MESSAGE$_{ix}$ Workshop
Session 2: Building an Energy System Model (Part I)

Energy, Climate, and Environment (ECE) Program
International Institute for Applied Systems Analysis (IIASA), Austria

MESSAGEix Workshop (online), 8 June 2021

The MESSAGEix Modeling Framework

Recap...

- **MESSAGEix** is an open, version-controlled systems engineering **modeling framework**
- ix modeling ***platform*** (*ixmp*) is a data warehouse for facilitating high-powered modeling work
- python and R are the main interfaces for modelling using MESSAGEix
- MESSAGEix **mathematical model** is written and solved in GAMS
- Documentation of the MESSAGEix model and tutorials are available online:

https://docs.messageix.org

MESSAGEix framework: Building an energy system – Part 1

Agenda of this Session

- A note on optimization

- MESSAGEix mathematical model and its structure

- Working with MESSAGEix tutorials: building a simple model

➔ Voting feature will be used to measure how much time we should spend

After this tutorial

The goal is to...

- Learn about the logic behind the MESSAGEix energy system model
- Be able to work on a MESSAGEix model using Jupyter Notebook
- Be familiar with basic terminology of a MESSAGEix model

Requirements

- MESSAGEix framework installed and running
- Knowledge on energy systems
- Patience, motivation, and curiosity

Linear programming (LP)

Finding the best (optimal) solution

- The goal is to optimize a linear objective function

$$\text{Maximize} \quad \mathbf{c}^{\mathrm{T}}\mathbf{x}$$

- There are a set of *decision variables*
- There are some constraints (bounds on or relationship between decision variables)

$$\begin{aligned} &\text{subject to} \quad && A\mathbf{x} \leq \mathbf{b} \\ &\text{and} && \mathbf{x} \geq \mathbf{0} \end{aligned}$$

Example: the best way to commute to work

- **Decision variables:** walking, biking, bus, train, taxi, private car, car sharing
- **Objective function:** cheapest or fastest option (least environmental footprint, least walking option)
- **Constraints:** maximum 2 hours commute/day, maximum 300 euro/month, no later than 7 PM, ...
- **Feasible region**: usually there many alternative solutions but not all of them are feasible

Linear programming (LP) (reminder)

Applications of LP

- Production management
- Personnel management
- Marketing management
- Resource/ inventory management
- Blending problem, etc

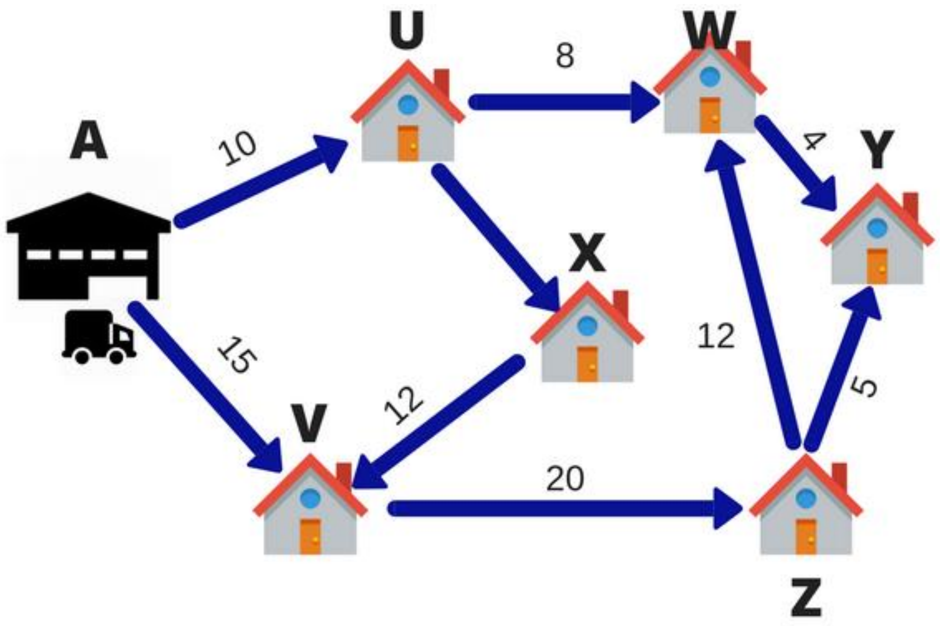


image: deepai.org

Principle:

Maximizing the utility

Or

Minimizing the cost

Energy Systems

Different scales: community, city, country, region, and global

- A system of energy resources, conversion/processing, transmission and distribution technologies, and services

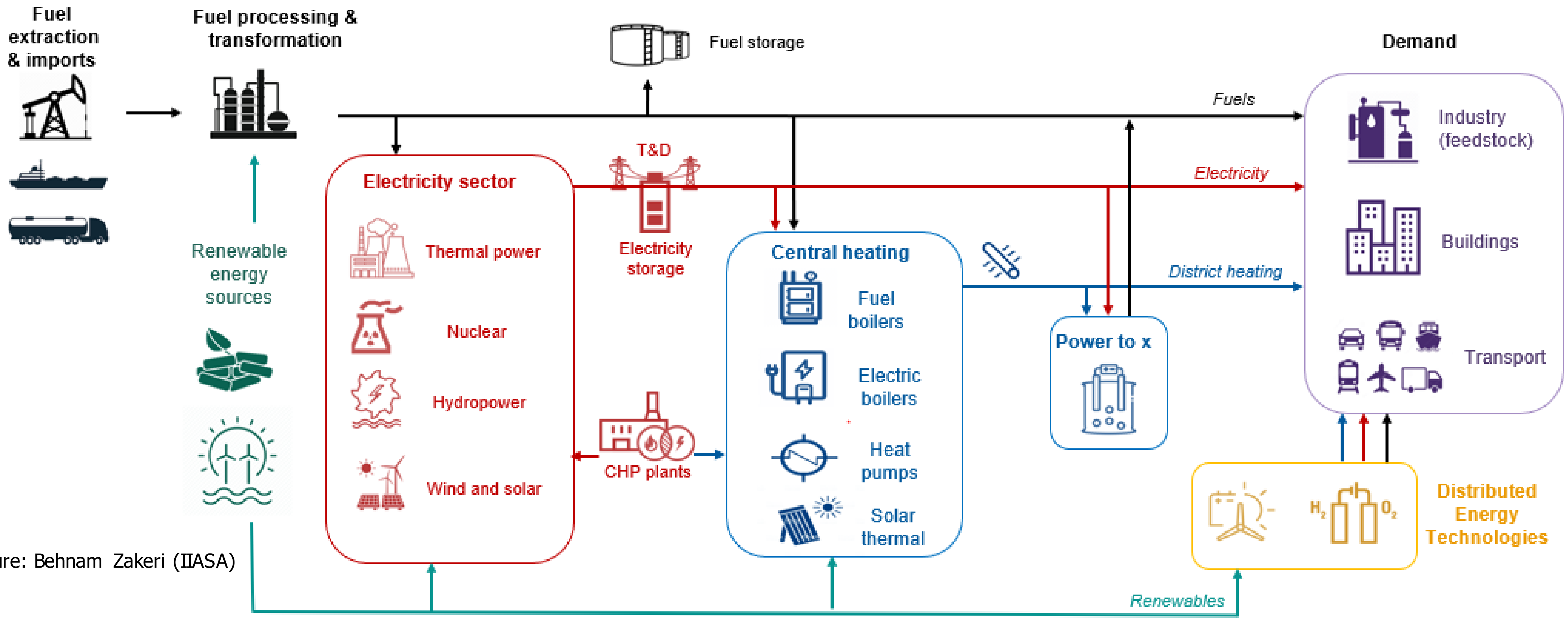


Figure: Behnam Zakeri (IIASA)

MESSAGEix: a model for investment and planning

Minimizing total discounted cost of the system

- **Objective:** The least cost option for meeting certain services (demand) ➔ min $cT \cdot x$
- **System:** a network of technologies (processes), resources, and commodities (products)
- **Cost of the system**: installing/maintaining ***capacity***, cost of ***activity*** (O&M), taxes, emission penalties, land use costs (if any), etc.
- Constraints: maximum use of a technology, growth/decline rates of activity, capacity factor, etc.

➔ $s.t. A \cdot x \leq b$

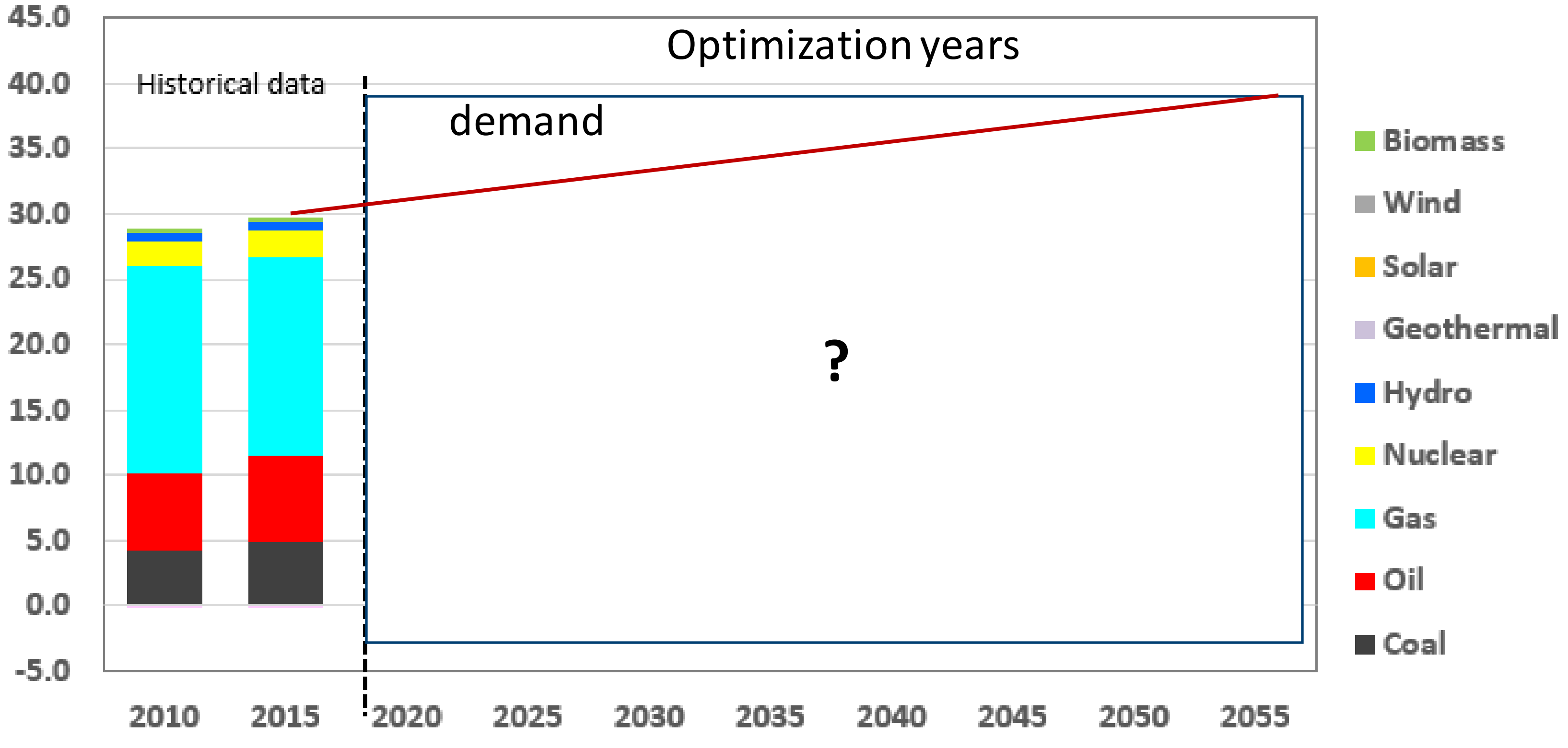
A note on "capacity" and "activity" (MESSAGEix formulation)

- **Capacity:** installed units of a technology (e.g., 150 MW power plant)
- **Activity:** operation of that technology (e.g., 800 GWh)
- **Reminder:** capacity ≠ activity capacity * capacity factor = activity

MESSAGE$_{ix}$ for Investment Planning

How can transition happen over multiple decades?

Electricity generation (TWh)

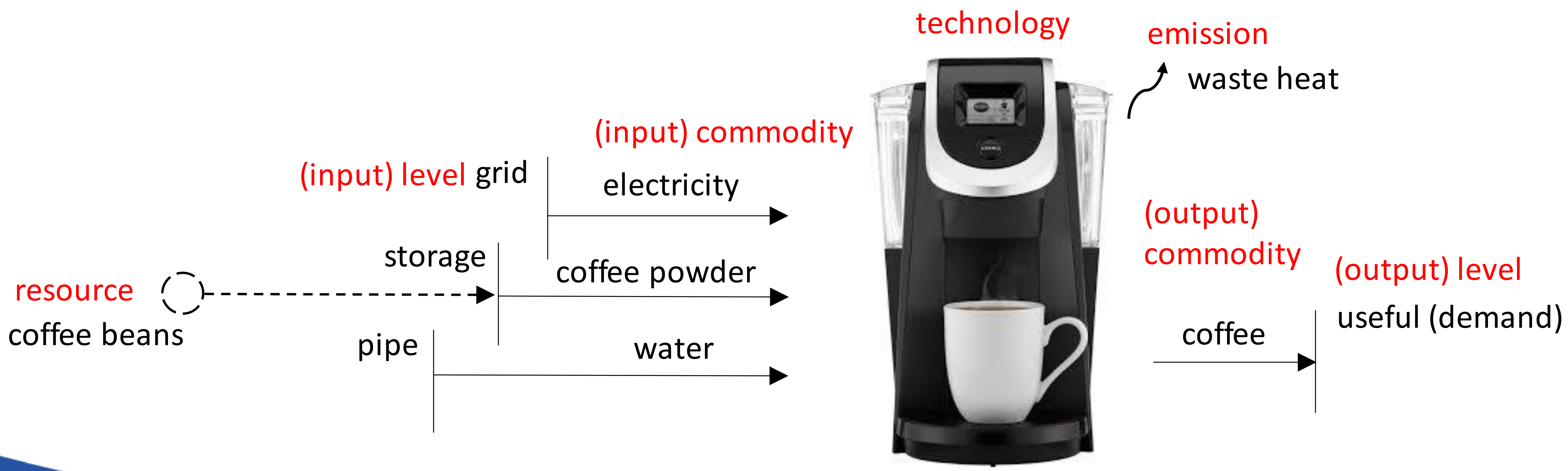


MESSAGEix: a technology-based model

Technologies and resources meet demand

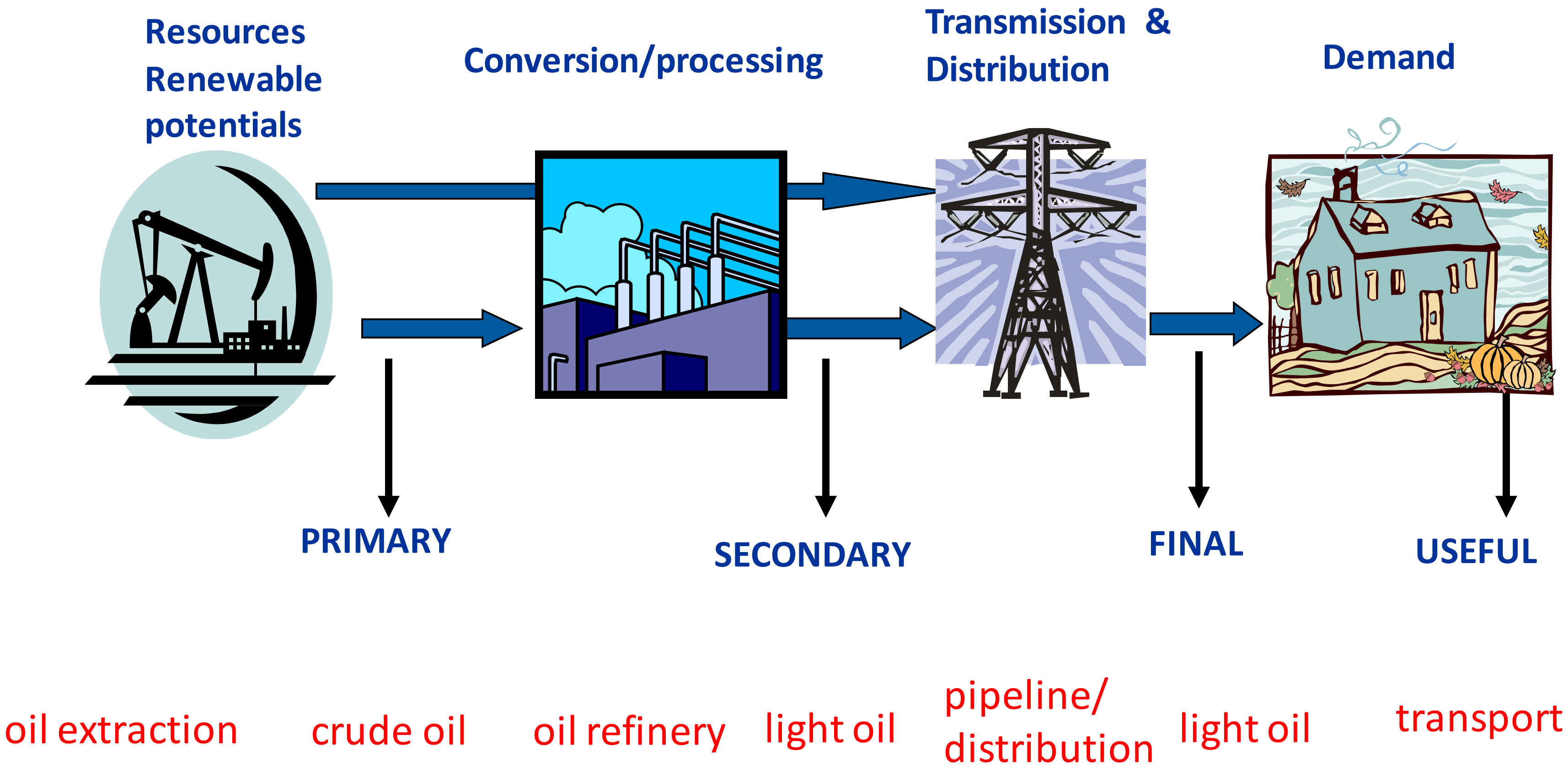
- Example **technologies:** electric car, reactor, pipeline, power plant, building, ship, industrial process

A sample technology: coffee machine



MESSAGEix: demand is exogenous (input)

Supply must meet demand under specified techno-economic parameters



MESSAGEix: A flexible tool for modeling different systems

Building a model in MESSAGEix

- There is no pre-defined sectors, technologies, commodities, etc.
- The level of technical detail depends on the user's preferences and research questions
- Flexibility remains for temporal and spatial representation

Aggregate representation

Detailed representation

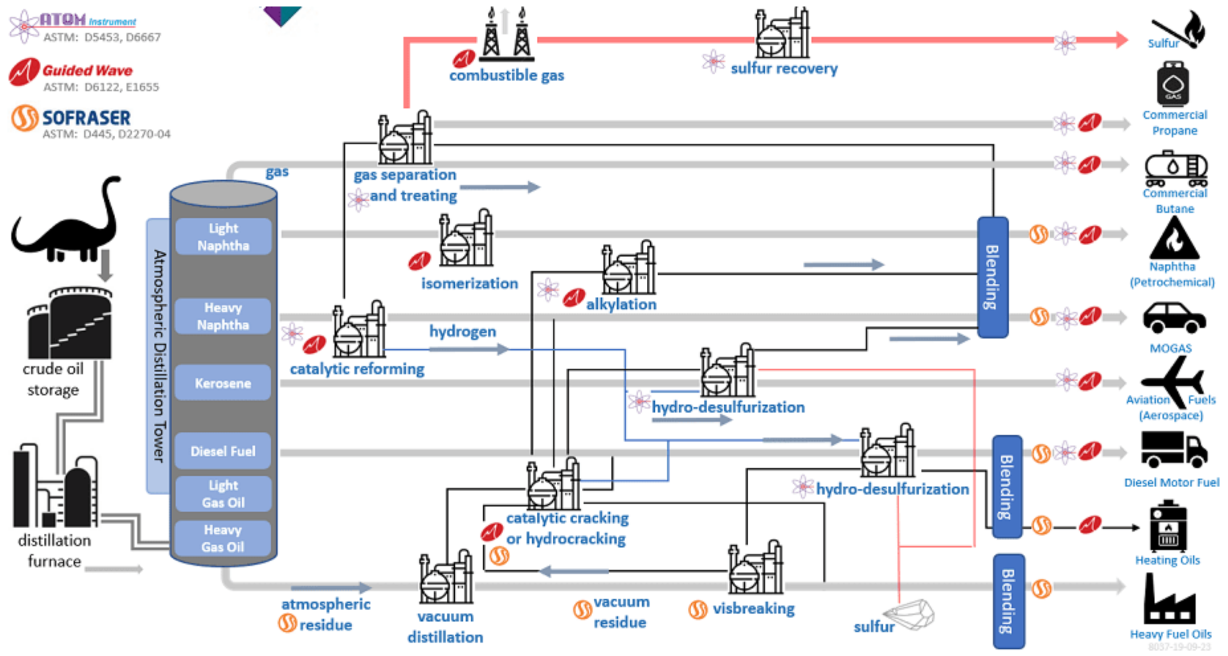


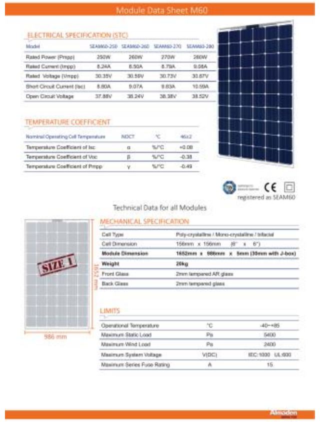
image: www.azom.com

MESSAGEix: Mathematical notation (GAMS)

Sets:

- List of elements for building a model
- Example: technology, commodity, node, emission

set	technology	commodity
members	Solar PV, pipeline	gas, heat, steel,



Parameters:

- Defining quantities (specification), *e.g., lifetime, efficiency, costs*
- Defining relationships between sets, *e.g., input and output of technology*
- Defining constraints, *e.g., bounds and growth rates*

EQUATIONS:

- Relationship between sets, parameters, **VARIABLES**, etc.
- Building the model

VARIABLES:

- decision variables to meet the objective and constraints, e.g., ACT, CAP

Images from: https://edyeazul.blogspot.com/ (above) and https://weburbanist.com/wp-content/uploads/2015/11/arc-kit-2.jpg (below)

Building a MESSAGEix model

Different steps of modeling

- Creating a new scenario (or loading an existing one)
- Declaring required sets (*node, technology, commodity, level*, etc.)
- Defining required parameters (adding numeric data, relating sets to each other, etc.)

  - demand

  - techno-economic parameters (lifetime, efficiency, investment cost, O&M cost, etc.)

  - bounds and dynamic constraints (growth rates, diffusion rates of technologies)
- Solving the model
- Postprocessing and plotting

Building a MESSAGEix model (2)

Minimum information for building a model

- Sets: *technology*, *node*, *commodity*, *level*, *mode* (of operation), *year*
- Parameters

  - ***demand***

  - ***output*** **(of technologies)**

➔ In MESSAGEix efficiency of technologies is defined with two parameters: *input, output*

eff = output/input

Homework

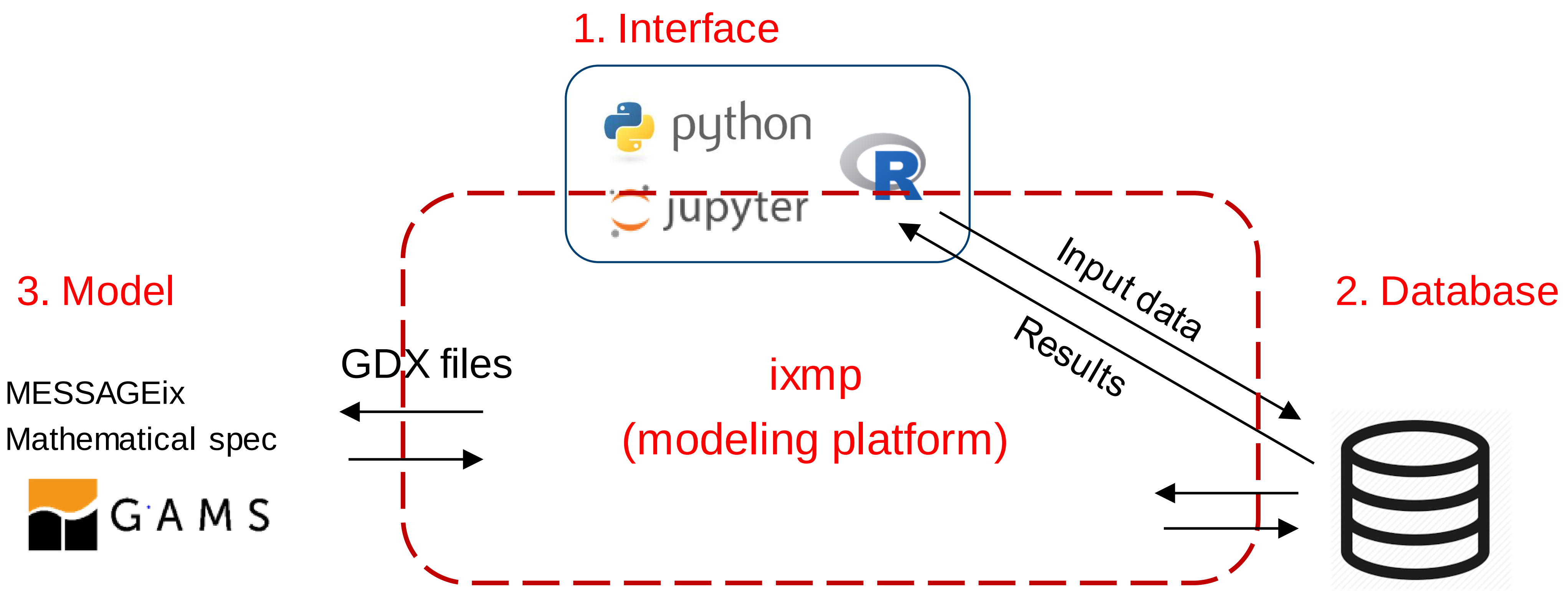
To be done before Wed 9 June 13:00 CEST

1. Try to extend the coffee machine example, for example, by adding another year in the model such as 2023 and defining demand for 380 cups of coffee in that year.

2. After downloading MESSAGEix tutorials, open Jupyter Notebook like what you did today, and run the Westeros Baseline scenario. Can you identify different steps of modeling as stated in the slide 14? We will review this tutorial together tomorrow.

The MESSAGE$_{ix}$ framework : Workflow of modeling

Recap…



Thank you very much for your attention!

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