Modeling Tools for Energy Scenario Analysis: The Canadian Transportation Energy and Emissions Model

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Systems models are descriptions of complex systems representing the interrelationships among the processes that constitute the system; they combine observations of past states of the system with scientific understanding of processes. As such, simulators are explicit and communicable representations of the mental models that guide human perceptions and actions. Unlike verbal or mathematical descriptions of systems, simulators are active and can be experienced. Learning how the system works arises from the experience of using the simulator. The user will come to appreciate the complex system-as-a-whole behaviour as it emerges out of dynamic interactions among relatively well-understood processes.

Thus, simulators are primarily learning devices that extend the human powers of perception; they cannot predict what will happen nor can they prescribe what should happen. Just as flight simulators support learning how an aircraft responds to the controls, systems simulators may be used for exploring the responsiveness of systems to potential societal actions involving, for example, population growth, life-style and technology innovation.

The dynamic systems modelling approach developed for assessing sustainability of technologies has the following characteristics:

1. In general, the systems model must take the present state of the system as its starting point and be capable of generating future possible trajectories of the system, subject to time dependent control variables that control the penetration of new technologies into the system.

2. The model is concerned with answering the question 'Where can the system go, if a specified technology is deployed?' It is, however, not concerned with the following questions:

- 'Where will the system go?'
- 'Where should the system go?'
- 'What policies have to be put in place to make the system track a particular trajectory?'

3. To answer the question in (2), the model must focus on what is physically feasible – there it must be a model of a physical economy focusing on the representation of physical transformation processes and on physical stocks and flows. An example is the Australian Stocks and Flows Framework. In short, the model must abide by the laws of physical science.

4. The physical economy is subject to human volition or control. Control is exercised and coordinated by institutions, governments, private enterprises, families and individuals, who exchange information through contracts and price signals. Since the concern is with answering the question of where the system can go, there is no need for the model to represent the behaviour of the controller.

5. The aim of the model is physical coherence, not causality. Feedback in these systems is accomplished by means of, or through, the controller. Since the controller is not represented, feedback is not to be expected. In exercising the model, the user acts as the external feedback mechanism. Depending on the outcome of simulating a particular scenario, the user devises additional scenarios for investigation based on his objective and intuition. Sensitivity analysis is also facilitated.

6. Processes are independently controlled; the whole system, if it is to be controllable at all, must be over-determined in terms of the control variables. This means that there may be settings of the control variables that are incoherent, which leads to 'tension'. In these models, it has been found to be useful to allow for the possibility of tension between the requirements for feedstocks and the availability of those feedstocks. A tension manifested by insufficient availability to meet requirements is an indicator of unsustainability.

CanTEEM Model Overview

The CanTEEM Model was developed by Robbert Associates as an application of the whatIf? modeling software technology in partnership with the Transportation Energy Use Division of the Office of Energy Efficiency, Natural Resources Canada and the National Research Council.
CanTEEM simulates alternate transportation scenarios in the context of the Canadian economy and the demand and supply of fuels for Canada. The scenarios run from the present (2001) to 2050 in one year steps. The model is calibrated over historical time from 1976 to 2000 in one year steps. The stocks in 2000 (vehicles, fuel production capacity, population) are the common starting point for all scenarios. New technologies for vehicles and for fuel production can be introduced only as new vehicles and new capacity are required for expansion and/or replacement of the stock

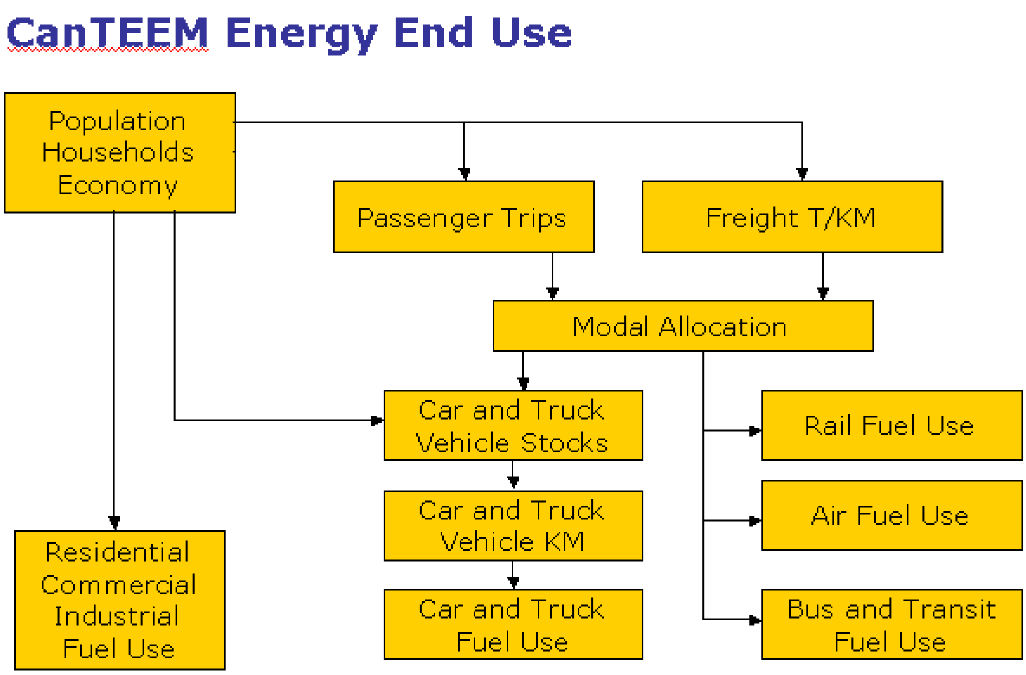
The CanTEEM model assures coherency among the population of people, transportation services, stocks of vehicles, fuel use, production and trade, feedstock production, use and trade, emissions from the production and use of fuels. Coherency is assured both over time and within time periods through the use of stock-flow accounting rules, vintaged stocks and life tables, and
supply/disposition balances for fuels and feedstocks

CanTEEM accounts for emissions of green house gases (CO_2, CH_4, and N_2O) and ground level emissions (non-methane hydrocarbons, CO, NOx, SO_2, sulphates, and prticulaes). Emissions accounted for at point of source (process, sector and province).

CanTEEM composition

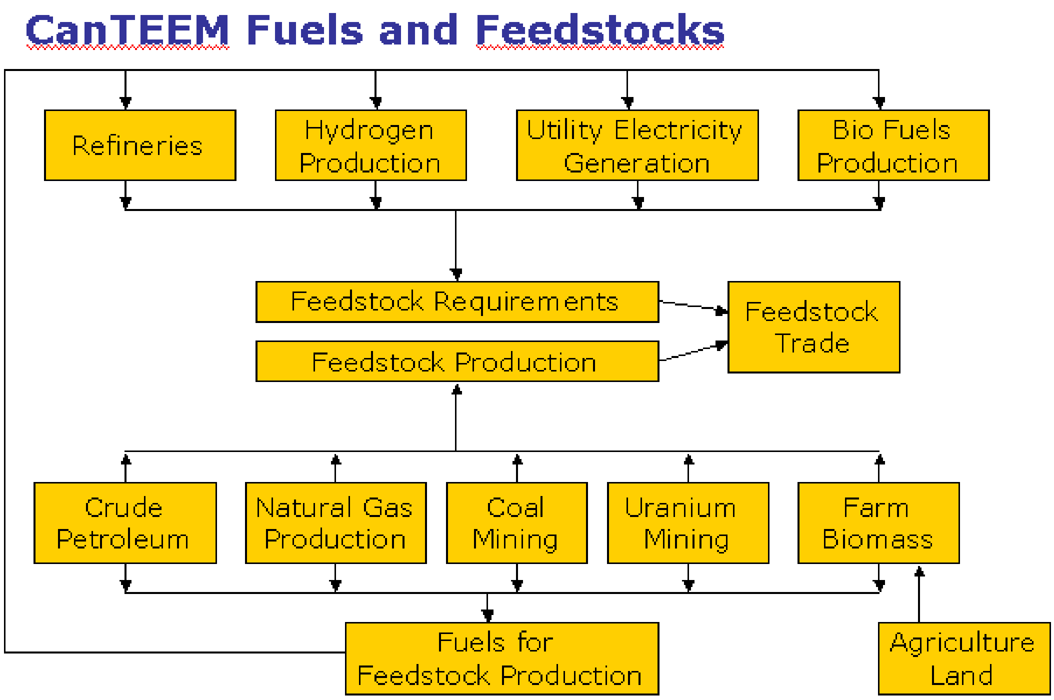
- Geography: provinces (10)
- Population: age (91), sex (2)
- Households: age of head (7), household type (11)
- Passenger trips: type (4), mode (6)
- Freight: types (3), mode (3)
- Road vehicles: uses (4), sizes (5), engine types (22), fuel (20)
- Biomass fuels production pathways: (15)
- Electricity generation pathways: (19)nHydrogen production pathways: (17)
- Energy feedstocks: (42)
- Crops: (16)

The CanTEEM model consists of an energy end-use component and a fuel production component. The energy end-use component is shown in the following diagram.



The energy end use component keeps track of the stock of light and heavy duty road motor vehicles in Canada, their per vehicle use characteristics, the amount of fuel required to operate the stock, and the tailpipe emissions at the point of use associated with vehicle use. The stock and use of personal-use vehicles are independently related to the number of households in Canada. The stock and use of both heavy and light duty commercial-use vehicles are independently related to the Real Domestic Product (RDP is the index that measures production in constant dollars, i.e., discounting the change in prices) of Canada. Both households and RDP are projected independently. The model represents light duty personal and commercial - use vehicles by 3 size classes: small passenger vehicles (compact and sub-compact), large passenger vehicles (full-size) and light trucks (vans, pick-up trucks and SUVs). Heavy-duty vehicles are represented in two size classes. Vehicles are also represented by engine type: gasoline engines (capable of using gasoline and 10% ethanol blends), diesel engines, and E85 engines capable of using 85% ethanol blends, and engines hydrogen fuel. Vehicle stocks are vintaged by 31 one-year age classes. Discards from the stock are governed by age and time specific survivorship probabilities. As new vehicles enter the stock, either to increase the stock or replace discards from the stock, they are allocated to vehicle sizes and engine types by means of share parameters. In this way the composition of the stock is determined by the composition of the stock existing at the beginning of the simulation period, the level of stock required, the life tables and the new vehicle share parameters.

The fuels and feedstocks component is shown in the following diagram:



The fuel production component represents the process chains associated with the production of petroleum-based fuels, hydrogen, electricity and of bio fuels that may be blended with conventional fuels. It also calculates the emissions associated with the production of the required feedstocks. It keeps track of the emissions associated with resource extraction, including crop production, transport of resource feedstock to the point of fuel production, fuel production, blending, transportation to point of distribution, leaks and flares, and dispensing. Feedstocks can be taken from plant payload production (grains or switchgrass) and/or plant by-product production. The land compartment keeps track of land use for plant production by province, of which there are ten, transfers of land from potential agriculture land to crop land, carbon content of soil and CO2 emissions from soil. It also tracks CO2 emissions from changes in yearly average above ground biomass. The carbon content of soil is simulated by a linear first order set of difference equations and depends on the starting carbon content for both land types, land transfers, biomass yield for root, support and payload, amount of support incorporated and the oxidization rate.

Observed data for the land compartment were taken from the Agriculture census of Statistics Canada, and the average biomass yields from Agriculture Canada. Oxidation rates were estimated for cropland by assuming that continuous conventional cultivation with the average provincial crop distribution over the long term would result in a soil carbon content of 3%. Potential agriculture land is assumed to have a soil carbon content of 11%. Starting soil carbon content is then estimated by running the land compartment from the beginning of time, which varies by province, till 1997. This results in starting soil carbon contents that vary between 4.6% to 9.6%, depending on province.

The CanTEEM model can be used to simulate

- population and economic growth
- travel patterns by household and freight intensity
- modal shares by trip type and freight type
- vehicle size and engine type
- vehicle fuel efficiency
- vehicle fuel mix
- fuel production pathways
- technology performance
- feedstock sources

Future Developments

The CanTEEM Model, as currently articulated, focuses on the two sectors most important from the perspective of reducing dependence on refined petroleum products and reducing emissions. The energy end use components can be further articulated so that fuel substitution possibilities and possibilities for improving energy efficiency in the residential commercial and industrial sectors can be simulated.

The residential and commercial sector models are straightforward stovk/flow models. Early versions have been developed for the Demand Policy Analysis Division of the

Office of Energy Efficiency and these would have to be adapted and integrated into the CanTEEM model. Essentially, these models relate the stock of dwelling units and commercial building space to the population and calculates energy and emissions for space conditioning using a degree day method. They also keep track of vintaged stocks of appliances, the energy used in the stocks, and energy required for hot water heating.

Two approaches have been developed for the industrial sector model. The first and simplest involves relating energy use to industrial output which is in turn related to the product of population and gross domestic product per capita. The second is to introduce materials accounting to trace the flows of material from the natural resource base through the industrial processes that transform them into the end products required by the population. Energy use can then be related to the various industrial processes in such a way that materials and energy balances are maintained that are coherent with one another. This second approach has been used in the Australian Stocks and Flows Framework.

Concluding Remarks

The approach, methods, and software tools used in the CanTEEM project can be readily adapted for use by other countries or groups countries. These models are particularly appropriate for exploring coherent long term energy scenarios – that involve the penetration of new energy consuming and producing technologies and the introduction of alternative fuels such as hydrogen and bio-fuels.

The CanTEEM model has already been used at the National Research Council to explore scenarios that involve increased penetrational of bio-ethanol and a study of bio-diesel. is currently in process.

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