxygen + 2 L-Tyrosine <=> 2 3,4-Dihydroxy-L-phenylalanine  
R01422[c] [c]:ATP + Benzoate + CoA <=> AMP + Diphosphate + S-Benzoate coenzyme A  
R01424[c] [c]:Hippurate + H2O <=> Benzoate + Glycine  
R02515[c] [c]:3-Hydroxyphenylacetate + Oxygen + NADH + H+ <=> Homogentisate + NAD+ + H2O  
R00982[c] [c]:ATP + Anthranilate + CoA <=> AMP + Diphosphate + Anthranilyl-CoA  
R00997[c] [c]:1-Aminocyclopropane-1-carboxylate + H2O <=> 2-Oxobutanoate + NH3  
R03366[c] [c]:S-Adenosyl-L-methionine + Caffeate <=> S-Adenosyl-L-homocysteine + Ferulate  
R05651[c] [c]:Sulfoacetaldehyde + Orthophosphate <=> Acetyl phosphate + Sulfite  
R06921[c] [c]:1,2-Dihydroxy-8-carboxynaphthalene + Oxygen <=> 2-Carboxy-2-hydroxy-8-carboxychromene  
R00907[c] [c]:L-Alanine + 3-Oxopropanoate <=> Pyruvate + beta-Alanine  
R00706[c] [c]:3-Oxopropanoate + CoA + NADP+ <=> Acetyl-CoA + CO2 + NADPH + H+  
R00740[c] [c]:3-Oxopropanoate + CoA + NADP+ <=> Malonyl-CoA + NADPH + H+  
R02293[c] [c]:L-2,4-Diaminobutanoate + Pyruvate <=> L-Aspartate 4-semialdehyde + L-Alanine  
R06977[c] [c]:L-Glutamate + L-Aspartate 4-semialdehyde <=> 2-Oxoglutarate + L-2,4-Diaminobutanoate  
R00846[c] [c]:sn-Glycerol 3-phosphate + Oxygen <=> Glycerone phosphate + H2O2  
R05612[c] [c]:all-trans-Hexaprenyl diphosphate + Isopentenyl diphosphate <=> all-trans-Heptaprenyl diphosphate + Diphosphate  
R06911[c] [c]:1,2-Dihydroxy-8-methylnaphthalene + Oxygen <=> 2-Hydroxy-8-methylchromene-2-carboxylate  
R06536[c] [c]:Delphinidin + UDP-glucose <=> Delphinidin 3-O-glucoside + UDP  
R03494[c] [c]:ATP + Geranyl-CoA + HCO3- <=> ADP + Orthophosphate + 3-(4-Methylpent-3-en-1-yl)pent-2-enediyl-CoA  
R00220[c] [c]:L-Serine <=> Pyruvate + NH3  
R00782[c] [c]:L-Cysteine + H2O <=> Hydrogen sulfide + Pyruvate + NH3  
R00282[c] [c]:Acceptor + NADPH + H+ <=> Reduced acceptor + NADP+  
R00734[c] [c]:L-Tyrosine + 2-Oxoglutarate <=> 3-(4-Hydroxyphenyl)pyruvate + L-Glutamate  
R00489[c] [c]:L-Aspartate <=> beta-Alanine + CO2  
R01770[c] [c]:Inosine + H2O <=> Hypoxanthine + D-Ribose  
R00081[c] [c]:3 Oxygen + 4 Ferrocyclochrome c + 12 H+ <=> 4 Ferricytochrome c + 6 H2O  
R01677[c] [c]:Guanosine + H2O <=> Guanine + D-Ribose  
R05052[c] [c]:L-erythro-4-Hydroxyglutamate + 2-Oxoglutarate <=> D-4-Hydroxy-2-oxoglutarate + L-Glutamate  
R00717[c] [c]:Glycolate + NAD+ <=> Glyoxylate + NADH + H+  
R01629[c] [c]:3,4-Dihydroxybenzoate + Oxygen + NADH + H+ <=> Benzene-1,2,4-triol + CO2 + NAD+ + H2O  
R01542[c] [c]:2-Dehydro-3-deoxy-D-gluconate + NAD+ <=> (4S)-4,6-Dihydroxy-2,5-dioxohexanoate + NADH + H+  
R03300[c] [c]:3,4-Dihydroxyphenylacetaldehyde + NAD+ + H2O <=> 3,4-Dihydroxyphenylacetate + NADH + 2 H+

R01377[c] [c]:Phenylpyruvate <=> Phenylacetaldehyde + CO2  
R02536[c] [c]:Phenylacetaldehyde + NAD+ + H2O <=> Phenylacetic acid + NADH + 2 H+  
R01171[c] [c]:Butanoyl-CoA + NAD+ <=> Crotonoyl-CoA + NADH + H+  
R03532[c] [c]:Reduced acceptor + H2O2 <=> Acceptor + 2 H2O  
R04203[c] [c]:(2S,3S)-3-Hydroxy-2-methylbutanoyl-CoA + NAD+ <=> 2-Methylacetoacetyl-CoA +  
NADH + H+  
R03172[c] [c]:(S)-2-Methylbutanoyl-CoA + Acceptor <=> 2-Methylbut-2-enoyl-CoA + Reduced  
acceptor  
R00538[c] [c]:Aldehyde + NAD+ + H2O <=> Carboxylate + NADH + 2 H+  
R00699[c] [c]:L-Phenylalanine <=> Phenethylamine + CO2  
R03332[c] [c]:1-Phosphatidyl-D-myo-inositol + H2O <=> Inositol 1-phosphate + 1,2-Diacyl-sn-  
glycerol  
R00634[c] [c]:Aldehyde + NADP+ + H2O <=> Carboxylate + NADPH + 2 H+  
R01030[c] [c]:sn-glycero-3-Phosphocholine + H2O <=> Choline + sn-Glycerol 3-phosphate  
R02383[c] [c]:Tyramine + Oxygen + NADH + H+ <=> Dopamine + NAD+ + H2O  
R01630[c] [c]:3,4-Dihydroxybenzoate + Oxygen + NADPH + H+ <=> Benzene-1,2,4-triol + CO2 +  
NADP+ + H2O  
R02941[c] [c]:Salicylaldehyde + NAD+ + H2O <=> Salicylate + NADH + 2 H+  
R00392[c] [c]:Acyl-CoA + Acceptor <=> 2,3-Dehydroacyl-CoA + Reduced acceptor  
R02297[c] [c]:Xanthosine + Orthophosphate <=> Xanthine + alpha-D-Ribose 1-phosphate  
R00540[c] [c]:Nitrile + 2 H2O <=> Carboxylate + NH3  
R00794[c] [c]:Nitrite + NAD+ + H2O <=> Nitrate + NADH + H+  
R00829[c] [c]:Succinyl-CoA + Acetyl-CoA <=> CoA + 3-Oxoadipyl-CoA  
R01010[c] [c]:Glycerone phosphate + H2O <=> Glycerone + Orthophosphate  
R02485[c] [c]:Deoxycytidine + H2O <=> Deoxyuridine + NH3  
R01678[c] [c]:Lactose + H2O <=> alpha-D-Glucose + D-Galactose  
R01100[c] [c]:Lactose + H2O <=> D-Glucose + D-Galactose  
R01791[c] [c]:Dextrin + H2O <=> alpha-D-Glucose + Dextrin  
R00705[c] [c]:3-Oxopropanoate + CoA + NAD+ <=> Acetyl-CoA + CO2 + NADH + H+  
R00760[c] [c]:ATP + D-Fructose <=> ADP + D-Fructose 6-phosphate  
R00895[c] [c]:L-Cysteine + 2-Oxoglutarate <=> Mercaptopyruvate + L-Glutamate  
R02549[c] [c]:4-Aminobutanal + NAD+ + H2O <=> 4-Aminobutanoate + NADH + H+  
R01155[c] [c]:Putrescine + 2-Oxoglutarate <=> 4-Aminobutanal + L-Glutamate  
R00736[c] [c]:L-Tyrosine <=> Tyramine + CO2  
R00181[c] [c]:AMP + H2O <=> IMP + NH3  
R06520[c] [c]:Sphinganine 1-phosphate + H2O <=> Sphinganine + Orthophosphate  
R03244[c] [c]:L-Ribulose 5-phosphate <=> L-Xylulose 5-phosphate  
R02380[c] [c]:UDP-glucose + Sinapate <=> UDP + 1-O-Sinapoyl-beta-D-glucose  
R01498[c] [c]:Glucosylceramide + H2O <=> D-Glucose + N-Acylsphingosine  
R02661[c] [c]:2-Methylpropanoyl-CoA + Acceptor <=> 2-Methylprop-2-enoyl-CoA + Reduced  
acceptor  
R06521[c] [c]:Sphingosine 1-phosphate + H2O <=> Sphingosine + Orthophosphate  
R07939[c] [c]:Caffeine + NADPH + Oxygen + H+ <=> 1,7-Dimethylxanthine + NADP+ +  
Formaldehyde + H2O  
R01293[c] [c]:4-Hydroxybenzaldehyde + NAD+ + H2O <=> 4-Hydroxybenzoate + NADH + 2 H+  
R00638[c] [c]:Aldehyde + Acceptor + H2O <=> Fatty acid + Reduced acceptor  
R00544[c] [c]:Aldehyde + Acceptor + H2O <=> Carboxylate + Reduced acceptor  
R00118[c] [c]: NADP+ + H2O --> Orthophosphate + NAD+  
R00619[c] [c]: ATP + Thiamine --> AMP + Thiamin diphosphate  
R00761[c] [c]: D-Fructose 6-phosphate + Orthophosphate --> Acetyl phosphate + D-Erythrose 4-  
phosphate + H2O  
R00946[c] [c]: 5-Methyltetrahydrofolate + L-Homocysteine --> Tetrahydrofolate + L-Methionine  
R01087[c] [c]: Maleic acid --> Fumarate  
R01334[c] [c]: 2-Phosphoglycolate + H2O --> Glycolate + Orthophosphate  
R01350[c] [c]:16 Glycerol + 33 Fatty acid --> 19 Triacylglycerol + 33 H+  
R01373[c] [c]: Prephenate --> Phenylpyruvate + H2O + CO2

R01621[c] [c]: D-Xylulose 5-phosphate + Orthophosphate --> Acetyl phosphate + D-Glyceraldehyde 3-phosphate + H2O  
R01667[c] [c]: dCDP + H2O --> dCMP + Orthophosphate  
R01720[c] [c]: Nicotinate + NADP+ + H2O --> 6-Hydroxynicotinate + NADPH + H+  
R01866[c] [c]: (S)-Dihydroorotate + NADP+ --> Orotate + NADPH + H+  
R01867[c] [c]: (S)-Dihydroorotate + Oxygen --> Orotate + H2O2  
R02135[c] [c]: Thiamine + Orthophosphate --> Thiamin monophosphate + H2O  
R02222[c] [c]: Stearoyl-CoA + 2 Ferrocyclochrome b5 + Oxygen + 2 H+ --> Oleoyl-CoA + 2 Ferricyclochrome b5 + 2 H2O  
R02250[c] [c]: Triacylglycerol + H2O --> 1,2-Diacyl-sn-glycerol + Fatty acid  
R02322[c] [c]: Nicotinamide D-ribonucleotide + H2O --> Nicotinate D-ribonucleotide + NH3  
R02721[c] [c]: D-Glyceraldehyde 3-phosphate + Pyruvate --> 5-(2-Hydroxyethyl)-4-methylthiazole  
R03013[c] [c]: L-Histidinol phosphate + H2O --> L-Histidinol + Orthophosphate  
R03204[c] [c]: 2,5-Dihydroxypyridine + Oxygen + H2O --> Maleamate + Formate  
R03991[c] [c]: Tetradecanoyl-CoA + Acetyl-CoA --> CoA + 3-Oxopalmitoyl-CoA  
R04170[c] [c]: (S)-3-Hydroxydodecanoyl-CoA --> 2-trans-Dodecenoyl-CoA + H2O  
R04738[c] [c]: (S)-3-Hydroxyhexadecanoyl-CoA --> trans-Hexadec-2-enoyl-CoA + H2O  
R04740[c] [c]: (S)-3-Hydroxytetradecanoyl-CoA --> trans-Tetradec-2-enoyl-CoA + H2O  
R04744[c] [c]: (S)-Hydroxydecanoyl-CoA --> trans-Dec-2-enoyl-CoA + H2O  
R04746[c] [c]: (S)-Hydroxyoctanoyl-CoA --> trans-Oct-2-enoyl-CoA + H2O  
R04749[c] [c]: (S)-Hydroxyhexanoyl-CoA --> trans-Hex-2-enoyl-CoA + H2O  
R05069[c] [c]: (S)-2-Aceto-2-hydroxybutanoate --> (R)-3-Hydroxy-3-methyl-2-oxopentanoate  
R05700[c] [c]: Coniferyl aldehyde + H2O + NAD+ --> Ferulate + NADH + 2H+  
R06578[c] [c]: 5-Hydroxyferuloyl-CoA + S-Adenosyl-L-methionine --> Sinapoyl-CoA + S-Adenosyl-L-homocysteine  
R06584[c] [c]: Feruloyl-CoA --> 5-Hydroxyferuloyl-CoA  
R06798[c] [c]: Pelargonidin 3-O-glucoside --> Pelargonidin 3-O-(6-caffeoyl-beta-D-glucoside) 5-O-beta-D-glucoside  
R07064[c] [c]: Phosphatidylcholine + H2O --> 1-Acyl-sn-glycero-3-phosphocholine + Linoleate  
R07676[c] [c]: L-Galactonate + NADP+ --> D-Galacturonate + NADPH + H+  
R07758[c] [c]: Malonyl-CoA + Palmitoyl-CoA --> 3-Oxostearoyl-CoA + CoA + CO2  
R07860[c] [c]: Phosphatidylcholine + H2O --> 2-Acyl-sn-glycero-3-phosphocholine + (9Z,12Z,15Z)-Octadecatrienoic acid  
R01626[c] [c]: Malonyl-CoA + Acyl-carrier protein --> CoA + Malonyl-[acyl-carrier protein]  
R00845[c] [c]: sn-Glycerol 3-phosphate + NADP+ --> D-Glyceraldehyde 3-phosphate + NADPH + H+  
R00203[c] [c]: Methylglyoxal + NAD+ + H2O --> Pyruvate + NADH + H+  
R01016[c] [c]: Glycerone phosphate --> Methylglyoxal + Orthophosphate  
R00850[c] [c]: sn-Glycerol 3-phosphate + D-Glucose --> Glycerol + D-Glucose 6-phosphate  
R07740[c] [c]: (-)-Medicarpin + UDP-glucose --> (-)-Medicarpin + UDP  
R07743[c] [c]: 8 (-)-Medicarpin --> 11 (-)-Medicarpin  
R02416[c] [c]: p-Coumaroyl-CoA + Shikimate --> CoA + 4-Coumaroylshikimate  
R07433[c] [c]: 5-O-Caffeoylshikimic acid + CoA --> Caffeoyl-CoA + Shikimate  
R06582[c] [c]: 4-Coumaroylshikimate + Oxygen + NADPH + H+ --> 5-O-Caffeoylshikimic acid + NADP+ + H2O  
R06572[c] [c]: Coniferyl aldehyde + NADPH + H+ + Oxygen --> 5-Hydroxyconiferaldehyde + NADP+ + H2O  
R06576[c] [c]: 5-Hydroxyconiferaldehyde + S-Adenosyl-L-methionine --> Sinapoyl aldehyde + S-Adenosyl-L-homocysteine  
R06573[c] [c]: Coniferyl alcohol + NADPH + H+ + Oxygen --> 5-Hydroxyconiferyl alcohol + NADP+ + H2O  
R06577[c] [c]: 5-Hydroxyconiferyl alcohol + S-Adenosyl-L-methionine --> Sinapyl alcohol + S-Adenosyl-L-homocysteine  
R00959[c] [c]: D-Glucose 1-phosphate <==> alpha-D-Glucose 6-phosphate  
R00137[c] [c]: Diphosphate + NAD+ --> ATP + Nicotinamide D-ribonucleotide  
R00207[c] [c]: Acetyl phosphate + H2O2 + CO2 --> Pyruvate + Orthophosphate + Oxygen  
R00230[c] [c]: CoA + Acetyl phosphate --> Acetyl-CoA + Orthophosphate

R00306[c] [c]: 2 D-Glucose --> Cellobiose + H2O  
R00320[c] [c]: Orthophosphate + Acetyl phosphate --> Diphosphate + Acetate  
R00364[c] [c]: Glyoxylate + NH3 + 2 Ferrocycytochrome c + 2 H+ --> Glycine + H2O + 2 Ferricytochrome c  
R00522[c] [c]: Formate + CO2 --> Oxalate  
R00708[c] [c]: L-Glutamate + NADPH + H+ --> (S)-1-Pyrroline-5-carboxylate + NADP+ + 2 H2O  
R00835[c] [c]: D-Glucono-1,5-lactone 6-phosphate + NADPH + H+ --> D-Glucose 6-phosphate + NADP+  
R00836[c] [c]: UDP + alpha,alpha'-Trehalose 6-phosphate --> UDP-glucose + D-Glucose 6-phosphate  
R00849[c] [c]: Glycerone phosphate + Hydroquinone --> sn-Glycerol 3-phosphate + Quinone  
R00881[c] [c]: GMP + D-Mannose 1-phosphate --> GDP-mannose + H2O  
R01081[c] [c]: D-Ribulose --> D-Ribose  
R01090[c] [c]: 4-Methyl-2-oxopentanoate + L-Glutamate --> L-Leucine + 2-Oxoglutarate  
R01113[c] [c]: Glutathione disulfide + 2 L-Cysteine --> L-Cystine + 2 Glutathione  
R01140[c] [c]: dADP + D-Fructose 6-phosphate --> dATP + D-Fructose  
R01215[c] [c]: 3-Methyl-2-oxobutanoic acid + L-Alanine --> L-Valine + Pyruvate  
R01278[c] [c]: trans-Hexadec-2-enoyl-CoA + NADPH + H+ --> Palmitoyl-CoA + NADP+  
R01314[c] [c]: 2-Acyl-sn-glycero-3-phosphocholine + Carboxylate --> Phosphatidylcholine + H2O  
R01330[c] [c]: dADP + D-Mannose 6-phosphate --> dATP + D-Mannose  
R01446[c] [c]: (S)-Lactate + NADH + H+ --> (S)-Lactaldehyde + NAD+ + H2O  
R01526[c] [c]: ADP + D-Ribulose 5-phosphate --> ATP + D-Ribulose  
R01573[c] [c]: ADP + D-Arabinose 5-phosphate --> ATP + D-Arabinose  
R01652[c] [c]: (2S)-2-Isopropyl-3-oxosuccinate --> 4-Methyl-2-oxopentanoate + CO2  
R01706[c] [c]: Acyl-carrier protein + Hexadecanoic acid --> Hexadecanoyl-[acp] + H2O  
R01875[c] [c]: Sulfite + Glutathione disulfide + Hydrogen sulfide --> Thiosulfate + 2 Glutathione + H+  
R01951[c] [c]: Diphosphate + GDP-L-fucose --> GTP + L-Fucose 1-phosphate  
R02092[c] [c]: dTMP + Orthophosphate --> dTDP + H2O  
R02133[c] [c]: 4-Amino-5-hydroxymethyl-2-methylpyrimidine + 5-(2-Hydroxyethyl)-4-methylthiazole + H+ --> Thiamine + H2O  
R02263[c] [c]: Glycerone phosphate + (S)-Lactaldehyde --> L-Rhamnulose 1-phosphate  
R02437[c] [c]: L-Rhamnulose --> L-Rhamnose  
R02593[c] [c]: Coniferyl aldehyde + NADPH + H+ --> Coniferyl alcohol + NADP+  
R03014[c] [c]: ADP + L-Rhamnulose 1-phosphate --> ATP + L-Rhamnulose  
R03161[c] [c]: ADP + L-Fucose 1-phosphate --> ATP + 6-Deoxy-L-galactose  
R04558[c] [c]: D-erythro-1-(Imidazol-4-yl)glycerol 3-phosphate +',1-(5'-Phosphoribosyl)-5-amino-4-imidazolecarboxamide + L-Glutamate --> N-(5'-Phospho-D-1'-ribulosylformimino)-5-amino-1-(5"-phospho-D-ribose)-4-imidazolecarboxamide + L-Glutamine  
R06975[c] [c]: ADP + Orthophosphate +',1-(5'-Phosphoribosyl)-5-formamido-4-imidazolecarboxamide -> Formate + ATP + 1-(5'-Phosphoribosyl)-5-amino-4-imidazolecarboxamide  
R07358[c] [c]: NAD+ + Hydroquinone --> NADH + H+ + Quinone  
R07359[c] [c]: NADP+ + Hydroquinone --> NADPH + H+ + Quinone  
R07873[c] [c]: Pelargonidin 3-O-(6-caffeoyl-beta-D-glucoside) + CoA --> Pelargonidin 3-O-glucoside + Caffeoyl-CoA  
R07875[c] [c]: Pelargonidin 3-O-(6-caffeoyl-beta-D-glucoside) 5-O-beta-D-glucoside + UDP --> Pelargonidin 3-O-(6-caffeoyl-beta-D-glucoside) + UDP-glucose  
R08633[c] [c]: Hydrogen sulfide + 2-Aminobut-2-enoate --> L-Homocysteine  
R03336[c] [c]: 3-(4-Hydroxyphenyl)pyruvate + NADH + H+ --> 3-(4-Hydroxyphenyl)lactate + NAD+  
R05701[c] [c]: Ferulate + NADPH + H+ --> Coniferyl aldehyde + H2O + NADP+  
R00343[p] [p]: Oxaloacetate + NADPH + H+ --> (S)-Malate + NADP+  
R00214[p] [p]: (S)-Malate + NAD+ --> Pyruvate + CO2 + NADH + H+  
R00004[p] [p]: Diphosphate + H2O --> 2 Orthophosphate  
R01067[p] [p]: D-Fructose 6-phosphate + D-Glyceraldehyde 3-phosphate --> D-Erythrose 4-phosphate + D-Xylulose 5-phosphate  
R01334[p] [p]: 2-Phosphoglycolate + H2O --> Glycolate + Orthophosphate  
R00009[p] [p]: 2 H2O2 --> Oxygen + 2 H2O  
R01388[p] [p]: Hydroxypyruvate + NADH + H+ --> D-Glycerate + NAD+

R01514[p] [p]: ATP + D-Glycerate --> ADP + 3-Phospho-D-glycerate  
Rxn\_mod\_1[p] [p]: L-Serine + 2-Oxoglutarate --> Hydroxypyruvate + L-Glutamate  
Light rxn\_1 12H+[c] + 2 H2O [c] + 2 NADP [c] + 9 hvi [c] --> 14 H+ [p] + 2 NADPH[c] + O2 [c] + 9hvo[c]  
Light\_rxn\_2 3 ADP [c] + 14 H+ [p] + 3 pi [c] --> 3 ATP [c] + 11 H+ [c] + 3 H2O [c]  
R01648[c] [c]:4-Aminobutanoate + 2-Oxoglutarate <==> Succinate semialdehyde + L-Glutamate  
R02950[c] [c]:4-Coumarate + Oxygen + Caffeate <==> Caffeate + H2O + Caffeoquinone  
R01342[p] [p]:alpha-Amino acid + H2O + Acceptor <==> 2-Oxo acid + NH3 + Reduced acceptor  
R01131[c] [c]:ATP + Inosine <==> ADP + IMP  
R02150[p] [p]:1H-Imidazole-4-ethanamine + Oxygen + H2O <==> Imidazole-4-acetaldehyde + NH3 + H2O2  
R00717[p] [p]:Glycolate + NAD+ <==> Glyoxylate + NADH + H+  
R05604[c] [c]:D-Arabitol + NAD+ <==> D-Xylulose + NADH + H+  
R04162[c] [c]:2-Acyl-1-alkyl-sn-glycero-3-phosphate + H2O <==> 1-Alkyl-2-acylglycerol + Orthophosphate  
R00813[c] [c]:1,6-Dihydroxy-cis-2,4-cyclohexadiene-1-carboxylic acid + NAD+ <==> Catechol + NADH + CO2 + H+  
R00818[c] [c]:Salicylate + Oxygen + NADH + H+ <==> Catechol + CO2 + NAD+ + H2O  
R02065[p] [p]:2 Geranylgeranyl diphosphate <==> Diphosphate + Prephytoene diphosphate  
R01030[p] [p]:sn-glycero-3-Phosphocholine + H2O <==> Choline + sn-Glycerol 3-phosphate  
R01463[c] [c]:Cholesterol + Oxygen + NADPH + H+ <==> 7alpha-Hydroxycholesterol + NADP+ + H2O  
R05337[p] [p]:4-Hydroxybutyryl-CoA <==> Vinylacetyl-CoA + H2O  
R00818[p] [p]:Salicylate + Oxygen + NADH + H+ <==> Catechol + CO2 + NAD+ + H2O  
R01678[p] [p]:Lactose + H2O <==> alpha-D-Glucose + D-Galactose  
R01791[p] [p]:Dextrin + H2O <==> alpha-D-Glucose + Dextrin  
R00892[c] [c]:2 L-Cysteine + NAD+ <==> L-Cystine + H+ + NADH  
R00305[c] [c]:D-Glucose + Acceptor <==> D-Glucono-1,5-lactone + Reduced acceptor  
R00736[p] [p]:L-Tyrosine <==> Tyramine + CO2  
R01342[c] [c]:alpha-Amino acid + H2O + Acceptor <==> 2-Oxo acid + NH3 + Reduced acceptor  
R02978[p] [p]:Sphinganine + NADP+ <==> 3-Dehydrosphinganine + NADPH + H+  
R00987[c] [c]:L-Kynurenine + H2O <==> Anthranilate + L-Alanine  
R04686[c] [c]:trans-beta-D-Glucosyl-2-hydroxycinnamate <==> cis-beta-D-Glucosyl-2-hydroxycinnamate  
R06518[c] [c]:Dihydroceramide + H2O <==> Fatty acid + Sphinganine  
R02941[p] [p]:Salicylaldehyde + NAD+ + H2O <==> Salicylate + NADH + H+  
R03181[c] [c]:4-Maleylacetoacetate <==> 4-Fumarylacetoacetate  
R03493[c] [c]:3-Hydroxy-3-(4-methylpent-3-en-1-yl)glutaryl-CoA <==> 3-(4-Methylpent-3-en-1-yl)pent-2-enediyl-CoA + H2O  
R08100[c] [c]:2-Fluorobenzoate + NADH + H+ + Oxygen <==> 2-Fluorocyclohexadiene-cis,cis-1,2-diol-1-carboxylate + NAD+  
R01939[c] [c]:L-2-Aminoadipate + 2-Oxoglutarate <==> 2-Oxo adipate + L-Glutamate  
R01339[c] [c]:2-Oxo acid + L-Glutamate <==> alpha-Amino acid + 2-Oxoglutarate  
R00690[c] [c]:L-Phenylalanine + Oxygen <==> 2-Phenylacetamide + CO2 + H2O  
R00338[c] [c]:Oxaloacetate + H2O <==> Oxalate + Acetate  
R00921[c] [c]:Propanoyl-CoA + Orthophosphate <==> Propanoyl phosphate + CoA  
R00211[c] [c]:Pyruvate + CoA + Oxygen <==> H2O2 + Acetyl-CoA + CO2  
R00210[c] [c]:Pyruvate + CoA + NADP+ <==> Acetyl-CoA + CO2 + NADPH + H+  
R07959[c] [c]:1,7-Dimethylxanthine + NADH + H+ + Oxygen <==> 1-Methylxanthine + NAD+ + Formaldehyde + H2O  
R02257[c] [c]:Propane-1,2-diol + NAD+ <==> (S)-Lactaldehyde + NADH + H+  
R07254[c] [c]:Propane-1,2-diol + NAD+ <==> (S)-Lactaldehyde + NADH + H+  
R03581[c] [c]:Geraniol + NADP+ <==> Geranial + NADPH + H+  
R00493[c] [c]:L-Aspartate + 2-Oxo acid <==> alpha-Amino acid + Oxaloacetate  
R00776[c] [c]:(-)-Ureidoglycolate <==> Glyoxylate + Urea  
R00526[c] [c]:N-Formyl-L-aspartate + H2O <==> Formate + L-Aspartate



R07143[c] [c]:D-Arabitol + NADP+ <=> D-Xylulose + NADPH + H+  
R00264[c] [c]:2,5-Dioxopentanoate + NADP+ + H2O <=> 2-Oxoglutarate + NADPH + H+  
R02673[c] [c]:(S)-4-Hydroxymandelate + Oxygen <=> 4-Hydroxybenzaldehyde + H2O2 + CO2  
R00064[c] [c]:4-(4-Deoxy-beta-D-gluc-4-enuronosyl)-D-galacturonate <=> 2 5-Dehydro-4-deoxy-D-glucuronate  
R03341[c] [c]:3-(4-Hydroxyphenyl)pyruvate <=> 4-Hydroxyphenylacetaldehyde + CO2  
R02422[c] [c]:Allantoate + H2O <=> (-)-Ureidoglycolate + Urea  
R02260[c] [c]:(S)-Lactaldehyde + NADP+ <=> Methylglyoxal + NADPH + H+  
R00277[c] [c]:Pyridoxamine phosphate + H2O + Oxygen <=> Pyridoxal phosphate + NH3 + H2O2  
R00367[c] [c]:S-Adenosyl-L-methionine + Glycine <=> S-Adenosyl-L-homocysteine + Sarcosine  
R00893[c] [c]:L-Cysteine + Oxygen <=> 3-Sulfinyl-L-alanine  
R00353[c] [c]:Malonyl-CoA + Pyruvate <=> Acetyl-CoA + Oxaloacetate  
R00108[c] [c]:NADPH + 2 Ferricytochrome c2 <=> NADP+ + 2 Ferrocyclochrome c2 + H+  
R00932[c] [c]:2-Hydroxyglutarate + CoA <=> Propanoyl-CoA + H2O + Glyoxylate  
R03350[c] [c]:3-Deoxy-D-manno-octulosonate 8-phosphate + H2O <=> 3-Deoxy-D-manno-octulosonate + Orthophosphate  
R02008[c] [c]:10-Oxogeranial <=> Iridodial  
R01050[c] [c]:ATP + D-Ribose 5-phosphate <=> ADP + D-Ribose 1,5-bisphosphate  
R00326[c] [c]:Acetaldehyde + Acceptor + H2O <=> Acetate + Reduced acceptor  
R00278[c] [c]:Pyridoxine phosphate + Oxygen <=> H2O2 + Pyridoxal phosphate  
R06837[c] [c]:alpha-D-Ribose 1-phosphate <=> D-Ribose 1,5-bisphosphate  
R00833[c] [c]:(R)-Methylmalonyl-CoA <=> Succinyl-CoA  
R00152[c] [c]:NH3 + CO2 <=> Cyanide  
R03171[c] [c]:(S)-3-Methyl-2-oxopentanoic acid + CoA + NAD+ <=> (S)-2-Methylbutanoyl-CoA + CO2 + NADH + H+  
R03415[c] [c]:1-(1-Alkenyl)-sn-glycero-3-phosphoethanolamine + H2O <=> Aldehyde + sn-glycero-3-Phosphoethanolamine  
R00700[c] [c]:Hydrogen + NAD+ <=> NADH + H+  
R03674[c] [c]:L-Dopachrome <=> 5,6-Dihydroxyindole + CO2  
R03666[c] [c]:Cadaverine <=> Piperidine  
R01426[c] [c]:Benzoate + Acetate + NADH + H+ <=> trans-Cinnamate + 2 H2O + NAD+  
R02363[c] [c]:2 p-Benzenediol + Oxygen <=> 2 p-Benzoquinone + 2 H2O  
R05483[c] [c]:1,2,4-Trichlorobenzene + Hydrochloric acid <=> 1,3,4,6-Tetrachloro-1,4-cyclohexadiene  
R06839[c] [c]:3-Chlorocatechol + Oxygen <=> 2-Chloro-cis,cis-muconate  
R01426[p] [p]:Benzoate + Acetate + NADH + H+ <=> trans-Cinnamate + 2 H2O + NAD+  
R00977[c] [c]:5,6-Dihydrouracil + NAD+ <=> Uracil + NADH + H+  
R03872[c] [c]:Methylmalonate <=> (S)-Methylmalonate semialdehyde  
R07376[c] [c]:Phosphatidylethanolamine + L-Serine <=> Phosphatidylserine + Ethanolamine  
R02409[c] [c]:L-Cystine + Sulfate <=> S-Sulfo-L-cysteine + L-Cysteine  
R03891[c] [c]:Benzene-1,2,4-triol + Oxygen <=> 2-Maleylacetate  
R06857[c] [c]:3-Chloro-cis-1,2-dihydroxycyclohexa-3,5-diene + NAD+ <=> 3-Chlorocatechol + NADH + H+  
R05500[c] [c]:Trichloroethene + 2 H+ <=> trans-1,2-Dichloroethene + Hydrochloric acid  
R06272[c] [c]:Divinyl chlorophyllide a + NADPH + H+ <=> Chlorophyllide + NADP+  
R01367[c] [c]:Acetoacetate <=> 3-Butynoate + H2O  
R00188[c] [c]:[Adenosine 3',5'-bisphosphate + H2O <=> AMP + Orthophosphate]  
R08499[c] [c]:10-Hydroxygeraniol + 2 NADP+ <=> 10-Oxogeranial + 2 NADPH + 2 H+  
R08398[c] [c]:Geranyl diphosphate <=> Geranial  
R00363[c] [c]:Oxaloacetate <=> 2-Hydroxyethylenedicarboxylate  
R00894[c] [c]:ATP + L-Glutamate + L-Cysteine <=> ADP + Orthophosphate + gamma-L-Glutamyl-L-cysteine  
R01644[c] [c]:4-Hydroxybutanoic acid + NAD+ <=> Succinate semialdehyde + NADH + H+  
R07756[c] [c]:8 Trifolirhizin <=> 11 (-)-Maackiain  
R00459[c] [c]:L-Lysine <=> L-Pipecolate  
R01957[c] [c]:L-Kynurenine + Glyoxylate <=> 4-(2-Aminophenyl)-2,4-dioxobutanoate + Glycine  
R07729[c] [c]:Formononetin + UDP-glucose <=> Ononin + UDP

R07753[c] [c]:(-)-Maackiain + UDP-glucose <=> Trifolirhizin + UDP  
R02636[c] [c]:UDP-D-galacturonate <=> UDP-L-arabinose + CO2  
R00466[c] [c]:Glyoxylate + Oxygen + H2O <=> Oxalate + H2O2  
R08372[c] [c]:1-Hydroxyalkyl-sn-glycerol <=> Aldehyde + Glycerol  
R03533[c] [c]:Sulfur + Reduced acceptor <=> Hydrogen sulfide + Acceptor  
R05090[c] [c]: 17 Iridotrial <=> 10 Deoxyloganin  
R07733[c] [c]:8 Ononin <=> 8 Formononetin + 11 H+  
R07101[c] [c]:Chloral + H2O <=> Chloral hydrate  
R01860[c] [c]:4-Aminobenzoate <=> Aniline + CO2  
R06741[c] [c]:5-Aminopentanal <=> Piperideine  
R02254[c] [c]:trans-Cinnamate + Oxygen + NADPH + H+ <=> trans-2-Hydroxycinnamate + NADP+ + H2O  
R07881[c] [c]:2-Naphthoyl-CoA + H2O <=> 2-Naphthoic acid + CoA  
R05539[c] [c]:CO2 <=> 3-Isochromanone  
R00017[c] [c]:H2O2 + 2 Ferrocycytochrome c <=> 2 Ferricytochrome c + 2 H2O  
R02233[c] [c]:Cyclohexylamine + Oxygen + H2O <=> Cyclohexanone + H2O2 + NH3  
R07969[c] [c]:1-Methylxanthine + NADH + H+ + Oxygen <=> Xanthine + NAD+ + Formaldehyde + H2O  
R06512[c] [c]:1-Methylxanthine + NADH + H+ + Oxygen <=> Xanthine + NAD+ + Formaldehyde + H2O  
R06288[c] [c]:Divinylchlorophyll a <=> Chlorophyll a  
R07134[c] [c]:D-Arabitol + NAD+ <=> D-Ribulose + NADH + H+  
R06270[c] [c]:13(1)-Oxo-magnesium-protoporphyrin IX 13-monomethyl ester + Acceptor <=> Divinylprotochlorophyllide + Reduced acceptor  
R07482[c] [c]:24-Methylenecycloartanol <=> Cycloeucalenol  
R07733[P] [c]:8 Ononin <=> 8 Formononetin + 11 H+  
R02749[c] [c]:2-Deoxy-D-ribose 1-phosphate <=> 2-Deoxy-D-ribose 5-phosphate  
R04393[c] [c]:Protein N(pi)-phospho-L-histidine + Lactose <=> Protein histidine + Lactose 6-phosphate  
R02029[c] [c]:Phosphatidylglycerophosphate + H2O <=> Phosphatidylglycerol + Orthophosphate  
R08396[c] [c]:Geranyl diphosphate + H2O <=> Geraniol + Diphosphate  
R07754[c] [c]:Trifolirhizin + Malonyl-CoA <=> (-)-Maackiain-3-O-glucosyl-6"-O-malonate + CoA  
R01283[c] [c]:L-Homocysteine + H2O <=> Hydrogen sulfide + NH3 + 2-Oxobutanoate  
R00445[c] [c]:L-Lysine + NAD+ <=> delta1-Piperideine-2-carboxylate + NH3 + NADH + 2 H+  
R01052[c] [c]:ADP + D-Ribose 5-phosphate <=> Orthophosphate + ADP-ribose  
R01319[c] [c]:Acyl-CoA + 2-Acyl-sn-glycero-3-phosphocholine <=> CoA + Phosphatidylcholine  
R00175[c] [c]:[S-Adenosyl-L-methionine + H2O <=> 5'-Methylthioadenosine + L-Homoserine  
R00864[c] [c]:Sulfite + Sulfur <=> Thiosulfate  
R02442[c] [c]:Naringenin + NADPH + H+ + Oxygen <=> Eriodictyol + NADP+ + H2O  
R02472[c] [c]:(R)-Pantoate + NADP+ <=> 2-Dehydropantoate + NADPH + H+  
R01611[c] [c]:3-Oxopropanoate <=> Propynoate + H2O  
R03165[c] [c]:Hydroxymethylbilane <=> Uroporphyrinogen III + H2O  
R01863[c] [c]:Inosine + Orthophosphate <=> Hypoxanthine + alpha-D-Ribose 1-phosphate  
R01876[c] [c]:Uridine + Orthophosphate <=> Uracil + alpha-D-Ribose 1-phosphate  
R02601[c] [c]:2-Hydroxy-2,4-pentadienoate + H2O <=> 4-Hydroxy-2-oxopentanoate  
R07204[c] [c]:3alpha,7alpha-Dihydroxy-5beta-cholestane + NADPH + H+ + Oxygen <=> 3alpha,7alpha,12alpha-Trihydroxy-5beta-cholestane + NADP+ + H2O  
R02561[c] [c]:4-Aminobenzoate + Oxygen + NADH + H+ <=> 4-Hydroxyaniline + CO2 + NAD+ + H2O  
R00067[c] [c]:2 e- + 2 H+ <=> Hydrogen  
R00002[c] [c]:5 ATP + 5 H2O + 3 Reduced ferredoxin <=> 5 Orthophosphate + 5 ADP + 3 Oxidized ferredoxin + 10 H+  
R00643[c] [c]:L-Galactono-1,4-lactone + Oxygen <=> Ascorbate + H2O2  
R01308[c] [c]:4-Hydroxybenzoate + Acetate + NADH + H+ <=> 4-Coumarate + 2 H2O + NAD+  
R06938[c] [c]:cis-1,2-Dihydroxy-1,2-dihydro-7-methylnaphthalene <=> 4-Methylsalicylate  
R01302[c] [c]:4-Hydroxybenzoate + Pyruvate <=> Chorismate

R06938[p] [p]:cis-1,2-Dihydroxy-1,2-dihydro-7-methylnaphthalene <=> 4-Methylsalicylate  
R06924[c] [c]:3-Formylsalicylic acid + Oxygen + H2O <=> 2-Hydroxyisophthalic acid + H2O2  
R05137[c] [c]:trans-O-Hydroxybenzylidenepyruvate <=> 2-Hydroxychromene-2-carboxylate  
R00915[c] [c]:beta-Alanine <=> Pyridine-2,3-dicarboxylate  
R01777[c] [c]:Succinyl-CoA + L-Homoserine <=> CoA + O-Succinyl-L-homoserine  
R07980[c] [c]:Caffeine + Oxygen + 2 H+ <=> 1,3,7-Trimethyluric acid + H2O  
R08090[c] [c]:3-Hydroxy-3-(4-methylpent-3-en-1-yl)glutaryl-CoA <=> 7-Methyl-3-oxo-6-octenoyl-CoA + Acetate  
R00476[c] [c]:Glycolate + Acceptor <=> Glyoxylate + Reduced acceptor  
R00260[c] [c]:L-Glutamate <=> D-Glutamate  
R04902[c] [c]:Eriodictyol + NADPH + H+ + Oxygen <=> Pentahydroxyflavanone + NADP+ + H2O  
R08431[c] [c]:1-Methylpyrrolinium <=> Tropinone  
R02451[c] [c]:S-Benzoate coenzyme A + Reduced acceptor + 2 ATP + 2 H2O <=> S-1,5-Cyclohexadiene-1-carboxylate coenzymeA + Acceptor + 2 Orthophosphate + 2 ADP  
R01647[c] [c]:Succinate semialdehyde + Pyruvate <=> 2,4-Dihydroxyhept-2-enedioate  
R07226[c] [c]:Acetyl phosphate + NH3 + Thioredoxin disulfide + H2O <=> Glycine + Orthophosphate + Thioredoxin  
cpTransport\_C00022 Pyruvate [c] <=> Pyruvate [p]  
cxTransport\_C00002 ATP [c] <=> ATP [x]  
cxTransport\_C00010 CoA [c] <=> CoA [x]  
cxTransport\_C00001 H2O [c] <=> H2O [x]  
cmTransport\_C00002 ATP[c] <=> ATP[m]  
cmTransport\_C00010 CoA [c] <=> CoA[m]  
cpTransport\_C00007 O2[c] <=> O2[p]  
cmTransport\_C00008 ADP[c] <=> ADP[m]  
cmTransport\_C00009 Phosphate [c] <=> Phosphate [m]  
cxTransport\_C00013 Pyrophosphate[c] <=> Pyrophosphate [x]  
cmTransport\_C00013 Pyrophosphate[c] <=> Pyrophosphate [m]  
cxTransport\_C00311 Isocitrate[c] <=> Isocitrate[x]  
cmTransport\_C00033 Acetate[c] <=> Acetate[m]  
cxTransport\_C00020 AMP[c] <=> AMP[x]  
cmTransport\_C00042 Succinate [c] <=> Succinate[m]  
cmTransport\_C00022 Pyruvate [c] <=> Pyruvate [m]  
cmTransport\_C00026 2-Oxoglutarate[c] <=> 2-Oxoglutarate[m]  
cmTransport\_C00080 H+[c] <=> H+[m]  
cmTransport\_C00001 H2O [c] <=> H2O [m]  
cmTransport\_C00158 Citrate[c] <=> Citrate[m]  
cpTransport\_C00001 H2O [c] <=> H2O [p]  
cxTransport\_C00080 H+[c] <=> H+[x]  
cpTransport\_C00074 Phosphoenolpyruvate[c] <=> Phosphoenolpyruvate[p]  
cmTransport\_C00149 L-Malate[c] <=> L-Malate[m]  
cxTransport\_C00036 Oxaloacetate[c] <=> Oxaloacetate[x]  
cxTransport\_C00149 L-Malate[c] <=> L-Malate[x]  
cxTransport\_C00158 Citrate[c] <=> Citrate[x]  
cvTransport\_C00059 Sulfate[c] <=> Sulfate[v]  
cvTransport\_C00149 L-Malate[c] <=> L-Malate[v]  
cvTransport\_C00244 Nitrate[c] <=> Nitrate[v]  
cvTransport\_C00089 Sucrose[c] <=> Sucrose[v]  
cvTransport\_C00158 Citrate[c] <=> Citrate[v]  
cxTransport\_C00024 Acetyl-CoA[c] <=> Acetyl-CoA[x]  
cpTransport\_C00169 Carbamoyl phosphate[c] <=> Carbamoyl phosphate[p]  
cpTransport\_C00279 D-Erythrose 4-phosphate [c] <=> D-Erythrose 4-phosphate[p]  
cmTransport\_C00091 Succinyl-CoA[c] <=> Succinyl-CoA[m]  
cmTransport\_C05993 Acetyl adenylate[c] <=> Acetyl adenylate[m]  
cxTransport\_C00417 cis-Aconitate[c] <=> cis-Aconitate[x]  
cxTransport\_C03221 2-trans-Dodecenoyl-CoA[c] <=> 2-trans-Dodecenoyl-CoA[x]

cxTransport\_C05271 trans-Hex-2-enoyl-CoA[c] <=> trans-Hex-2-enoyl-CoA[x]  
 cxTransport\_C05259 3-Oxopalmitoyl-CoA[c] <=> 3-Oxopalmitoyl-CoA[x]  
 cxTransport\_C05264 (S)-Hydroxydecanoyl-CoA[c] <=> (S)-Hydroxydecanoyl-CoA[x]  
 cxTransport\_C00016 FAD[c] <=> FAD[x]  
 cpTransport\_C00041 L-Alanine[c] <=> L-Alanine[p]  
 cpTransport\_C00236 3-Phospho-D-glyceroyl phosphate[c] <=> 3-Phospho-D-glyceroyl phosphate[p]  
 cxTransport\_C01144 (S)-3-Hydroxybutanoyl-CoA[c] <=> (S)-3-Hydroxybutanoyl-CoA[x]  
 cxTransport\_C02593 Tetradecanoyl-CoA[c] <=> Tetradecanoyl-CoA[x]  
 cxTransport\_C05275 trans-Dec-2-enoyl-CoA[c] <=> trans-Dec-2-enoyl-CoA[x]  
 cxTransport\_C05260 (S)-3-Hydroxytetradecanoyl-CoA[c] <=> (S)-3-Hydroxytetradecanoyl-CoA[x]  
 cxTransport\_C05266 (S)-Hydroxyoctanoyl-CoA[c] <=> (S)-Hydroxyoctanoyl-CoA[x]  
 cxTransport\_C00154 Palmitoyl-CoA[c] <=> Palmitoyl-CoA[x]  
 cxTransport\_C01352 FADH2[c] <=> FADH2[x]  
 cpTransport\_C01353 Carbonic acid[c] <=> Carbonic acid[p]  
 cxTransport\_C00249 Hexadecanoic acid[c] <=> Hexadecanoic acid[x]  
 cxTransport\_C05276 trans-Oct-2-enoyl-CoA[c] <=> trans-Oct-2-enoyl-CoA[x]  
 cxTransport\_C05273 trans-Tetradec-2-enoyl-CoA[c] <=> trans-Tetradec-2-enoyl-CoA[x]  
 cxTransport\_C05258 (S)-3-Hydroxyhexadecanoyl-CoA[c] <=> (S)-3-Hydroxyhexadecanoyl-CoA[x]  
 cxTransport\_C05262 (S)-3-Hydroxydodecanoyl-CoA [c] <=> (S)-3-Hydroxydodecanoyl-CoA[x]  
 cxTransport\_C05268 (S)-Hydroxyhexanoyl-CoA[c] <=> (S)-Hydroxyhexanoyl-CoA[x]  
 cpTransport\_C05378 beta-D-Fructose 1,6-bisphosphate[c] <=> beta-D-Fructose 1,6-bisphosphate[p]  
 cpTransport\_C00117 D-Ribose 5-phosphate[c] <=> D-Ribose 5-phosphate[p]  
 cxTransport\_C00332 Acetoacetyl-CoA[c] <=> Acetoacetyl-CoA[x]  
 cmTransport\_C01353 Carbonic acid[c] <=> Carbonic acid[m]  
 cmTransport\_C00122 Fumarate[c] <=> Fumarate[m]  
 cxTransport\_C00160 Glycolate[c] <=> Glycolate[x]  
 cxTransport\_C00027 H2O2[c] <=> H2O2[x]  
 cpTransport\_C00988 2-Phosphoglycolate[c] <=> 2-Phosphoglycolate[p]  
 cxTransport\_C00042 Succinate[c] <=> Succinate[x]  
 cpTransport\_C01182 D-Ribulose 1,5-bisphosphate[c] <=> D-Ribulose 1,5-bisphosphate[p]  
 cpTransport\_C00088 Nitrite[c] <=> Nitrite[p]

Ex1 CO2[e] <=> CO2[c]  
 Ex2 H2O[e] <=> H2O[c]  
 Ex3 Oxygen[c] <=> Oxygen[e]  
 Ex4 Nitrate[e] --> Nitrate[c]  
 Ex5 NH3[e] --> NH3[c]  
 Ex6 Hydrogen sulfide[e] --> Hydrogen sulfide[c]  
 Ex7 Sulfate[e]--> Sulfate[c]  
 Ex8 alpha-D-Glucose[c] <=> alpha-D- Glucose[e]  
 Ex9 beta-D-Fructose[c] <=> beta-D-Fructose[e]  
 Ex10 Maltose[c] <=> Maltose[e]  
 Ex11 hv[e] --> hv[c]  
 Ex12 Sucrose[c] <=> Sucrose[e]  
 Ex13 Orthophosphate[e] --> Orthophosphate[c]  
 Ex14 Potassium[e] --> Potassium[c]  
 Ex15 Chloride[e] --> Chloride[c]  
 Ex16 hvo[c] --> hvo[e]

Glyceroltripalmitate synthesis [c]: Glycerol + Palmitic acid --> Glyceroltripalmitate + 3 C00001  
 Glyceroltristearate synthesis [c]: Glycerol + Stearic acid --> Glyceroltristearate+ 3 C00001  
 Glyceroltrioleate synthesis [c]: Glycerol + Oleic acid --> Glyceroltrioleate+ 3 C00001  
 Glyceroltrilinolate synthesis [c]: Glycerol + Linoleic acid --> Glyceroltrilinolate+ 3 C00001  
 Glyceroltrilinoleate synthesis [c]: Glycerol + alpha-Linolenic acid --> Glyceroltrilinoleate+ 3 C00001  
 Glyceroltripalmitoleate synthesis [c]: Glycerol + Palmitoleic acid --> Glyceroltripalmitoleate + 3 C00001  
 Amioacid synthesis [c]: 0.624 L-Alanine + 0.319 L-Arginine + 0.417 L-Aspartate + 0.231 L-Cystine + 0.378 L-Glutamate + 0.740 Glycine + 0.358 L-Histidine + 0.423 L-Isoleucine + 0.423 L-Leucine + 0.380 L-Lysine + 0.372 L-Methionine + 0.336 L-Phenylalanine + 0.483 L-Proline +0.529 L-Serine + 0.467 L-Threonine

+ 0.272 L-Tryptophan + 0.307 L-Tyrosine + 0.474 L-Valine -> Amino acids  
Protein synthesis [c]: 1.153 L-Alanine + 0.096 L-Arginine + 0.414 L-Aspartate + 0.031 L-Cystine + 1.527 L-Glutamate + 0.044 Glycine + 0.091 L-Histidine + 0.464 L-Isoleucine + 1.509 L-Leucine + 0.00005713 L-Lysine + 0.123 L-Methionine + 0.313 L-Phenylalanine + 0.762 L-Proline + 0.612 L-Serine + 0.175 L-Threonine + 0.004 L-Tryptophan + 0.244 L-Tyrosine + 0.249 L-Valine -> Protein  
Carbohydrate synthesis [c]: 0.067 D-Ribose + 0.278 D-Glucose + 0.111 D-Fructose + 0.055 D-Mannose + 0.055 D-Galactose + 0.146 Sucrose + 0.006 Cellulose + 2.33 Hemicellulose + 0.086 UDP-D-galacturonate -> Carbohydrates  
Hemicellulose synthesis [c]: 0.548 D-Arabinose + 1.248 D-Xylose + 0.300 D-Mannose + 0.144 D-Galactose + 3.253 D-Glucose + 0.166 D-Galacturonate + 0.166 D-Glucuronate -> Hemicellulose  
Lignin synthesis [c]: 2.221 4-Coumaryl alcohol + 1.851 Coniferyl alcohol + 1.587 Sinapyl alcohol -> Lignin  
Lipid synthesis [c]: 0.373 Glyceroltripalmitate + 0.093 Glyceroltristearate + 1.466 Glyceroltrioleate + 1.035 Glyceroltrilinolate + 0.157 Glyceroltrilinoleate + 0.034 Glyceroltripalmitoleate -> Lipids  
Material synthesis [c]: 20.461 Potassium + 5.641 Chloride -> Materials  
Nitrogenous compound synthesis [c]: 0.781 Amino acids + 6.799 Proteins + 0.061 Nucleic acids -> Nitrogenous compounds  
Nucleic acid synthesis [c]: 0.246 ATP + 0.239 GTP + 0.259 CTP + 0.258 UTP + 0.254 dATP + 0.246 dGTP + 0.268 dCTP + 0.259 dTTP -> Nucleic acids  
Organic acid synthesis [c]: 0.555 Oxalate + 0.676 Glyoxylate + 1.515 Oxaloacetate + 0.746 L-Malate + 1.562 Citrate + 1.724 cis-Aconitate -> Organic acids  
Biomass synthesis 1.757 Nitrogenous compounds[c] + 4.415 Carbohydrates[c] + 0.079 Lipids[c] + 0.453 Lignin[c] + 0.339 Organic acids[c] + 1.305 Materials[c] + 30 ATP[c] -> Biomass[e] + 30 ADP[c] + 30 Pi[c]

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